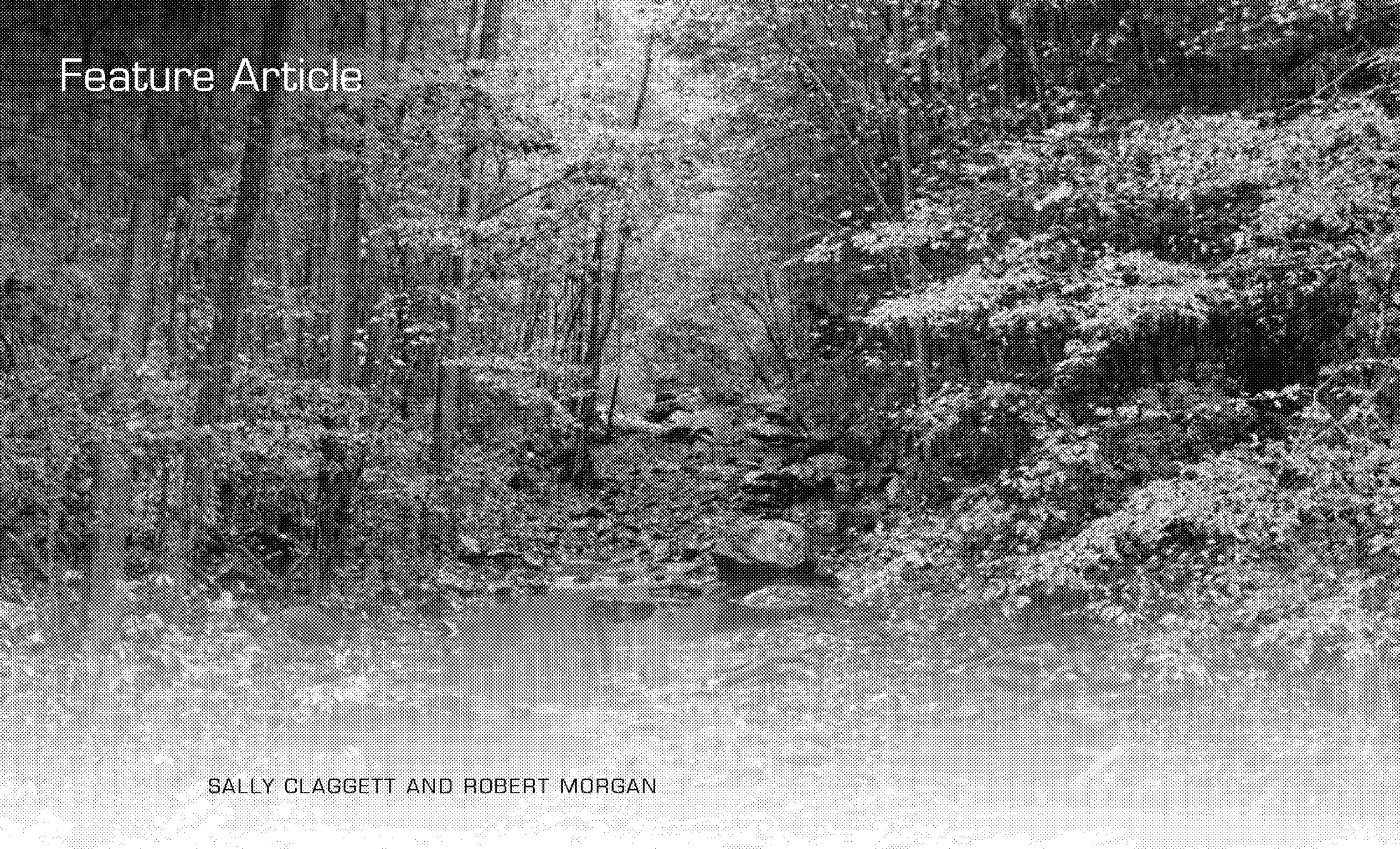
Feature Article



SALLY CLAGGETT AND ROBERT MORGAN

USFS Looks to the Future in Upcoming *Forests to Faucets* Analysis

AS THE WORLD'S URBAN FOOTPRINT EXPANDS AND THE CLIMATE CHANGES, THE US DEPARTMENT OF AGRICULTURE FOREST SERVICE WILL UPDATE ITS 2011 STUDY TO CLARIFY THE CONNECTION BETWEEN WATERSHED HEALTH AND DRINKING WATER SUPPLIES.

Layout imagery courtesy of Sally Claggett

The connection between forests and water quality and streamflow has been recognized for ages. More than 2,000 years ago, Plato observed that cutting mountain forests dried up the springs and floods carried the soil to the sea, "leaving the land nothing but skin and bone" (de la Crétaz & Barten 2007). This is somewhat self-evident—urban areas and farmland are used more intensively and therefore discharge more soil and pollutants—but a wealth of research also strongly supports the fact that trees and forests improve water by filtering runoff, recharging groundwater, and regulating the timing and magnitude of streamflows (Holmes et al. 2018, Binder et al. 2017, de la Crétaz & Barten 2007, Brown & Binkley 1994). Forests are the original water treatment facility (see the sidebar starting on page 43), and they naturally provide myriad benefits (e.g., clean air, recreational enjoyment, wildlife habitat).

Land-use decisions related to water will become more important as the earth becomes more populated. In the United States, populations continue to grow, which means a larger urban footprint and more water needed for agricultural, industrial, and household uses in the country. So as pressure for clean water increases, land conversion and climate change also apply pressure on the resource (Sun et al. 2008). As the US Department of Agriculture Forest Service (USFS) and partners embark on an update to the 2011 *Forests to Faucets* analysis, the aim is to promote better understanding of the connection between natural landscapes, water quality, and water availability with an eye to the future.

FOREST FRAGMENTATION

Forests have a unique and significant role in the water cycle (Figure 1). Day after day, evaporation moves water from oceans and land up to the sky. When this water precipitates back to land, it can recharge groundwater or run off into streams, but the majority returns to the atmosphere through plant evapotranspiration in the unending hydrological cycle (Pimentel et al. 2004). Forests transpire more water because of their large biomass and deep roots. Perhaps most important, mountainous regions—which are primarily forested—receive a disproportionate amount of precipitation. More than 50% of the water supply in the United States originates on forest lands; this increases to 65% in the West (Furniss et al. 2010).

Forests cover roughly one-third of the conterminous United States (a.k.a. the Lower 48). By 2060, forests are projected to shrink by 16 million to 34 million acres because of urbanization (USDA 2012). Most forests in the United States (~56%) are privately owned (Butler et al. 2010). These predominantly family-owned forests (i.e., not owned by a corporation) consist of smaller tracts (50 acres or less), and there is increasing pressure to fragment these lands into even smaller parcels. Fragmentation of forests will continue to compromise their ability to function (USDA 2012). Privately owned forests provide the vast majority of water supplied to population centers in the South and Northeast (USDA 2014).

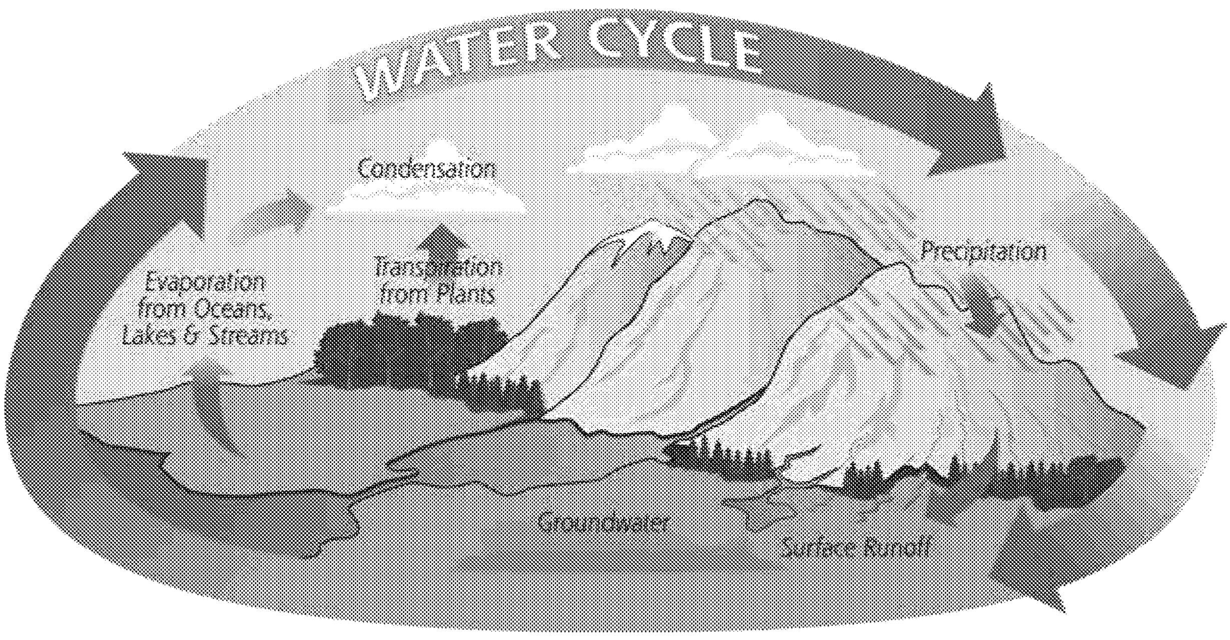
Across the West, insect epidemics, drought, and a loss of markets have put forests at higher risk for wildfires. Exacerbating these issues, fuel has been building up in most parts of the country—an unintended result of decades of fire suppression—making fires larger and more severe, which can destroy water quality. The American Forest Foundation released a report in 2015 that showed at least one-third of forests in key drinking water watersheds are at high risk of wildfire and are privately owned. Private landowners may want to manage their land to protect against fire or other threats, but 77% of landowners cited the high cost of management as a barrier (American Forest Foundation 2015). Without resources for the landowner, public benefits from private forests will continue to erode.

Upland forests are not the only land use beneficial to water quality; natural areas (e.g., grasslands, chaparral, sagebrush) are also important. Riparian areas and wetlands provide critical filtering of water pollutants coming off of farms, ranches, and developed areas.

INCREASING THREATS

USFS's new analysis will focus on surface-water supplies, which are the source of most (about 77%) drinking water in the United States (USEPA 2008). Surface water (e.g., streams, ponds, reservoirs) is naturally affected by topography, land use, soil, and other physical features;

FIGURE 1 An illustration showing the importance of topography in the water cycle



Source: NASA

Because mountainous regions are mostly forested, more than 50% of the water supply in the United States originates on forest lands.

compared with groundwater, it is more easily contaminated by pathogens and pollutants because of its accessibility. In addition, surface waters face challenges such as harmful algal blooms that typically do not affect groundwater quality. Threats to surface-water quality are often exacerbated by human activity and warmer water temperatures. *Threats on Tap,* a recent report by the Natural Resources Defense Council, details widespread concern that the Safe Drinking Water Act is not keeping up with enforcement of emerging, widespread contaminants, including some, such as harmful algal blooms, that are increasing because of climate change (Fedinick et al. 2017).

Upstream forests that provide source water protection should enable cost savings for downstream water utilities by reducing treatment requirements. In a recent study, Warziniack et al. (2017) found that, on average, water treatment plants with lower sediment and lower total organic carbon in their source water have lower treatment costs, supporting earlier work by Ernst (2004) on the importance of source water protection for water utilities. In addition, better-quality water in the influent may reduce the formation potential of disinfection byproducts and their associated risks to public health, as well as reduce waste streams and other operational burdens.

Threats to forests include conversion to other land uses, wildfire, invasive pests, and other climate-induced stresses such as increased temperatures and inconsistencies in water availability as mentioned previously. Climate change can alter a forest's ability to regulate water flows (Bergkamp et al. 2003), exacerbating the issue of water stress. Another exacerbating issue is forest fragmentation, which is accelerating in most regions (Furniss et al. 2010). These compounding threats to forests make future modeling vital.

WATER STRESS

Communities exert a large, consistent demand for water—a resource that may be seasonal and weather-dependent—and most have felt the stress of water shortages. Water stress is likely to worsen with the now-familiar double whammy of population growth and climate change. It can be evaluated by looking at water supply and water demand at the watershed level. USFS's new national *Forests to Faucets* analysis uses a simple model—the Water Supply Stress Index (WaSSI)—to simulate water supply stress across the United States. The water supply stress for a watershed is defined as the ratio of water

Forests reduce the flow and runoff energy that can cause scouring to streams and stream banks. *Photo courtesy of Sally Claggett*

How Forests Clean Water

Trees are nature's water filtration systems; they purify the water that eventually flows through our faucets. Naturally vegetated and forested areas reduce adverse impacts on water quality from impervious areas and agriculture, keeping watersheds cleaner.

Water cycling through forests can be simplified into two distinct paths, both of which improve water quality. The "downward" path starts with precipitation; evapotranspiration powers the "upward" path. The strong pumping action fueled by photosynthesis draws water up to the tree canopy, where it is transpired. But not all the water drawn up by the trees is released through evapotranspiration; some travels back down through the phloem—distributing carbohydrates made during photosynthesis—and out through trees' roots, influencing the surrounding soil.

PHYSICAL PROCESSES

Treetops intercept rain and snow, which trickle down stems and trunks to the forest floor. At this point, the forest–water interaction already has begun to reduce

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demand to water supply: WaSSI = D/S, where D is water demand (i.e., the total water withdrawal from different water users as defined by the US Geological Survey [USGS], which conducts a water use survey every five years), and S is water supply (i.e., the streamflow at each watershed plus the groundwater withdrawal from USGS).

USFS's modeling system tracks water supply monthly for all 2,100 larger sub-watersheds (Hydrologic Unit Code 8) in the United States. Climate change and precipitation variability are the major drivers of water supply. Factors that affect water demand include population growth, crop irrigation water use, socioeconomic change, and associated energy demand.

The nexus of land use/forests, populations, and water supply is of primary interest as the USFS undertakes its next national *Forests to Faucets* analysis (see the sidebar on page 45).

> The purpose of this project is to quantify, rank, and illustrate the direct geographic connection between forests, surface drinking water supplies, and populations that depend on them.

How Forests Clean Water *(continued)*

runoff. The humus layer on the forest floor acts like a sponge. From the tree canopy to the topsoil, up to 18 in. of precipitation can be absorbed. The mature forest soil layers—including their abundant carbon—physically hold water between the soil particles, which allows further infiltration and adsorption by roots.

Unlike other types of land cover, forests have little surface erosion, and therefore less sediment is transported to surface water. Forests also reduce the flow and runoff energy that can cause scouring to streams and stream banks—a common source of sediment in developed areas.

BIOCHEMICAL PROCESSES

Forest soil hosts microbes that interact with pollutants, changing their chemistry and improving water quality. An example of the yeoman's work these microbes can accomplish in healthy forest soils is denitrification, in which excess nitrogen compounds such as nitrate are converted and released as inorganic nitrogen gas, the most common compound in the atmosphere.

Water is absorbed by roots into the woody structure of the tree through osmosis. This movement is supercharged by evapotranspiration, which exerts a pull strong enough to get water and nutrients 200 vertical feet or more up into the crown of the tallest trees. Forests use external nutrients (i.e., from soil, atmospheric deposition, or dissolved in storm runoff) for growth and cellular processing. A tree's trunk is full of porous tissue called xylem, which acts as a system of straws that run up and down the tree. Sap or water molecules can travel through this tissue, but it forms a barrier that filters larger molecules. Xylem thus removes bacteria and contaminants such as excess nutrients (e.g., nitrates and phosphates), metals, pesticides, chemical solvents, oils, and hydrocarbons.

Fast-growing trees, such as cottonwood, are deliberately used to clean contaminated groundwater through the natural phytoremediation process. Certain chemicals are broken down, degraded, and lost to the atmosphere through transpiration and volatilization.

Nonforest vegetation also transpires, but the biomass and longevity of trees makes their transpiration more substantial in cycling water and nutrients.

SCOPE OF STUDY

The national *Forests to Faucets* version 2.0 (referred to as F2F2) will build upon the original *Forests to Faucets* analysis (Weidener & Todd 2011) by updating that study's base data layers for the continental United States and by forecasting new threats. The F2F2 analysis, which is still in the production phase, aims to promote better understanding of the connection between watershed health and drinking water supplies. F2F2 will take a closer look at current and projected hydrologic systems and water stress. The analysis will be based on a series of biophysical and demographic data layers using the 12-digit Hydrologic Unit Code (HUC12) watershed as its base unit.

The United States is divided and subdivided into successively smaller hydrologic units that are classified into four levels: regions, sub-regions, accounting units, and cataloging units (USGS 2018). The hydrologic units are arranged or nested within each other from the largest geographic area (regions) to the smallest geographic area (cataloging units). Each hydrologic unit is identified by a unique HUC consisting of two to eight digits based on the four levels of classification in the hydrologic unit system.

There are more than 88,000 HUC 12s watersheds in the continental United States, and their average size is roughly 35 mi^2. Analysis at this scale provides information useful for states, counties, water utilities, and large land-management units such as national forests, while allowing for standardized comparisons in different areas. The HUC12 scale is useful for evaluating risk factors since the spatial importance of these risks is often lost when summarized at larger scales. Also, this scale helps watershed managers target problem areas, which is an improvement over a shotgun approach.

The F2F2 analysis can be thought of in three parts. The first part will be an analysis of an HUC12 watershed's inherent ability to produce clean water based largely on land use. In the *Forests, Water and People* analysis (Barnes et al. 2009), this was called "Ability to Produce Clean Water" and was not specific to drinking water. However, most watersheds that have a stake in drinking water protection also support a high proportion of at-risk aquatic biodiversity, providing opportunities for joint benefits from water quality protection (USDA 2012).

The second part of the F2F2 analysis will look at which HUC12 watersheds are the most important to surface drinking water users. To determine these watersheds, flow is modeled upstream of source water intakes to indicate how that water has been influenced by upstream watersheds. The "importance factor" is directly tied to the approximate number of people who depend on that water source for their drinking water.

The third aspect will allow the user to weigh various threats to the quality and quantity of surface drinking water. They include threats to forests (e.g., forest loss or damage from fire or pathogens) and threats to water supply (i.e., using the WaSSI tool). Climate change is considered in both threat categories. Threats will also be forecast for two future time steps (i.e., 2040 and 2090) when data are available.

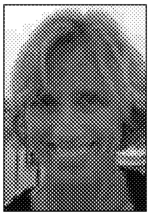
Results of the F2F2 analysis are intended to help planners, land managers, water resource managers, and anyone concerned with water supplies make critical land-use decisions. The end goal is to have a dynamic and interactive Internet presence to convey the various outcomes of the F2F2 analysis depending on users' needs. Current and future (projected) land-use statistics will be generated for each HUC12. The data produced by this assessment could also be used to identify opportunities for market-based approaches to sustain clean water production.

On the whole, the F2F2 project will provide a broad view of land-use characteristics and water supply threats to watersheds that feed surface drinking water sources. It does not displace the need for local land-use data, local knowledge, or different analyses of hydrologic regimes. However, F2F2 will be useful for long-range planning, municipal education, and prioritization of regional water needs, including indicating where alternative water supplies may be needed. It will help land management decision-makers know where practices may affect water needs, either positively or negatively.

Sample Questions the National *Forests to Faucets* 2.0 Analysis Will Address

- Which sub-watersheds have an inherent ability to produce clean water based on their land-use characteristics? Conversely, which watersheds are likely candidates for watershed restoration to provide higher-quality water?
- What is the relative importance of each sub-watershed in my state for providing drinking water to downstream consumers?
- How many US surface drinking water consumers/water supply utilities depend on public forest lands for water supply? How many depend on unprotected private forest land?
- Which water supply watersheds are likely to be most affected by development/land-use change throughout the United States over the next 20-plus years?
- What threats other than development (e.g., wildfire, invasive pests, water yield change because of climate change) do water supply watersheds face, and to what extent are they likely to be a concern?

ABOUT THE AUTHORS



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Threats to forests include conversion to other land uses, wildfire, invasive pests, and other climate-induced stresses.

Trees and forests improve water by filtering runoff, recharging groundwater, and regulating the timing and magnitude of streamflows. *Photo courtesy of Sally Claggett*

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