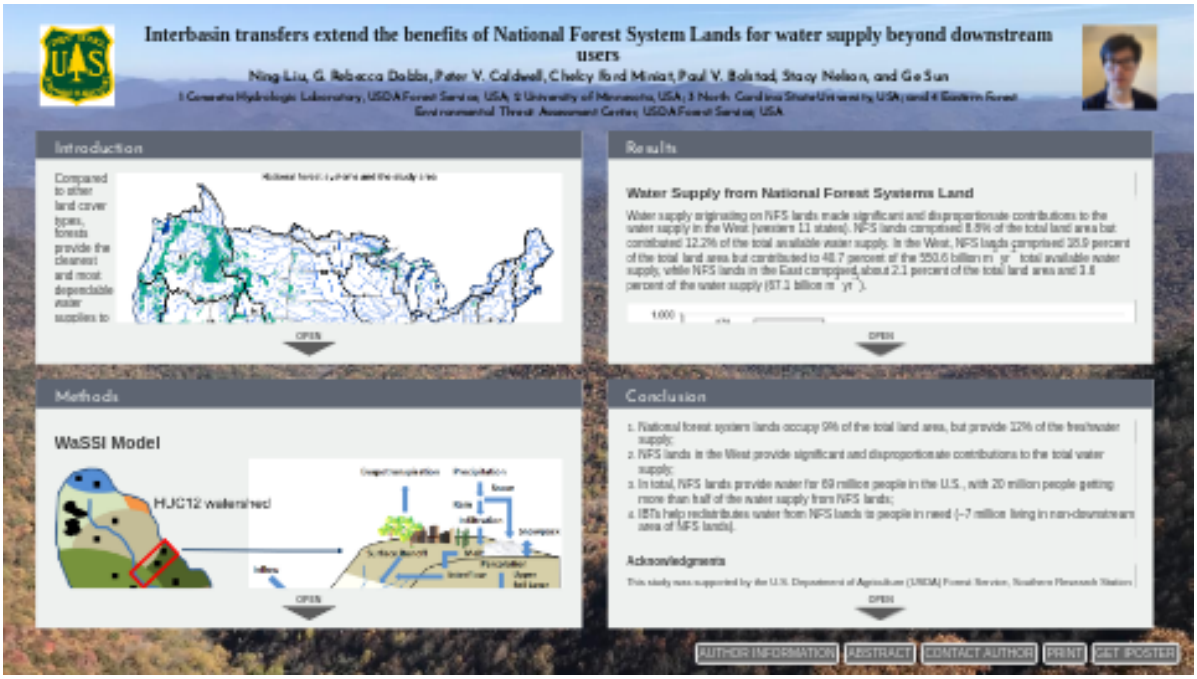
Interbasin transfers extend the benefits of National Forest System Lands for water supply beyond downstream users



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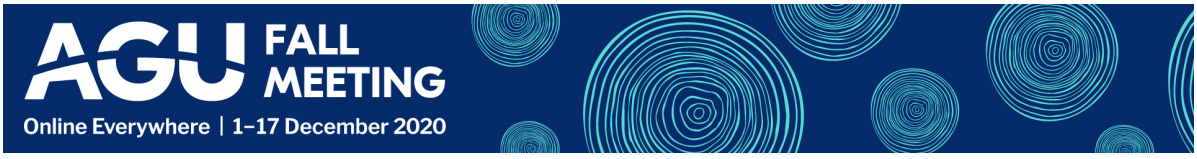
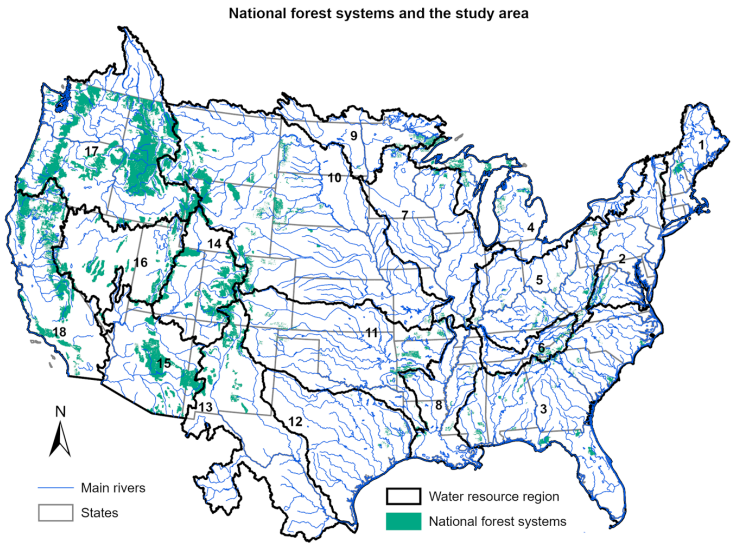


INTRODUCTION

Compared to other land cover types, forests provide the cleanest and most dependable water supplies to downstream communities. In addition to serving these downstream communities, water originating from forest lands is sometimes transferred hundreds of kilometers away to support people in big cities through inter-basin transfers (IBTs).



The USDA Forest Service (USFS) manages more than 779,000 km^2 of forests and grasslands that play a significant role in providing freshwater across the conterminous United States (CONUS). The contribution of these National Forest System (NFS) lands to specific surface drinking water supplies has not been assessed at the national scale nor have the effects of IBTs been considered in previous studies.

We quantified mean streamflow and the proportion of mean flow originating on NFS lands (172 unique National Forests and National Grasslands) at the 12-Digit Hydrologic Units scale across CONUS using USFS Water Supply Stress Index (WaSSI) model. We also modified the WaSSI model to account for water transfer through IBTs. Predictions of the proportion of water originating on NFS lands were linked to specific downstream communities and populations using surface drinking water intake information from the United States Environmental Protection Agency Safe Drinking Water Information System (SDWIS).

METHODS

WaSSI Model

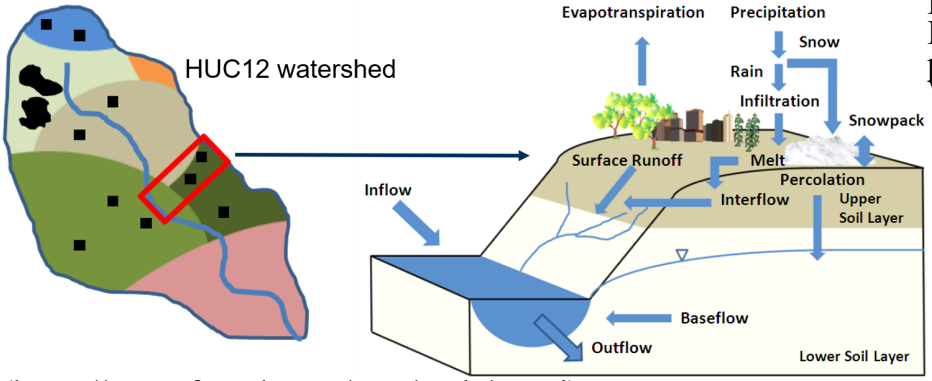


Figure 1 The Hydrologic processes in the WaSSI model (https://www.fs.usda.gov/ccrc/tools/wassi).

WaSSI is an integrated, process-based model that can be used to project the effects of forest land cover change, climate change, and water withdrawals on river flows, water supply stress, and ecosystem services. The core of WaSSI is a monthly water balance model that is sensitive to land cover and climate, computing the water balance independently for each land cover class in each watershed. Evapotranspiration, infiltration, soil storage, snow accumulation and melt, surface runoff, and base flow processes are accounted for within each basin, and discharge is conservatively routed through the stream network from upstream to downstream watersheds.

Drinking water intakes and population served

EPA's safe drinking water database (SDWIS) contains information about ~220,000 public water systems serving ≥25 persons. It includes public water system name, intake location, number of people served, and characteristics of their sources of water.

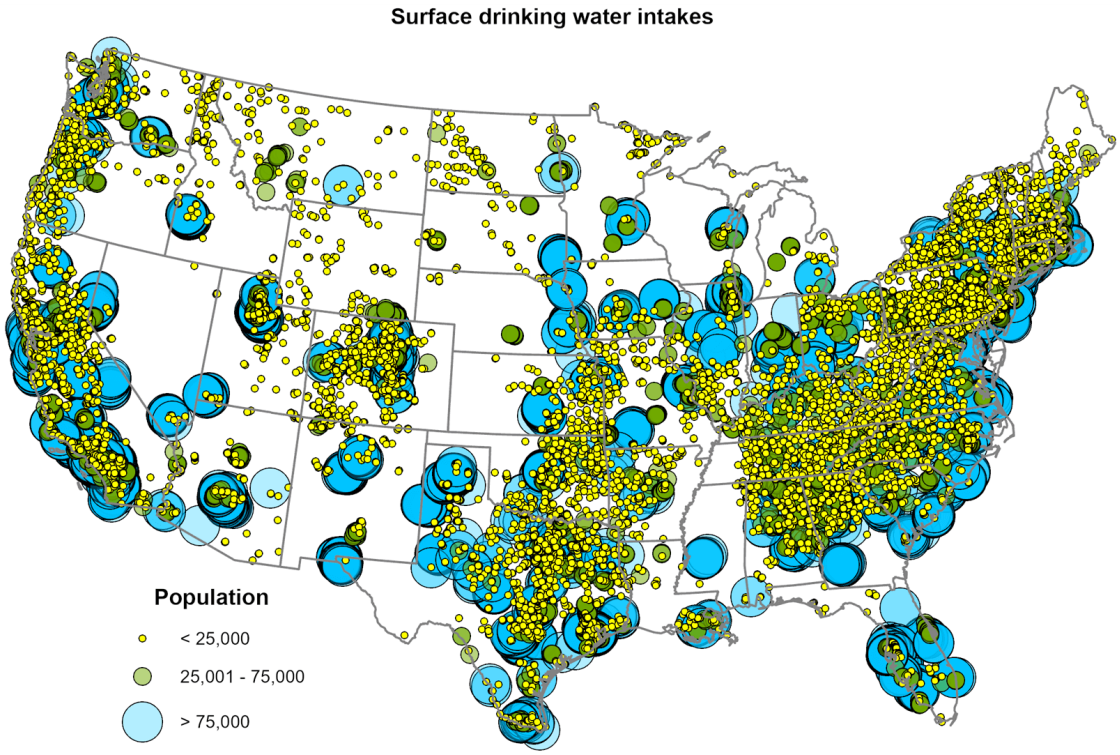


Figure 2 The surface drinking water intakes used in the study area. Intakes are sized and colored according to the population served at each intake.

Interbasin surface water transfers

There are 571 IBTs used in this study, transferring from 0.01 million m^3 yr^{-1} to 9,000 million m^3 yr^{-1} each, on average from 2001 to 2015. We modified the WaSSI model to account for water transfer through IBTs by incorporating the transfer from the source to the destination HUC12 for all IBTs in the flow accumulation calculations. In this way, the available water yield from NFS lands of all HUCs affected by a given IBT was updated based on the amount of surface water transferred through the IBT in the source and destination HUC12 as well as those downstream.

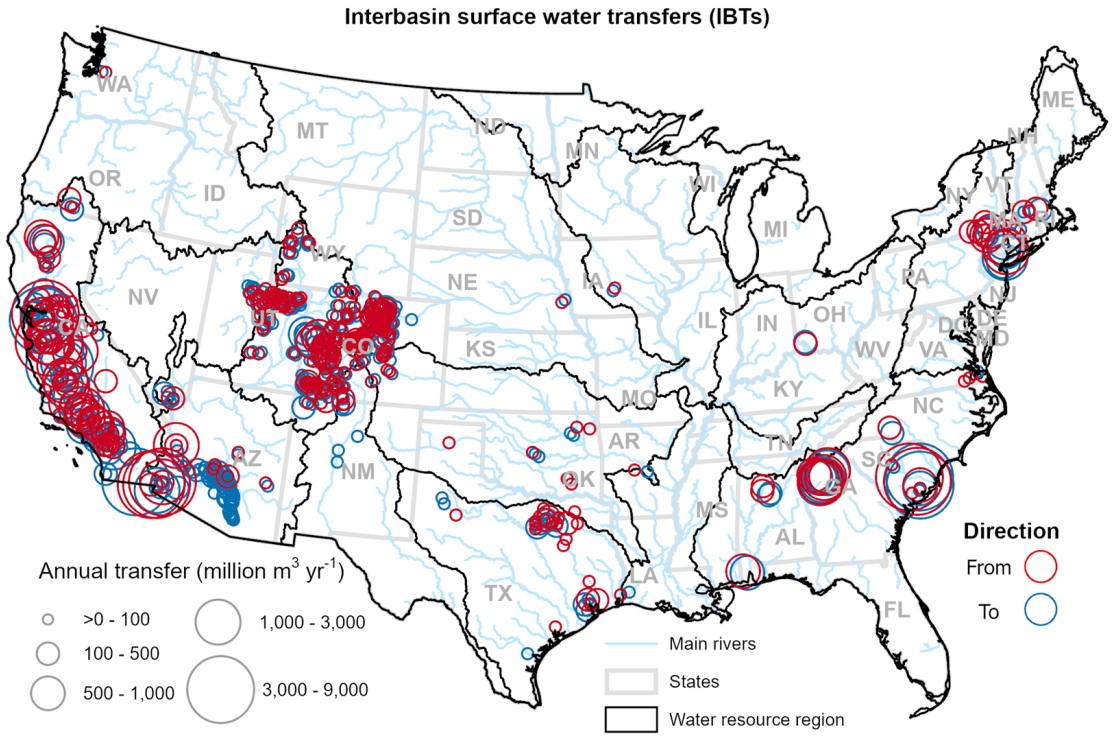


Figure 3—Interbasin surface water transfers (IBTs) in the conterminous United States from 2001 to 2015. Colors show the direction of IBTs and size represents mean annual transfer magnitudes between 12-digit hydrologic units (HUC12s).

RESULTS

Water Supply from National Forest Systems Land

Water supply originating on NFS lands made significant and disproportionate contributions to the water supply in the West (western 11 states). NFS lands comprised 8.8 percent of the total land area but contributed 12.2 percent of the total available water supply. In the West, NFS lands comprised 18.9 percent of the total land area but contributed to 40.7 percent of the 550.6 billion m^3 yr^{-1} total available water supply, while NFS lands in the East comprised about 2.1 percent of the total land area and 3.6 percent of the water supply (67.1 billion m^3 yr^{-1}).

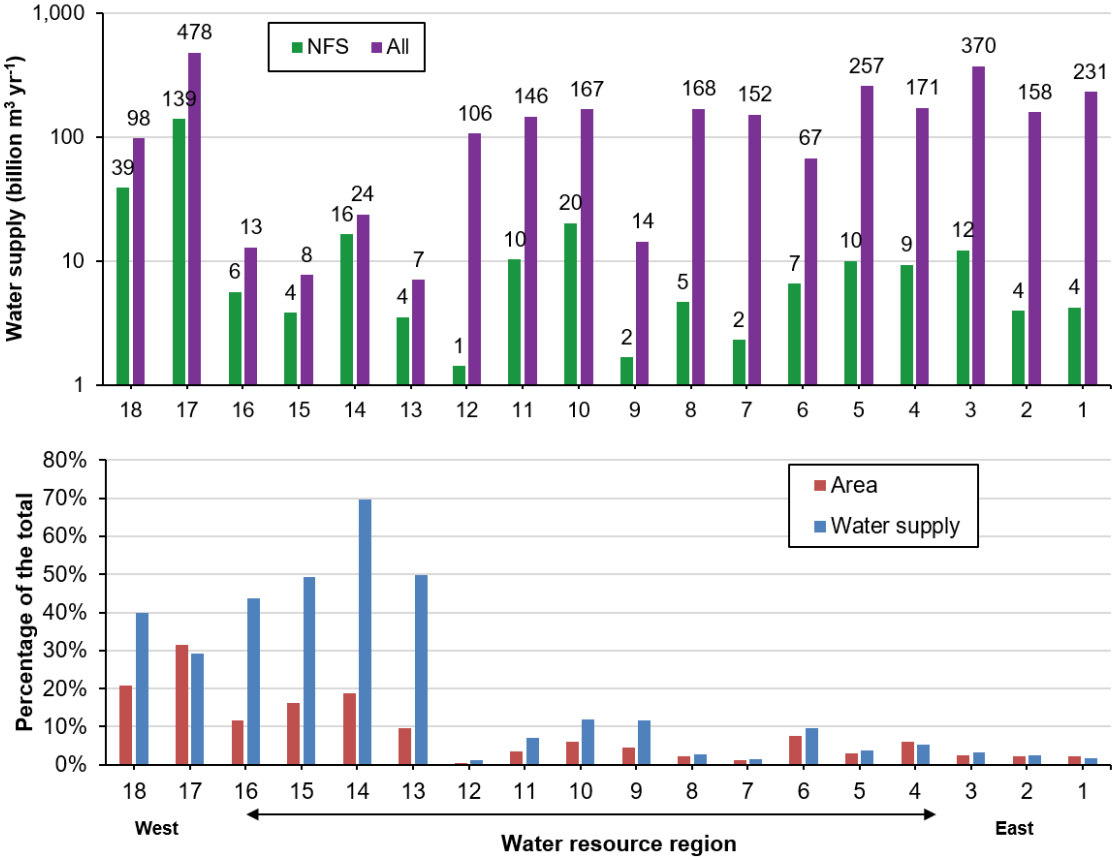


Figure 4—Mean annual water supply in billions of m^3 yr^{-1} (A) and percentage of water supply (B) originating on National forest systems (NFS) for each water resource region.

Population and Communities Served by Water from National Forest Systems Lands

Approximately 69.5 million people obtained some portion of their drinking water from NFS lands, and 19.8 million people received > 50 percent of water from NFS lands including those receiving water through IBTs.

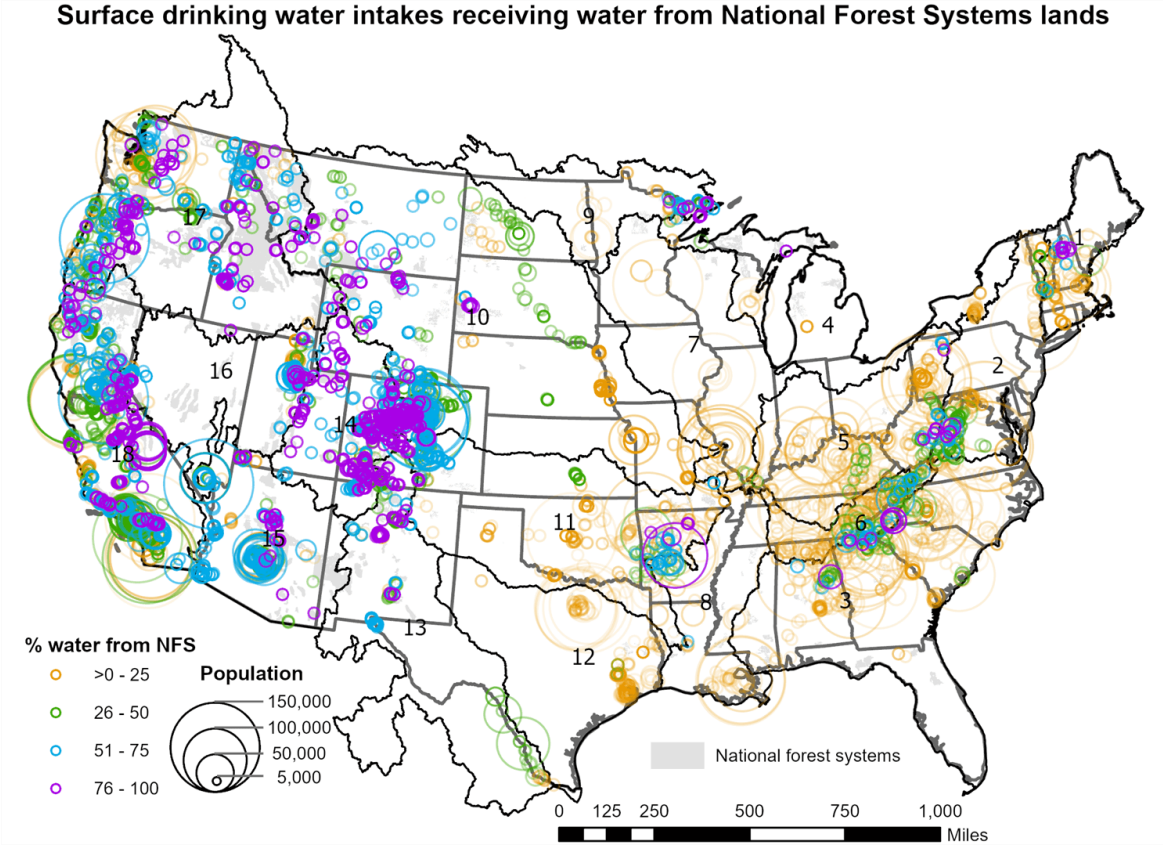


Figure 5—Intakes where some amount of source water originated on national forest system (NFS) lands. HUC12 watersheds are colored by the percentage of surface water from the national forest system (NFS) lands.

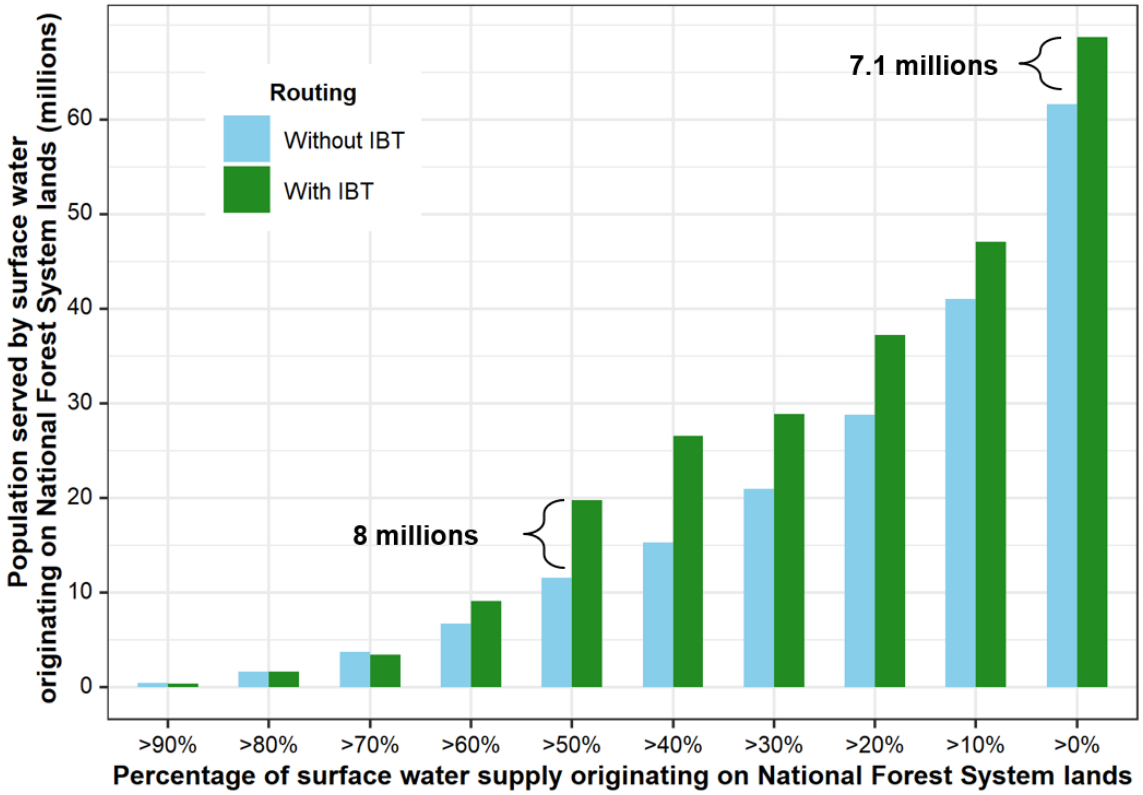


Figure 6—Cumulative frequency of population served according to the percentage of water coming from National Forest System lands.

There were 490 surface drinking water intakes that obtained all of their water from NFS lands through IBTs, 135 of these received >50 percent of water from NFS lands, serving 1.7 million people.

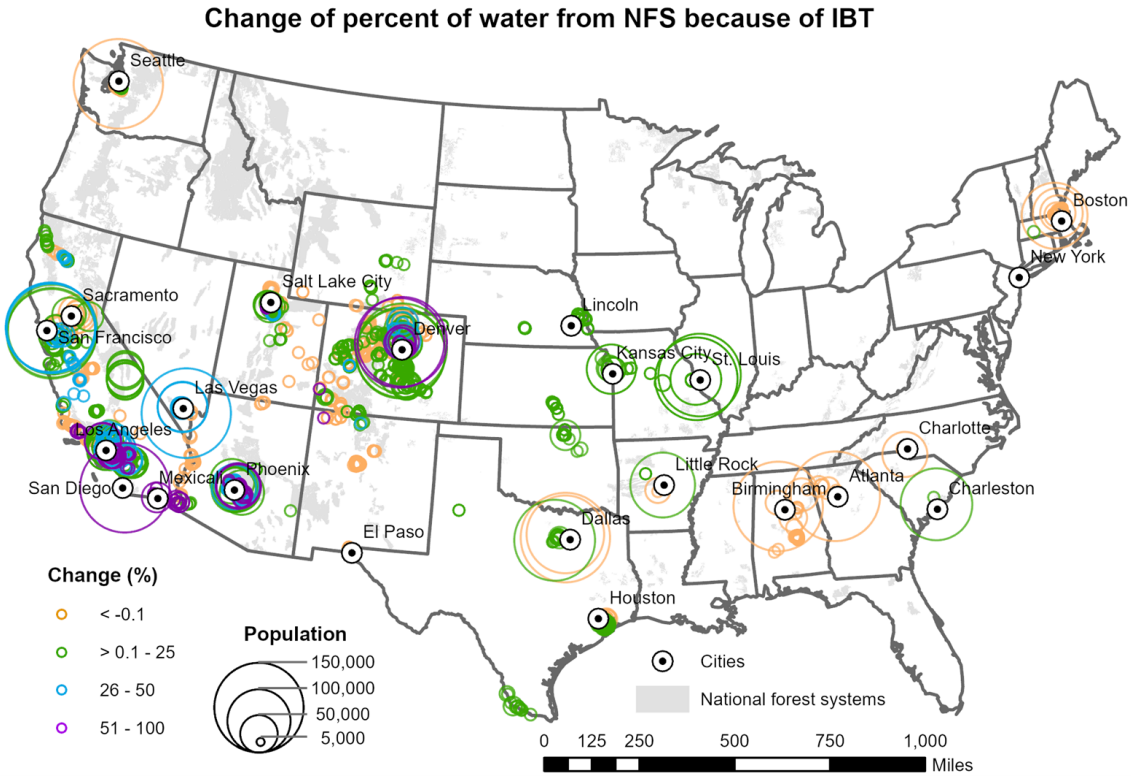


Figure 7—Change of the percentage of water coming from national forest system (NFS) lands because of IBTs.

Water transferred out of water resource region 14

A large amount of water is transferred from NFS lands in the Upper Colorado region (WRR 14) to other water resource regions.

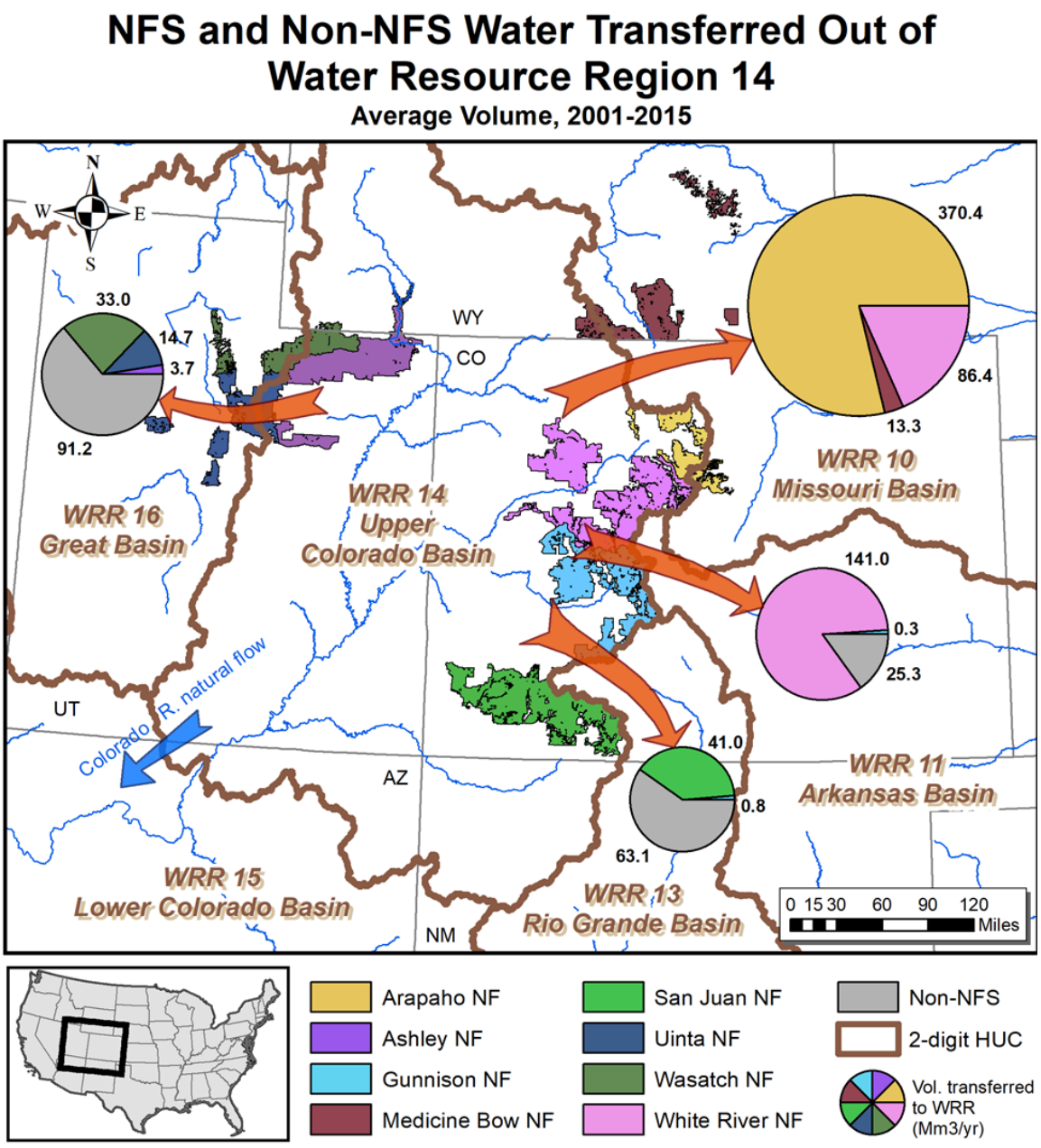


Figure 8—Mean annual water from each national forest that transferred out of water resource region 14.

The water source of key arid cities

Los Angeles-Long Beach-Riverside-San Bernardino urban area received more than 50% of the total surface water supply from NFS in the California region (WRR 18) and Colorado Basin (WRR 14 and WRR15), serving about 12.6 million people. Las Vegas-Henderson urban area got 62% of the total surface water supply from NFS in Colorado Basin, serving almost 2 million people.

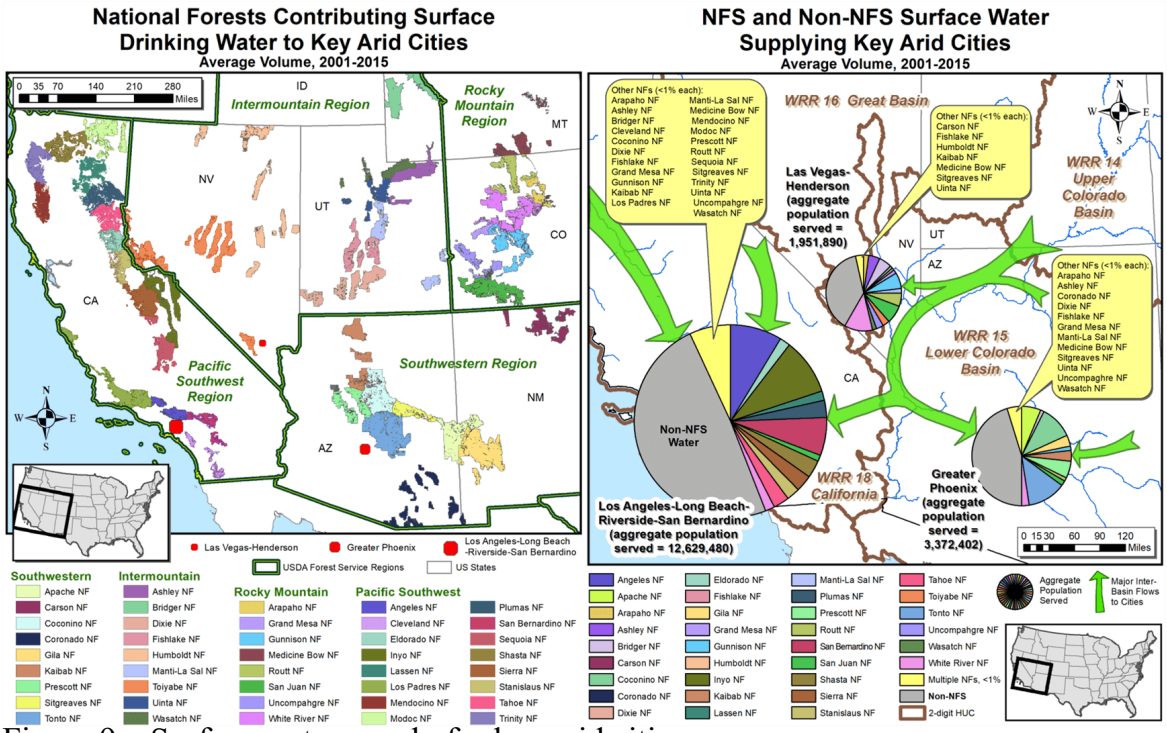


Figure 9—Surface water supply for key arid cities.

CONCLUSION

1. National forest system lands occupy 9% of the total land area, but provide 12% of the freshwater supply;
2. NFS lands in the West provide significant and disproportionate contributions to the total water supply;
3. In total, NFS lands provide water for 69 million people in the U.S., with 20 million people getting more than half of the water supply from NFS lands;
4. IBTs help redistributes water from NFS lands to people in need (~7 million living in non-downstream area of NFS lands).

Acknowledgments

This study was supported by the U.S. Department of Agriculture (USDA) Forest Service, Southern Research Station and the Southern Group of State Foresters by agreement number 18-JV-11330140-007 to Dr. S.A.C. Nelson at North Carolina State University, and USDA Forest Service, Washington Office, Water and Aquatic Resources by agreement number 17-CS-11330140-028 to Dr. P. Bolstad at the University of Minnesota.

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ABSTRACT

Compared to other land cover types, forests provide the cleanest and most dependable water supplies to downstream communities. In addition to serving these downstream communities, water originating from forest lands is sometimes transferred hundreds of kilometers away to support people in big cities through inter-basin transfers (IBTs). The USDA Forest Service (USFS) manages more than 779,000 km2 of forests and grasslands that play a significant role in providing fresh water across the conterminous United States (CONUS). The contribution of these National Forest System (NFS) lands to specific surface drinking water supplies has not been assessed at the national scale nor have the effects of IBTs been considered in previous studies. Here we modified the USFS Water Supply Stress Index (WaSSI) model to account for water transfer through IBTs. Our model results provide estimates of mean streamflow and the proportion of mean flow originating on NFS lands (172 unique National Forests and National Grasslands) at the 12-Digit Hydrologic Units scale across CONUS. Predictions of the proportion of water originating on NFS land were linked to specific downstream communities and populations using surface drinking water intake information from the United States Environmental Protection Agency Safe Drinking Water Information System (SDWIS). Our IBT database included 571 IBTs transferring from 0.01 million m^3 yr^{-1} to 8,900 million m^3 yr^{-1} each, for a total of 87,534 million m^3 yr^{-1}. We found that more than half of IBTs transferred water in which more than 50% originated on NFS lands. NFS lands comprised 8.8 percent of the total land area but contributed 12.2 percent of the total available water supply. In the West (western 11 states), NFS lands comprised 18.9 percent of the total land area but contributed to 40.7 percent of the 550.6 billion m^3 yr^{-1} total available water supply, while NFS lands in the East comprised about 2.1 percent of the total land area and 3.6 percent of the water supply (67.1 billionm^3 yr^{-1}). Approximately 69.5 million people derived some portion of their drinking water supply from NFS lands when IBTs were considered (62.5 million people without using an IBT). Almost 11.7 million people received greater than 50% of their drinking water supply from NFS lands. Another 8.1 million people derived the majority of their water from NFS lands via an IBT. NFS lands not only benefit and impact people living in the downstream communities, but also provide surface water for another 7.1 million people living in other areas through IBTs. This study provides a systemic understanding of the importance of NFS lands in providing water for drinking water supplies. Our results can aid water resource and forest managers in developing integrated watershed management plans at a time when climate, population growth, and land development threatens water supplies.