USDA
United States Department of Agriculture

Quantifying the Role of Forested Lands in Providing Surface Drinking Water Supply for Puerto Rico

Erika Cohen, Ge Sun, Liangxia Zhang, Peter Caldwell, and Suzanne Krieger

Forest Service
Southern Research Station
General Technical Report SRS-197 Addendum
September 2017

The Authors:

Erika Cohen, Resource Information Specialist, Eastern Forest Environmental Threat Assessment Center, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27606; **Ge Sun,** Research Hydrologist, Eastern Forest Environmental Threat Assessment Center, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27606; **Liangxia Zhang,** Lecturer, Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters (CIC-FEMD) / Jiangsu Key Laboratory of Agricultural Meteorology, Nanjing University of Information Science & Technology, Nanjing 210044, China; **Peter Caldwell,** Research Hydrologist, Coweeta Hydrologic Laboratory, Southern Research Station, U.S. Department of Agriculture Forest Service, Otto, NC 28763; and **Suzanne Krieger,** Regional Hydrology Program Manager, Region 8, U.S. Department of Agriculture Forest Service, Atlanta, GA 30309.

Cover photo

Unique, low-stature elfin forests are found on the tops of Puerto Rico's highest peaks. (Photo by Thomas J. Brandeis, Southern Research Station)

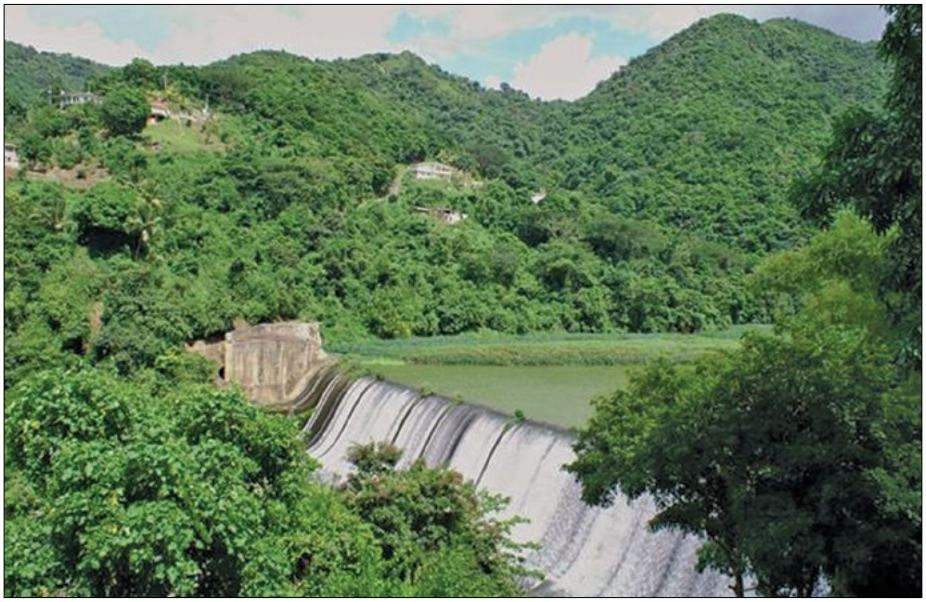
Forest Service
Southern Research Station
GTR-SRS-197 Addendum

September 2017
Southern Research Station
200 W.T. Weaver Blvd.
Asheville, NC 28804

www.srs.fs.usda.gov

Quantifying the Role of Forested Lands in Providing Surface Drinking Water Supply for Puerto Rico

Erika Cohen, Ge Sun, Liangxia Zhang, Peter Caldwell, and Suzanne Krieger



The delivery of fresh water, held here by the Rio de la Plata dam, is one of the vital ecosystem services provided by Puerto Rico's forests. (Photo by Dr. Humfredo Marcano, Southern Research Station)

Where not disturbed by human activity, dense, highly diverse forests cover the slopes of Puerto Rico's mountains. (Photo by Thomas J. Brandeis, Southern Research Station)

Contents

Abstract vi

Introduction 1

Study Area 1

Climate 2

Forest Land Cover 4

Methods 5

Extent and Scale of Analysis 5

Quantifying Water Supply from Forested Lands 5

Drinking Water Intakes and Population Served 9

Results 11

Water Supply from Forested Lands 11

Population and Communities Served by Water from Forested Lands 13

Discussion and Summary 19

References 20

Abstract

The Forest Service, U.S. Department of Agriculture published a General Technical Report (GTR-SRS-197) in 2014 that quantified the role that water originating on National Forest System lands contributed to the drinking water supply and determined what population and communities were being served in the 13 Southern States of Region 8 of the Forest Service. The Commonwealth of Puerto Rico is included in Region 8, but it was not included in the results of GTR-SRS-197 because at the time of that report the Water Supply Stress Index (WaSSI) model used for the assessment was not parameterized for Puerto Rico. The goal of this project was to implement the same methodology used in GTR-SRS-197 for the mainland of Puerto Rico. WaSSI is a monthly water balance and flow routing model that can quantify the amount of water at a watershed outlet. Water intake location data from the U.S. Geological Survey (USGS) and population served data from the Puerto Rico Aqueduct and Sewer Authority were used to quantify the amount of population being served by water originating on forested land. Puerto Rico has a total land area of 8,900 km^2, and 38 percent of that land area is forested with 1.2 percent in National Forest System land and 37.1 percent in commonwealth and private forest land. We estimated that all lands in mainland Puerto Rico produced 6.5 billion m^3/year of water. Of that total, National Forest System lands provided 219 million m^3/year of water (3.3 percent of total land), and commonwealth and private forest lands provided 2.6 billion m^3/year of water (40 percent of total land). A population of 3.6 million people was served by 113 intakes located downstream of commonwealth and private forest land, and 13 of those intakes were also located downstream of El Yunque National Forest and served a population of 780,000. National Forest System land and commonwealth and private forest land play an unequal role in providing water for the people of Puerto Rico. More than 2.1 million people receive at least 30 percent of their water from commonwealth and private forest land. In comparison, more than 139,000 people receive at least 30 percent of their water from National Forest System land. Our analysis provides quantitative information on water yield from forest lands and sources of water supply in Puerto Rico. This study is an addendum to GTR-SRS-197.

Keywords: commonwealth and private forest lands, drinking water, hydrologic modeling, National Forest System, Puerto Rico, State and private forest lands, WaSSI, water supply.

Introduction

The Southern Region (Region 8) of the Forest Service, U.S. Department of Agriculture manages National Forest System (NFS) lands in 13 Southern States and in the Commonwealth of Puerto Rico. The 13 States include Texas, Oklahoma, Arkansas, Louisiana, Mississippi, Tennessee, Kentucky, Alabama, Georgia, Florida, South Carolina, North Carolina, and Virginia. Region 8 conducted a project from 2012 to 2014 to determine what quantity of water originating on NFS lands contributed to the drinking water supply, and to determine the total population and communities being served by this water in the 13 Southern States of Region 8 (Caldwell and others 2014).

The project used the Water Supply Stress Index (WaSSI) model (Caldwell and others 2012; Sun and others 2008, 2011a, 2011b) developed by the Forest Service to quantify the amount of water originating from various land cover types in the South with particular focus on National Forest System Land. At the time of the project, the WaSSI model was not parameterized for Puerto Rico, and Puerto Rico was not included in the results of the General Technical Report-SRS-197, "*Quantifying the Role of National Forest System Lands in Providing Surface Drinking Water Supply for the Southern United States*" (Caldwell and others 2014). In 2015, the WaSSI model was refined and expanded to study Puerto Rico at the sixth-level Hydrologic Unit Code (HUC12) scale using improved hydrological algorithms unique to the forest ecosystems of the tropical rainforest. With this expansion, the capability exists to quantify the amount of water from various land cover types with a focus on forested lands. The overall goal of this project was to implement the same methodology described in GTR-SRS-197 to determine what role forests play in providing drinking water to the populations and communities within Puerto Rico. This report is an addendum to GTR-SRS-197.

The overall goal of this project was to implement the same methodology described in GTR-SRS-197 to determine what role forests play in providing drinking water to the populations and communities within Puerto Rico.

Study Area

The Commonwealth of Puerto Rico is an archipelago located in the northeastern Caribbean Sea. Mainland Puerto Rico is the smallest of the Greater Antilles, and it is composed of multiple islands, with the largest having a total land area of 8,900 km^2 (fig. 1). Puerto Rico is densely populated with 3.7 million people living primarily on the mainland island (U.S. Census Bureau 2012). The study area for this project was mainland Puerto Rico, a very mountainous region with four mountain ranges dominating the landscape. The two most notable of these mountain ranges are the Cordillera Central, which runs the full, east-west length of the island and contains the highest elevation on the island of 1330 m, and the Sierra de Luquillo, which is located in the northeastern portion of the island and contains the largest protected area on the island, El Yunque National Forest (NF) (fig. 2).

Figure 1—The Commonwealth of Puerto Rico is located in the northeastern Caribbean Sea (top); it comprises multiple islands, the largest of which has a total land area of 8,900 km^2 (bottom).

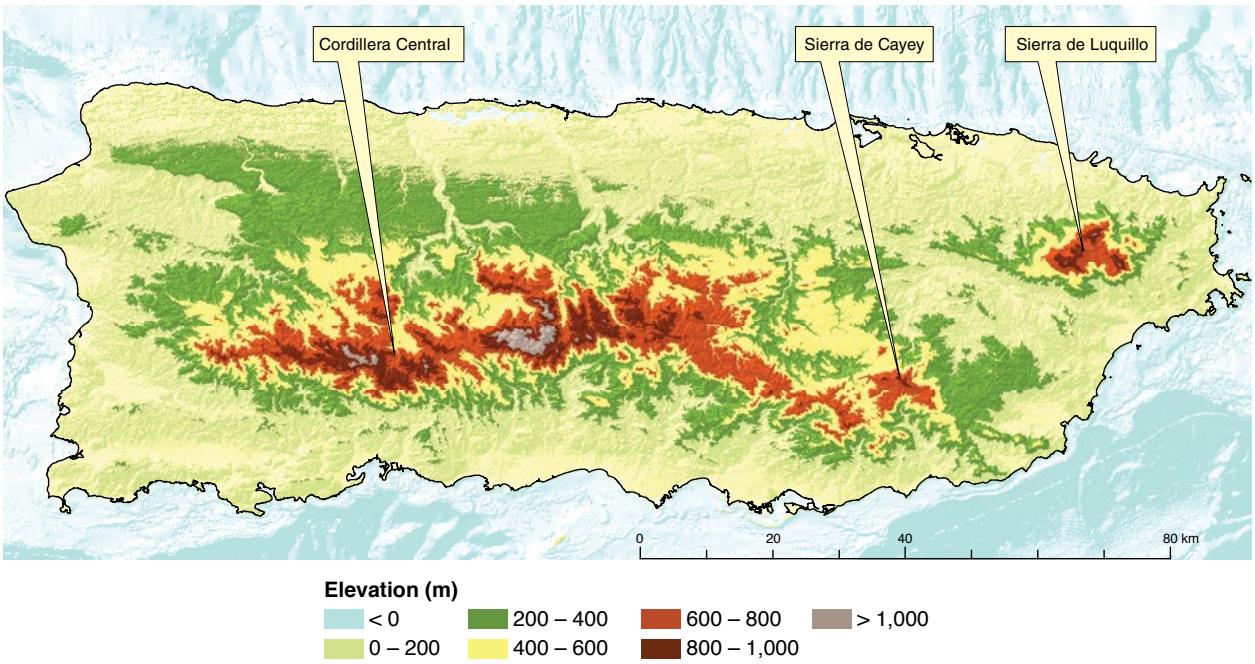


Figure 2—The topography of mainland Puerto Rico is very mountainous, including three notable ranges: the Cordillera Central, Sierra de Luquillo, and Sierra de Cayey.

As of December 2016, the Commonwealth of Puerto Rico has 164 protected areas, and 137 of those protected areas are terrestrial protected areas, which equates to 16 percent (143 590 ha) of the total land area (Caribbean Landscape Conservation Cooperative 2016). These protected areas are managed by Federal and Commonwealth agencies, as well as nonprofit and private organizations (Gould and others 2011, Quinones and others 2013). El Yunque National Forest spans nearly 11 310 ha and is the only tropical rainforest in the U.S. National Forest System (Weaver 2012). It is very diverse, with forest types including tabonuco (*Dacryodes excelsa*), palo Colorado (*Cyrilla racemiflora*), sierra palm (*Prestoea montana*), and dwarf forest. The tabonuco forests are found on foothills and slopes below 600 m. The palo Colorado forests are found on saturated soils, gentle slopes, and valleys between 600 m and 900 m. The sierra palm forests are found on steep slopes in the same elevation range as tabonuco and palo Colorado forests. The dwarf forests, also known as elfin forests, are found on the peaks above 900 m, with *Tabebuia rigida* as the dominant species (Harris and others 2012, McDowell and others 2012).

Climate

Puerto Rico has a tropical maritime climate (Daly and others 2003). The mountain range that runs the full length of mainland Puerto Rico—the Cordillera Central (fig. 2)—divides the island into two climate zones. The northern portion of the island has a relatively humid climate, and the southern portion has a semi-arid climate (Gómez-Gómez and others 2014). The mean annual air temperature ranges from 18 °C in the mountains to 27 °C along the coastline (Daly and others 2003) (fig. 3). On average, the coastal region can be slightly warmer (~ 2 °C) than the interior mountainous region (Gómez-Gómez and others 2014).

Precipitation in Puerto Rico is bimodal with the easterly waves affecting precipitation from May to November, which can range from no rainfall to low intensity to high intensity that produces flooding. The high rain events are normally caused by tropical storms and hurricanes. The cold fronts moving off the Eastern United States affect precipitation from November to April and can also produce flooding (Daly and others 2003). Localized drought can occur yearly within Puerto Rico because the number of easterly waves and cold fronts determines the frequency of rainfall events on the island (Gómez-Gómez and others 2014). Mean annual precipitation ranges from 768 mm/year to 4,305 mm/year, with

the highest amount occurring in the eastern part of the island in the Sierra de Luquillo region and the lowest amount occurring in the southwestern part of the island (Gómez-Gómez and others 2014) (fig. 4). The Cordillera Central and Sierra de Cayey mountains cause orographic effects on precipitation, resulting in higher precipitation on the windward side (north and northeast) and lower precipitation on the leeward side (south and southeast) of the island (Gómez-Gómez and others 2014).

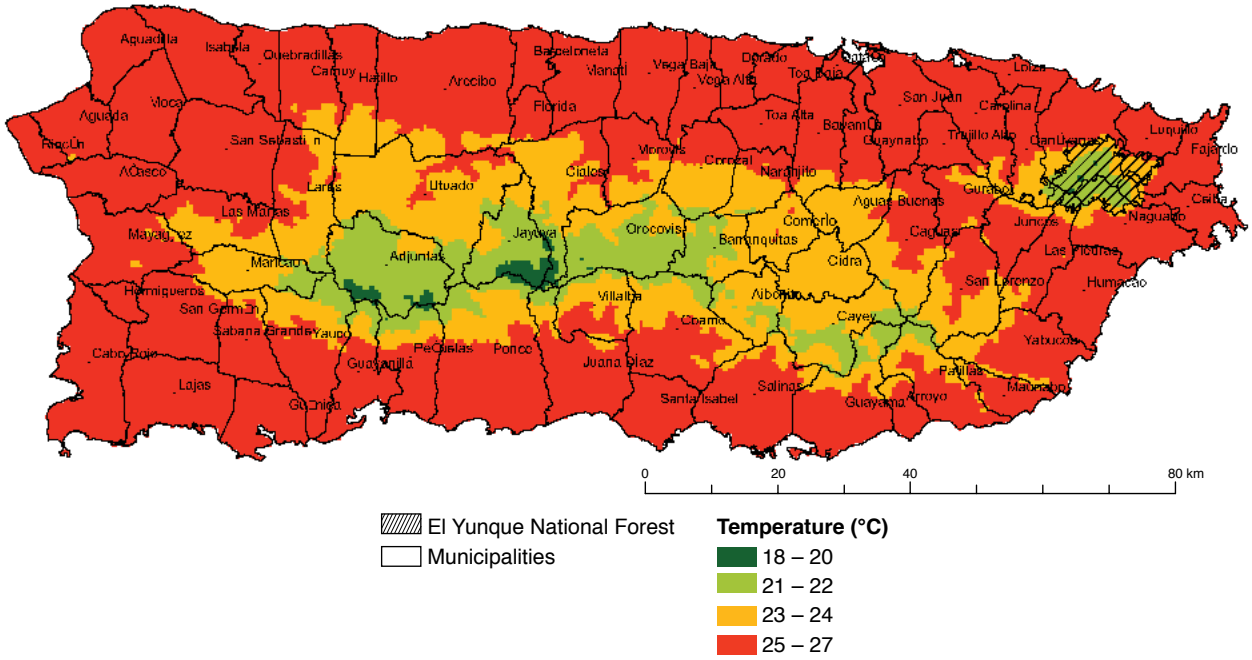


Figure 3—The mean annual temperature of mainland Puerto Rico, averaging years 1963–1995. Mapped using the PRISM (Parameter-elevation Regression on Independent Slopes Model) data by Daly and others (2003).

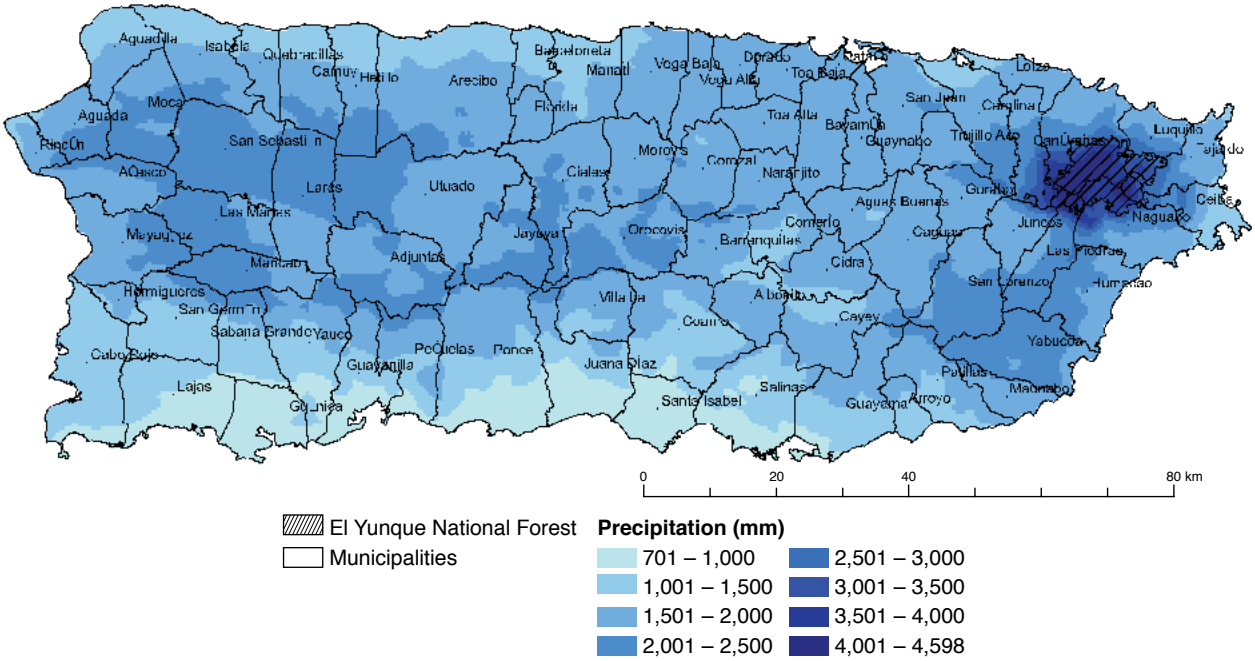


Figure 4—The mean annual precipitation of mainland Puerto Rico, averaging years 1963–1995. Mapped using the PRISM (Parameter-elevation Regression on Independent Slopes Model) data by Daly and others (2003).

Forest Land Cover

Prior to the 20th century, the landscape of mainland Puerto Rico was dominated by closed canopy forests. Significant deforestation occurred during the early 20th century to convert forest land for agricultural uses (Birdsey and Weaver 1982, Helmer 2004, Kennaway and Helmer 2007). By the late 1940s, forest land made up only 6 percent of the total land area of mainland Puerto Rico (Franco and others 1997). In the 1950s, mainland Puerto Rico began transitioning from an agriculture-driven economy to an industrial and service economy.

People migrated from rural to urban areas within Puerto Rico and to the mainland of the United States. The abandoned cropland, coffee shade, and pasture began to naturally regenerate into forest (Birdsey and Weaver 1982, Helmer 2004, Kennaway and Helmer 2007). In 1991, 2004, and 2009, forest made up 43.0, 52.7, and 54.7 percent of land cover, respectively, in mainland Puerto Rico (Brandeis and others 2007, Brandeis and Turner 2013, Gould and others 2008, Kenneway and Helmer 2007).

Prior to the 20th century, the landscape of mainland Puerto Rico was dominated by closed canopy forests. Significant deforestation occurred during the early 20th century to convert forest land for agricultural uses.

Puerto Rico's forested mountain slopes provide the island with fresh water. (Photo by Thomas J. Brandeis, Southern Research Station)

Methods

Extent and Scale of Analysis

This study focused on surface water supply and drinking water intakes encompassing the mainland portion of Puerto Rico. Surface water supply was estimated for intakes downstream of forest land in mainland Puerto Rico, specifically National Forest System land and commonwealth and private forest land. The special resolution of our analysis was the 12-digit, or sixth-level, Hydrologic Unit Code (HUC12) watershed scale. A hydrologic unit is "a topographically defined set of drainage areas organized in a nested hierarchy by size and number of divisions per nested level" (USGS and USDA-NRCS 2013). The HUC system comprises six nested levels which correspond to HUC numbers that range from 2 to 12 digits. For the continental United States, the watersheds are based on 1:24,000 scale, 1:25,000 scale in the Caribbean, and 1:63,360 scale in Alaska. There are 243 HUC12s in Puerto Rico, and they range in size from 80 to 34 800 ha (fig. 5).

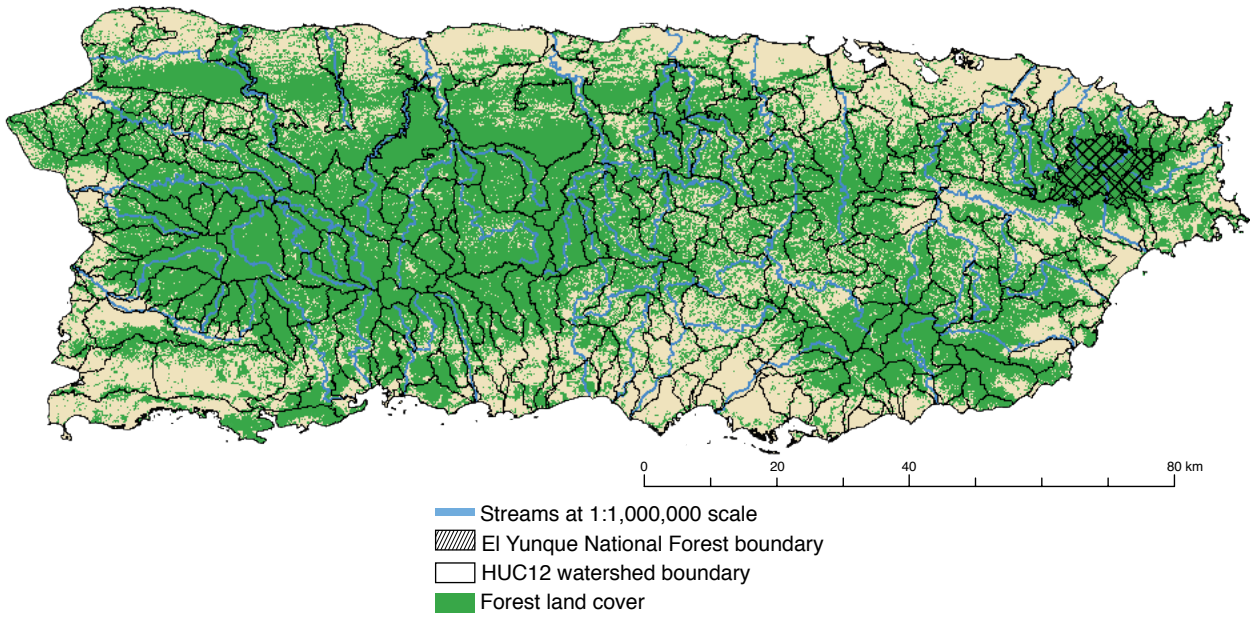


Figure 5—The location of forest land cover and HUC12 watershed boundaries in mainland Puerto Rico.

Quantifying Water Supply from Forested Lands

The Water Supply Stress Index (WaSSI) model was used to quantify the amount of water from forested lands. WaSSI is a monthly water balance and flow routing model developed and validated by the Forest Service that estimates the effects of population change, climate change, land use change, and water withdrawals on water quantity, water supply stress, and ecosystem productivity at the continental scale (Caldwell and others 2012; Lockaby and others 2011; Marion and others 2013; Sun and others 2008, 2011a, 2011b, 2013; Tavernia and others 2013). WaSSI requires climate (precipitation and temperature), land cover, leaf area index, and soil data in each HUC12 to run the model. All input datasets are scaled from the sets' native resolution to the HUC12 watershed scale using a Geographic Information System (GIS) (table 1). WaSSI runs at the monthly time step and simulates evapotranspiration, infiltration, soil storage, snow accumulation and melt, surface runoff, and base flow for each land cover class within the watershed. Once these hydrologic components are simulated, WaSSI routes the water through a flow network to simulate total flow from the headwaters to the mouth of the river network downstream.

Table 1—Input datasets for the Water Supply Stess Index (WaSSI) model

Data/database	Source	Resolution	Time period
Soil properties	STATSGO-based Sacramento Soil Moisture Accounting Model soil parameters and NOAA-NWS Hydrology Laboratory, Office of Hydrologic Development	1×1 km grid	–
Land cover	Puerto Rico GAP Analysis project (http://caribbeanlcc.org/data-center/)	15×15 m grid	2001
National Forest System lands	USFS Automated Lands Program Land Status Record System surface ownership parcels (basic ownership) (https://data.fs.usda.gov/geodata)	parcel	2013
Monthly mean leaf area index by land cover	Moderate Resolution Imaging Spectroradiometer (MODIS) (https://modis.gsfc.nasa.gov/)	1×1 km grid	2000–2011
Climate (monthly precipitation and temperature)	PRISM data (Daly and others 2003) (http://caribbeanlcc.org/interactive-map/)	450×450 m grid	1963–1995
River network	U.S. Geological Survey National Hydrography Dataset (https://nhd.usgs.gov/data.html)	1:100,000	–
Watershed boundaries	U.S. Department of Agriculture, Natural Resources Conservation Service Watershed Boundary Dataset (https://nhd.usgs.gov/wbd.html)	HUC12	–

– = Input data assumed to be constant over time.

WaSSI estimates water discharge at each of the watershed outlets by considering total flows into each watershed from upstream and water yield from the watershed examined, and estimates consumptive water use as water loss (fig. 6). Finally, WaSSI computes the water supply stress index as the ratio of water demand over water supply. In this study, the consumptive water use and water supply stress index was not estimated because no water demand data are available across the region. A Web version of WaSSI is available at https://www.wassiweb.sgcp.ncsu.edu/.

The Puerto Rico gap analysis project (PRGAP) land cover dataset was used as input into the WaSSI model. The dataset was derived from Landsat 7 ETM+ imagery that was pan-sharpened to a 15-m^2 resolution spanning the years 1999–2003; the dataset also was classified into 70 thematic classes (Gould and others 2008). The 70 PRGAP classes were combined into 10 WaSSI land cover classes for input into the model (table 2). Within WaSSI, NFS land is considered its own land cover category and is the 11th WaSSI land cover class. This separation

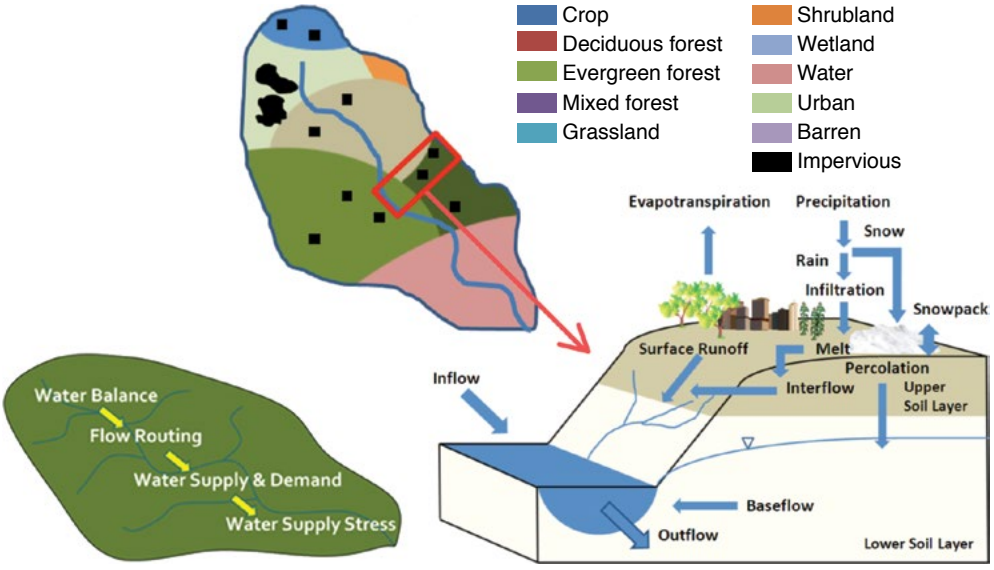


Figure 6—Schematic diagram illustrating the hydrological processes simulated by the Water Supply Stress Index (WaSSI) model.

Table 2—Crosswalk of Puerto Rico gap analysis project (PRGAP) land cover classes to WaSSI land cover classes

WaSSI land cover class	PRGAP land cover code and description	
Barren	570	Rocky cliffs and shelves
	580	Gravel beaches and stony shoreline
	590	Fine to coarse sandy beaches, mixed sand and gravel beaches
	600	Riparian and other natural barrens
	610	Salt and mudflats
	620	Salt production
	650	Artificial barrens
Crop	550	Hay and row crops
	560	Woody agriculture and plantations: palm plantations
Deciduous forest	10	Mature secondary lowland dry alluvial semideciduous forest
	20	Young secondary lowland dry alluvial semideciduous forest
	50	Mature secondary lowland dry limestone semideciduous forest
	60	Young secondary lowland dry limestone semideciduous forest
	110	Lowland dry limestone cliffside semideciduous forest
	130	Mature secondary lowland dry noncalcareous semideciduous forest
	140	Young secondary lowland dry noncalcareous semideciduous forest
	160	Mature secondary dry and moist serpentine semideciduous forest
	170	Young secondary dry and moist serpentine semideciduous forest
Evergreen forest	40	Mature secondary lowland dry limestone evergreen forest
	200	Mature secondary lowland moist alluvial evergreen forest
	210	Young secondary lowland moist alluvial evergreen forest
	260	Mature secondary lowland moist noncalcareous evergreen forest
	270	Young secondary lowland moist noncalcareous evergreen forest
	300	Mature secondary montane wet alluvial evergreen forest
	310	Young secondary montane wet alluvial evergreen forest
	330	Mature secondary montane wet noncalcareous evergreen forest
	340	Mature primary tabonuco and secondary montane wet noncalcareous evergreen forest
	350	Mature primary palo Colorado and secondary montane wet noncalcareous evergreen forest
	360	Mature primary sierra palm and secondary montane wet noncalcareous evergreen forest
	370	Mature primary elfin woodland and secondary montane wet noncalcareous evergreen cloud forest
	380	Young secondary montane wet noncalcareous evergreen forest
	400	Mature secondary montane wet serpentine evergreen forest
	410	Young secondary montane wet serpentine evergreen forest
	430	Montane wet evergreen abandoned and active coffee plantation
Grassland	480	Dry grasslands and pastures
	500	Moist grasslands and pastures

Continued

Table 2—(*Continued*) Crosswalk of Puerto Rico gap analysis project (PRGAP) land cover classes to WaSSI land cover classes

WaSSI land cover class	PRGAP land cover code and description	
Mixed forest	190	Abandoned dry forest plantation
	230	Mature secondary moist limestone evergreen and semideciduous forest
	240	Young secondary moist limestone evergreen and semideciduous forest
	290	Lowland moist abandoned and active coffee plantations
	460	Lowland dry riparian forest
	680	Lowland moist riparian forest
Shrubland	30	Lowland dry alluvial shrubland and woodland
	70	Lowland dry limestone woodland and shrubland
	80	Lowland dry limestone shrubland
	90	Lowland dry cactus shrubland
	100	Coastal dwarf woodland and shrubland
	120	Lowland dry limestone cliffside shrubland and woodland
	150	Lowland dry noncalcareous shrubland and woodland
	180	Dry and moist serpentine woodland and shrubland
	220	Lowland moist alluvial shrubland and woodland
	250	Moist limestone shrubland and woodland
	280	Lowland moist noncalcareous shrubland and woodland
	320	Montane wet alluvial shrubland and woodland
	390	Montane wet noncalcareous evergreen shrubland and woodland
	420	Wet serpentine shrubland and woodland
	440	Mangrove forest and shrubland
	470	Lowland dry riparian shrubland and woodland
	490	Dry cactus grassland and shrubland
	690	Lowland moist riparian shrubland and woodland
Urban	630	High-density urban development
	640	Low-density urban development
Water	660	Freshwater
	670	Saltwater
	700	Aquiculture
Wetland	450	Freshwater Pterocarpus swamp
	510	Emergent herbaceous nonsaline wetlands
	520	Emergent herbaceous saline wetlands
	530	Seasonally flooded herbaceous nonsaline wetlands
	540	Seasonally flooded herbaceous saline wetlands

from all other forest land was necessary to quantify the amount of water coming from only NFS lands. We used the Forest Service basic ownership dataset to identify NFS lands, and all other forest lands were considered commonwealth and private forest land.

In WaSSI, evapotranspiration (ET) is a function of potential evapotranspiration (PET), precipitation (P), and leaf area index (LAI) using an empirical relationship based on ET measurements from 13 eddy covariance sites (Sun and others 2011a) in the AmeriFlux network. These sites measure ecosystem carbon, water, and energy fluxes from the landscape. The 13 sites represent a variety of ecosystems, climatic zones, and land management techniques, and the equation derived from those sites is more appropriate for the national scale application of WaSSI. ET is calculated for each WaSSI land cover class (see table 2) within a watershed. For this study, the sites used to develop the ET relationship for the forest class needed to represent the tropical rainforest ecosystems of Puerto Rico. Five evergreen tropical rainforest eddy flux sites, located in Brazil and Vanuatu, were used to derive a new forest ET regression equation for the El Yunque National Forest region. (Zhang and others, in review):

$$ET = 28.6 + 0.55PET - 0.032P + 1.478LAI \ (R^2 = 0.25, \ p < 0.0001)$$

where P is monthly total precipitation (mm), LAI is the monthly averaged leaf area index derived from continental MODIS products, and PET was calculated with Hamon's method that used air temperature and potential daytime length and was widely used due to its simplicity and reliability compared to more complex methods (Lu and others 2005, Vörösmarty and others 1998). This new ET model appears to improve the WaSSI model performance in matching measured streamflow in the study region (Zhang and others, in review).

WaSSI models natural water balance and does not account for any engineering structures on streams like dams or diversions, and also does not account for interbasin transfer. WaSSI estimates water quantity at the outlet of each watershed that includes flow from all upstream contributions. We used the same definition as in Caldwell and others (2014) to quantify the mean annual discharge, the fraction of mean annual discharge from NFS land, and the fraction of mean annual discharge from commonwealth and private forest land.

WaSSI models natural water balance and does not account for any engineering structures on streams like dams or diversions, and also does not account for interbasin transfer. WaSSI estimates water quantity at the outlet of each watershed that includes flow from all upstream contributions.

Drinking Water Intakes and Population Served

The U.S. Geological Survey (USGS) Caribbean Water Science Center provided water intake locations for mainland Puerto Rico for water treatment plants from their National Water Information System (NWIS) database. This dataset included 127 intakes that were field verified as of September 2014. The dataset contained general descriptive information on each intake (e.g., station name) and detailed information on water use and site use. Six intakes had a site use or water use code of "u" for unused or abandoned and were not included in the study analysis. A total of 121 intakes were included in the study analysis. Those intakes had a site use code of "w" for withdrawal of water, and a water use code of "p" for public supply. Public supply water use is water that is pumped to five or more homes or trailers and summer camps with five or more units. Hotels and motels are not included in this category. This definition of public supply water use differs from the U.S. Environmental Protection Agency standard definition which adheres to a 25-people or 15-service connection minimum.

The Puerto Rico Aqueduct and Sewer Authority (PRASA) provided data on population served for 141 intakes associated with water treatment plants in mainland Puerto Rico. This dataset included general descriptive information on each intake including location, name, water source, water treatment plant, public water system identification, and municipality. Both datasets provided physical location for the intakes, but those locations were not coincident. The USGS location was used for our study because those locations had been field verified, and the attribute information contained in each dataset was used to link the PRASA population served value to the 121 USGS intakes using specific criteria (table 3). Joining the USGS and PRASA data using those criteria provided a final 113 intakes used in the analysis. These intakes were downstream of commonwealth and private forest land and served a population of 3.6 million people; 13 of those intakes were also downstream of El Yunque National Forest and served a population of approximately 780,000 people.

Table 3—Criteria used to join the Puerto Rico Aqueduct and Sewer Authority (PRASA) population served data to the U.S. Geological Survey (USGS) water intakes within a HUC12 watershed

Criterion	Action	USGS intake count
USGS station name = PRASA water treatment plant name	PRASA population assigned to USGS intake	108
Multiple USGS station names = single PRASA water treatment plant name	PRASA population divided equally among the USGS intake	5
All remaining USGS stations not meeting above criteria	Not used	8

View from the Sierra de Luquillo in El Yunque National Forest. (Photo by Thomas J. Brandeis, Southern Research Station)

Results

Water Supply from Forested Lands

The mean annual water yield from 1963–1995 ranged between 20 and 2,411 mm, and the mountain regions of the Sierra de Luquillo (including El Yunque National Forest) and Cordillera Central were the two areas yielding the most water (fig. 7). These two areas receive higher rainfall, are dominated by forest land, and have the highest elevations within mainland Puerto Rico. The water yield (Q) to precipitation (P) ratio also highlights areas with the potential for higher Q. Ratios closer to 1 have the potential to yield more water for a given amount of P, such as that found in the mountain regions (fig. 8).

The mean annual water supply for mainland Puerto Rico for the time period 1963–1995 ranged from 0 to 1142 million m^3/year and varied spatially across mainland Puerto Rico (fig. 9).

The HUC12 with the highest water supply of 1,142 million m^3/year was located downstream of El Yunque National Forest at the mouth of the Rio Grande De Loíza. The Rio Grande De Loíza watershed provides 50 percent of the drinking water for the San Juan metropolitan area (Larsen 2008). In mainland Puerto Rico, NFS land accounts for 1.2 percent of the total land area, and commonwealth and private forest land accounts for 37.1 percent of the total land area (table 4). These lands make a significant contribution to the water supply of Puerto Rico. Our model estimated that NFS land contributed 219 million m^3/year of water (~3.3 percent of the total water supply), and commonwealth and private forest land contributed 2.6 billion m^3/year of water (~40 percent of the total).

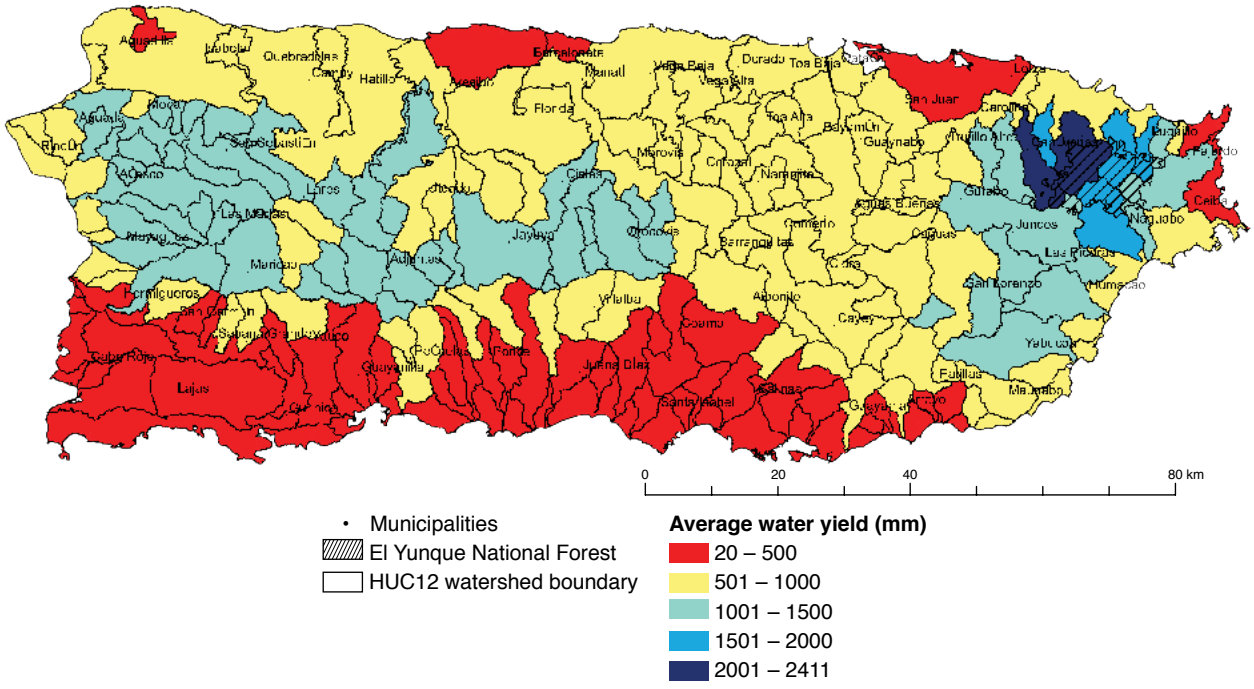


Figure 7—Estimated mean annual water yield by HUC12 watershed for the time period 1963–1995.

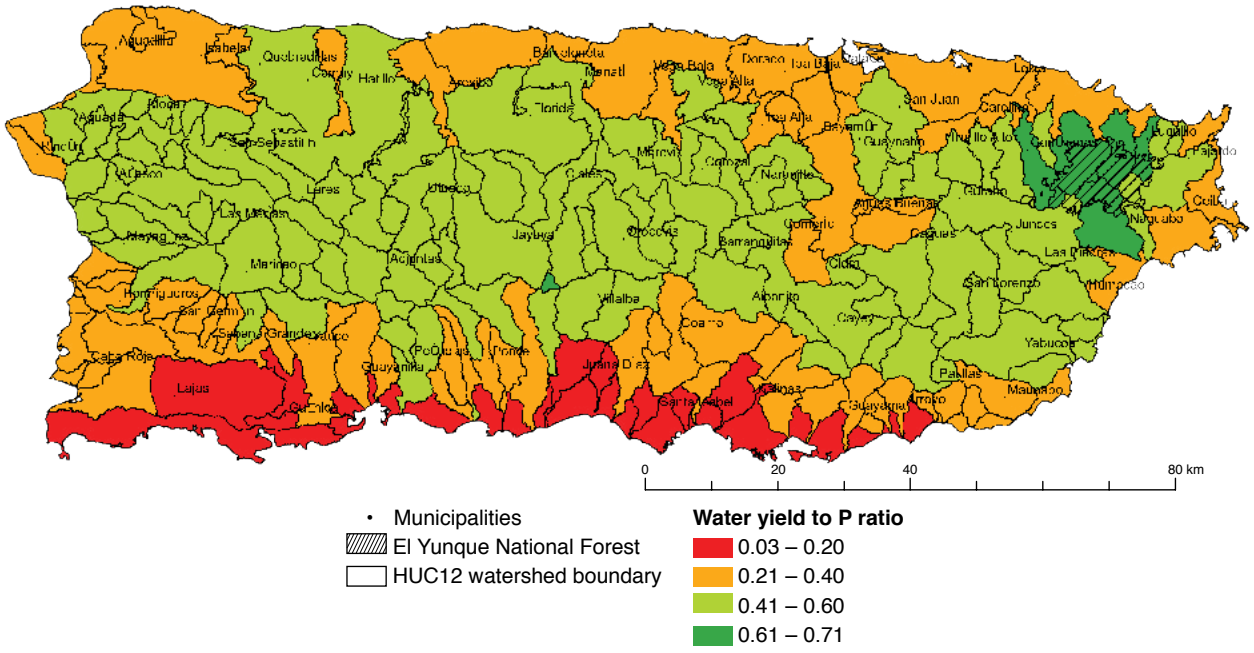


Figure 8—The water yield (Q) to precipitation (P) ratio for mainland Puerto Rico for the time period 1963–1995.

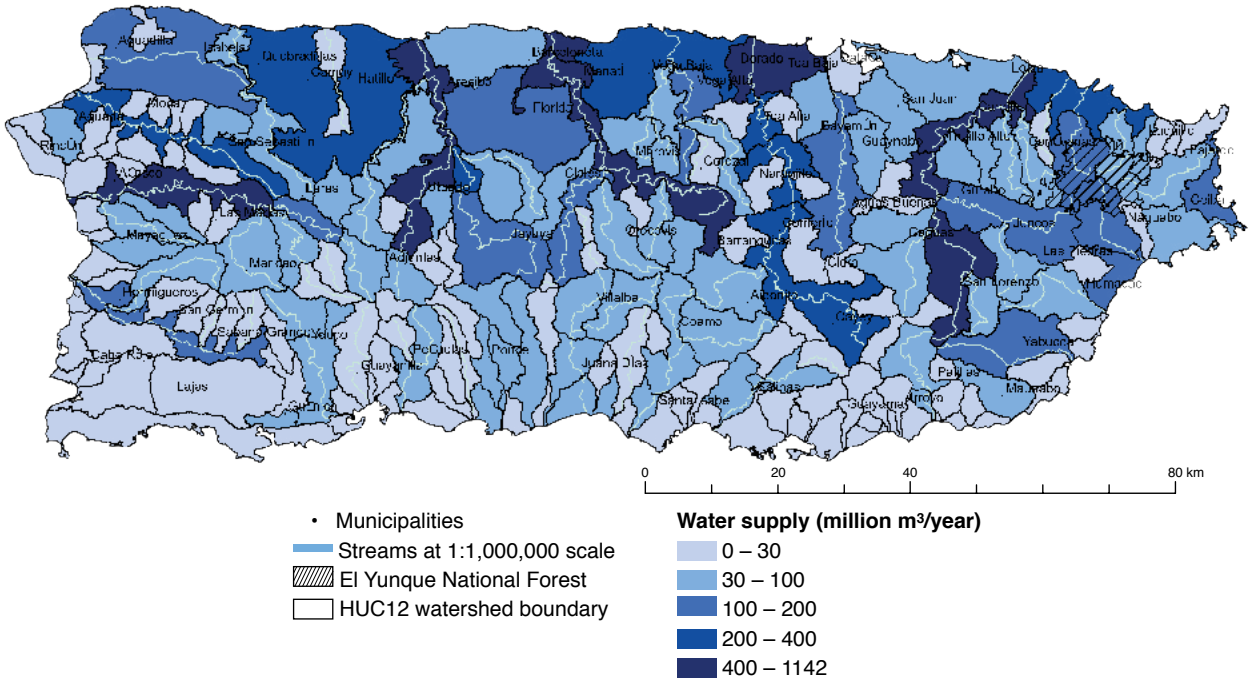


Figure 9—Estimated mean annual water supply for mainland Puerto Rico for the time period 1963–1995.

Table 4—Summary of water supply from forested land cover serving drinking water intakes in Puerto Rico

Total land area (km²)	8,900
Percentage of total land area in National Forest System land	1.2%
Percentage of total land area in commonwealth and private forest land	37.1%
Mean total annual water supply from all land (billion m³/year)	6.5
Mean percentage of total annual water supply originating on National Forest System land	3.3%
Mean percentage of total annual water supply originating on commonwealth and private forest land	40.0%

Population and Communities Served by Water from Forested Lands

National Forest System lands—The WaSSI model estimated that 60 percent or more of precipitation in NFS land becomes water yield. Our study identified 13 water intakes downstream of El Yunque National Forest (fig. 10). Collectively, those intakes served a population of 780,812 people and provide water for approximately 13 municipalities. The intakes located closest to the El Yunque National Forest received at least 50 percent of their water from NFS land (table 5).

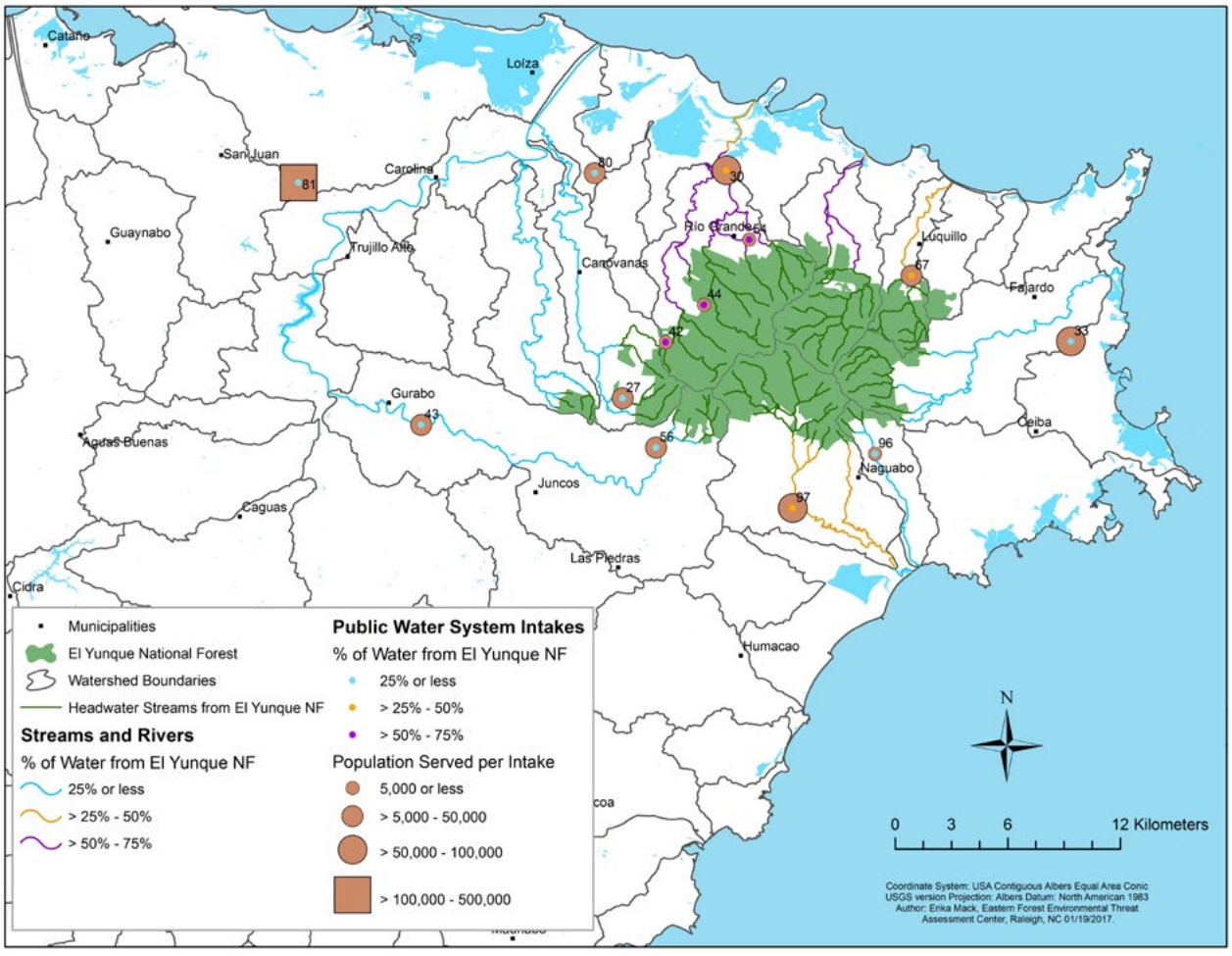


Figure 10—Communities and populations served by water originating in El Yunque National Forest.

Table 5—Water intakes receiving water from El Yunque National Forest and the population served by those intakes

				Total surface water		
Intake ID	Public water system name	Intake number for system	Population served by intake	Volume available to intake	Percent from El Yunque NF	Percent from commonwealth and private forest
				millions m³/ year		
27	CUBUY		5481	92	> 13.2%	42.7%
30	EL YUNQUE		54058	321	40.8%	17.5%
33	FAJARDO CEIBA		50837	92	> 17.4%	32.1%
42	GURABO URBANO	1 of 2	3854	154	> 56.1%	17.8%
43	GURABO URBANO	2 of 2	13639	191	2.9%	21.7%
44	GUZMAN ARRIBA		614	154	> 56.1%	17.8%
54	JIMENEZ		528	154	> 56.1%	17.8%
56	JUNCOS – CEIBA SUR	2 of 2	39460	191	2.9%	21.7%
67	LUQUILLO URBANO		8592	30	> 42.6%	27.3%
80	METROPOLITANO	3 of 4	37415	1142	13.2%	25.0%
81	METROPOLITANO	4 of 4	491621	63	0.0%	4.0%
96	RIO BLANCO, VIEQUES, CULEDRA	1 of 2	2610	23	> 12.1%	29.3%
97	RIO BLANCO, VIEQUES, CULEDRA	2 of 2	72103	126	> 30.4%	26.4%

> = Intakes are located upstream of the HUC12 outlet and may get more water from National Forest System lands than indicated in the table.

View from El Yunque National Forest looking south to the Caribbean Sea. (Photo by Maria M. Rivera)

Commonwealth and Private Forests—Our study identified 113 intakes downstream of commonwealth and private forest land. Collectively, those intakes served a population of 3.6 million people and provided water for approximately 78 municipalities in Puerto Rico (fig. 11). The percentage of total surface water from commonwealth and private forest land for the intakes varied spatially and ranged from 4.0 to 81.0 percent (table 6).

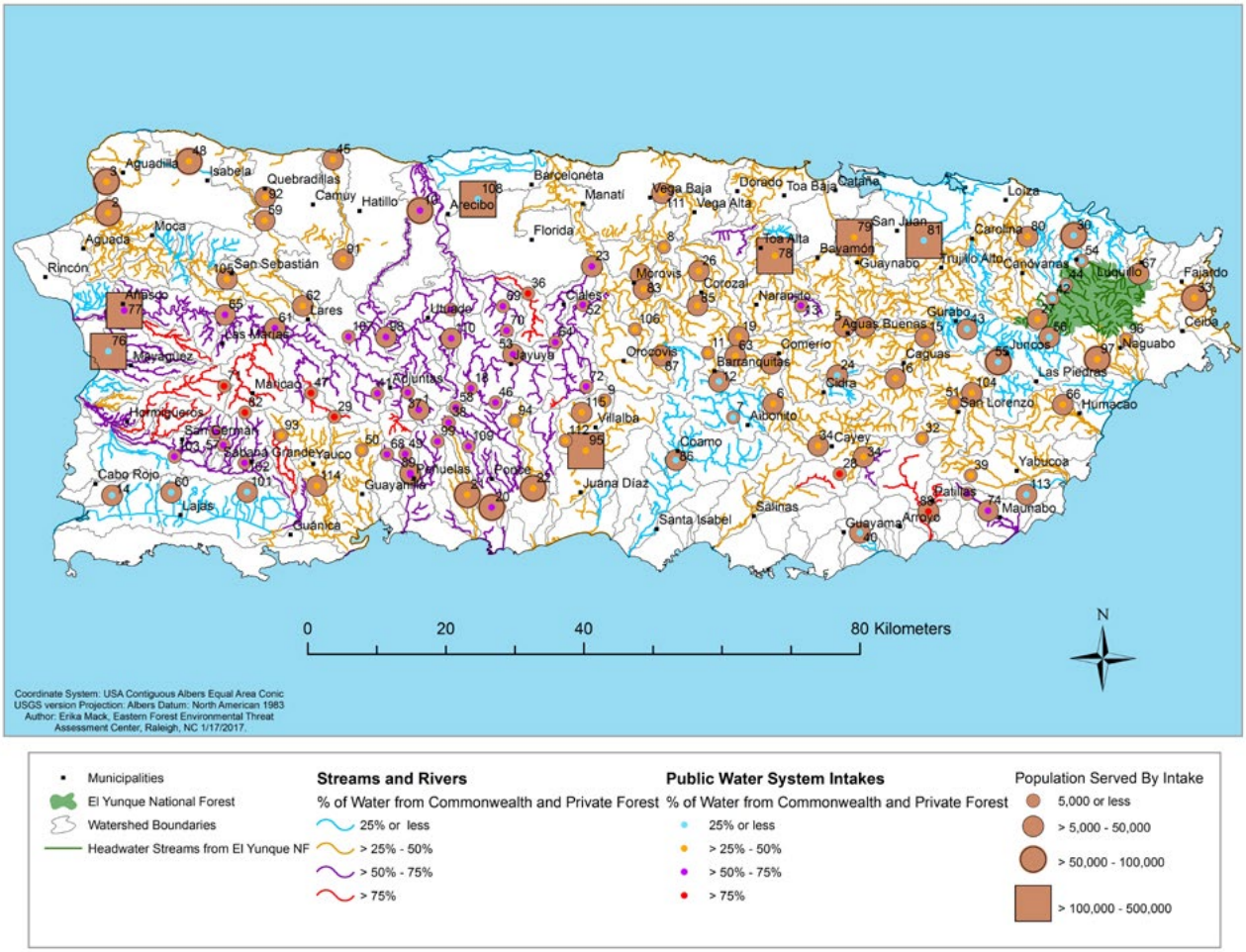


Figure 11—Communities and populations served by water originating on commonwealth and private forest land in mainland Puerto Rico.

Table 6—Water intakes receiving water from commonwealth and private forests and the population served by those intakes

				Total surface water		
Intake ID	Public water system name	Intake number for system	Population served by intake	Volume available to intake	Percent from El Yunque NF	Percent from commonwealth and private forest
				millions m³/year		
1	ADJUNTAS URBANO		5245	64	0.0%	70.2%
2	AGUADILLA	1 of 2	66358	309	0.0%	31.1%
3	AGUADILLA	2 of 2	66358	145	0.0%	34.8%
4	AGUAS BUENAS URBANO	1 of 2	10128	13	0.0%	36.5%
5	AGUAS BUENAS URBANO	2 of 2	17509	130	0.0%	35.9%
6	AIBONITO LA PLATA		17287	251	0.0%	35.7%
7	AIBONITO URBANO		4526	54	0.0%	21.2%
8	ALMIRANTE SUR		3479	51	0.0%	42.2%
9	APEADERO		533	82	0.0%	31.0%
10	ARECIBO URBANO		92942	68	0.0%	65.4%
11	BARRANCAS NUEVO		4336	437	0.0%	48.1%
12	BARRANQUITAS URBANO		5692	54	0.0%	21.2%
13	BO NUEVO		3452	12	0.0%	52.1%
14	CABO ROJO		21987	25	0.0%	14.1%
15	CAGUAS NORTE		41971	30	0.0%	29.8%
16	CAGUAS SUR		25725	60	0.0%	42.5%
17	CAIN ALTO		3326	10	0.0%	72.0%
18	CANALIZO		1147	131	0.0%	60.7%
19	CEDRO ARRIBA		6561	36	0.0%	39.0%
20	CERRILLOS	1 of 3	58554	33	0.0%	56.8%
21	CERRILLOS	2 of 3	58553	10	0.0%	47.1%
22	CERRILLOS	3 of 3	58553	42	0.0%	47.9%
23	CIALES URBANO		8190	45	0.0%	72.2%
24	CIDRA URBANO		34556	14	0.0%	20.3%
25	COMERIO URBANO		8957	251	0.0%	35.7%
26	COROZAL URBANO		11377	20	0.0%	34.5%
27	CUBUY		5481	92	> 13.2%	42.7%
28	CULEBRAS		1702	18	0.0%	75.1%
29	DUEY		3388	27	0.0%	77.7%
30	EL YUNQUE		54058	321	40.8%	17.5%
32	ESPINO		2072	18	0.0%	47.7%
33	FAJARDO CEIBA		50837	92	> 17.4%	32.1%
34	FARALLON	1 of 2	45908	251	0.0%	35.7%
35	FARALLON	2 of 2	17817	251	0.0%	35.7%
36	FRONTON		3347	36	0.0%	75.7%
37	GARZAS		2782	64	0.0%	70.2%
38	GUARAGUAO		1680	25	0.0%	65.2%
39	GUAYABOTA		1852	107	0.0%	39.6%

> = Intakes are located upstream of the HUC12 outlet and may get more water from NFS land or commonwealth and private forest land than indicated in the table.

Continued

Table 6—(*Continued*) Water intakes receiving water from commonwealth and private forests and the population served by those intakes

				Total surface water		
Intake ID	Public water system name	Intake number for system	Population served by intake	Volume available to intake	Percent from El Yunque NF	Percent from commonwealth and private forest
				millions m³/year		
40	GUAYAMA URBANO		43947	2	0.0%	10.1%
41	GUILARTE		2090	50	0.0%	73.5%
42	GURABO URBANO	1 of 2	3854	154	> 56.1%	17.8%
43	GURABO URBANO	2 of 2	13639	191	2.9%	21.7%
44	GUZMAN ARRIBA		614	154	> 56.1%	17.8%
45	HATILLO-CAMUY		37453	24	0.0%	32.7%
46	HOGARES SEGUROS		330	40	0.0%	69.5%
47	INDIERA ALTA		2273	27	0.0%	77.7%
48	ISABELA		59196	145	0.0%	34.8%
49	JAGUA CEIBA		1085	20	0.0%	63.8%
50	JAGUA PASTO		1270	29	0.0%	44.1%
51	JAGUAL		3870	505	0.0%	29.5%
52	JAGUAS PESAS (POZAS)		4272	178	0.0%	60.4%
53	JAYUYA URBANO		11248	131	0.0%	60.7%
54	JIMENEZ		528	154	> 56.1%	17.8%
55	JUNCOS – CEIBA SUR	1 of 2	74713	52	0.0%	20.1%
56	JUNCOS – CEIBA SUR	2 of 2	39460	191	2.9%	21.7%
57	LA MAQUINA		4803	10	0.0%	65.8%
58	LA PICA		595	40	0.0%	69.5%
59	LAGO GUAJATACA		10629	83	0.0%	38.7%
60	LAJAS		47310	26	0.0%	15.3%
61	LARES ESPINO		17554	520	0.0%	66.1%
62	LARES URBANO		14890	69	0.0%	37.7%
63	LAS BOCAS		5357	18	0.0%	26.1%
64	LAS DELICIAS		2195	45	0.0%	72.2%
65	LAS MARIAS		9356	520	0.0%	66.1%
66	LAS PIEDRAS HUMACAO		31428	67	0.0%	34.5%
67	LUQUILLO URBANO		8592	30	> 42.6%	27.3%
68	MALPASO		1029	20	0.0%	63.8%
69	MAMEYES ABAJO		1150	84	0.0%	72.0%
70	MAMEYES ARRIBA		2152	84	0.0%	72.0%
71	MARICAO		4489	66	0.0%	75.9%
72	MATRULLA		2350	15	0.0%	66.5%
73	MATUYAS		699	33	0.0%	57.7%
74	MAUNABO URBANO		12307	33	0.0%	57.7%
76	MAYAGUEZ	1 of 2	196128	6	0.0%	22.4%
77	MAYAGUEZ	2 of 2	181972	520	0.0%	66.1%
78	METROPOLITANO	1 of 4	337989	375	0.0%	37.0%

> = Intakes are located upstream of the HUC12 outlet and may get more water from NFS land or commonwealth and private forest land than indicated in the table.

Continued

Table 6—(*Continued*) Water intakes receiving water from commonwealth and private forests and the population served by those intakes

				Total surface water		
Intake ID	Public water system name	Intake number for system	Population served by intake	Volume available to intake	Percent from El Yunque NF	Percent from commonwealth and private forest
				millions m³/year		
79	METROPOLITANO	2 of 4	122905	39	0.0%	32.2%
80	METROPOLITANO	3 of 4	37415	1142	13.2%	25.0%
81	METROPOLITANO	4 of 4	491621	63	0.0%	4.0%
82	MONTE DEL ESTADO		973	97	0.0%	81.0%
83	MOROVIS URBANO	1 of 2	8018	31	0.0%	34.3%
84	MOROVIS URBANO	2 of 2	26687	31	0.0%	34.3%
85	NEGROS		17988	20	0.0%	34.5%
86	OROCOVIS URBANO	1 of 2	7501	64	0.0%	13.1%
87	OROCOVIS URBANO	2 of 2	19334	75	0.0%	30.7%
88	PATILLAS URBANO		44166	50	0.0%	78.7%
89	PENUELAS	1 of 2	10886	20	0.0%	63.8%
90	PENUELAS	2 of 2	10886	20	0.0%	63.8%
91	QUEBRADA		9144	284	0.0%	35.0%
92	QUEBRADILLAS URBANO		32645	284	0.0%	35.0%
93	RANCHERA		1560	38	0.0%	40.0%
94	REAL ANON		3623	42	0.0%	47.9%
95	REGIONAL VILLALBA TOA VACA		203296	82	0.0%	31.0%
96	RIO BLANCO,VIEQUES,CULEDRA	1 of 2	2610	23	> 12.14%	29.3%
97	RIO BLANCO,VIEQUES,CULEDRA	2 of 2	72103	126	> 30.38%	26.4%
98	RONCADOR		5221	18	0.0%	65.6%
99	RUCIO		308	60	0.0%	54.4%
100	SABANA GRANDE		2707	41	0.0%	59.5%
101	SABANA GRANDE	1 of 3	21315	26	0.0%	15.3%
102	SABANA GRANDE	2 of 3	3749	18	0.0%	74.2%
103	SABANA GRANDE	3 of 3	3749	198	0.0%	58.2%
104	SAN LORENZO URBANO		23276	505	0.0%	29.5%
105	SAN SEBASTIAN		34615	309	0.0%	31.1%
106	SANAMUERTO		2391	17	0.0%	35.6%
107	SANTA ISABEL		3690	68	0.0%	65.4%
108	SUPERACUEDUCTO		297172	47	0.0%	12.2%
109	TIBES		418	25	0.0%	65.2%
110	UTUADO URBANO		18787	41	0.0%	59.5%
111	VEGA BAJA URBANO		49853	75	0.0%	49.3%
112	VILLALBA URBANO		3698	82	0.0%	31.0%
113	YABUCOA URBANO		9868	24	0.0%	25.4%
114	YAUCO		42974	64	0.0%	40.9%
115	UN-NAMED		11095	82	0.0%	31.0%

> = Intakes are located upstream of the HUC12 outlet and may get more water from NFS land or commonwealth and private forest land than indicated in the table.

Discussion and Summary

This analysis incorporated an ET algorithm specific to tropical rainforests with the WaSSI model to estimate water balances in mainland Puerto Rico (Zhang and others, in review). By combining WaSSI water yield modeling results, water intake location data from the USGS, and population served data from the PRASA, we were able to quantify the role that forests play in providing drinking water supply to the population of Puerto Rico.

The WaSSI model estimated that all lands in mainland Puerto Rico produced 6.5 billion m^3/year of water, and of that amount, forest lands (38 percent of all lands) contributed disproportionately more water than other lands, approximately 43 percent of the total or 2.8 billion m^3/year of water. The forest land was further divided into NFS land and commonwealth and private forest land to understand each of their roles in providing water. NFS land provided 219 million m^3/year of water (3.3 percent of the total and 7.7 percent of the water from all forested lands), and commonwealth and private forest land provided 2.6 billion m^3/year of water (40 percent of the total and 92.3 percent of the water from all forested lands). The forest water contribution served a population of 3.6 million people (~97 percent of population), which represented almost all 78 municipalities in Puerto Rico.

Due to inherent differences in area occupied by each, NFS land and commonwealth and private forest land play an unequal role in providing water for the people of Puerto Rico. More than 2.1 million people receive at least 30 percent of their water from commonwealth and private forest land. In comparison, more than 139,000 people receive at least 30 percent of their water from NFS land (fig. 12). Commonwealth and private forest land provide more water and serve more of the population than NFS land due to their larger proportion of the land area in Puerto Rico. Of the protected areas in Puerto Rico, 6 percent are managed by commonwealth and nongovernment entities (Gould and others 2011). Quinones and others (2013) conducted an assessment of protected areas in Puerto Rico, and that assessment included a breakdown of the land cover types comprising the protected areas. Forest land was the most protected land cover type within protected areas in Puerto Rico, and the percentage of forest land cover decreased as distance from protected area increased, and built-up surfaces increased as the distance from protected area increased. Commonwealth and private forest land are providing more water and serving more of the population, and at least 60 percent is protected from conversion to other land use. Our analysis provides quantitative information on water yield from forest lands and sources of water supply in Puerto Rico.

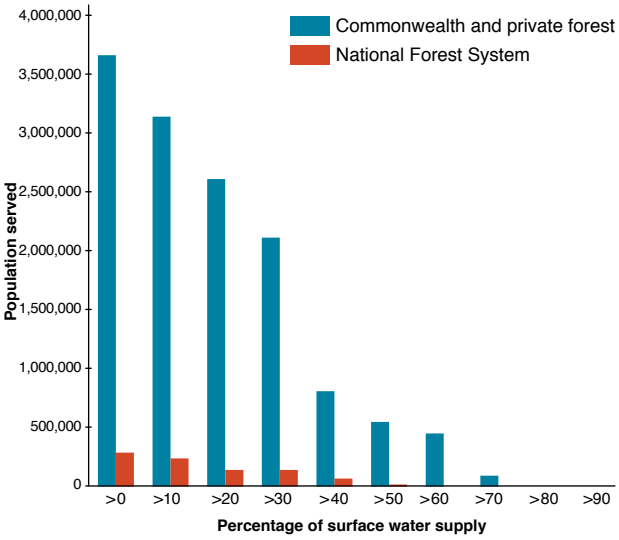


Figure 12—Percentage of surface water supply originating on National Forest System land and commonwealth and private forest land.

References

Birdsey, R.A.; Weaver, P.L. 1982. The forest resources of Puerto Rico. Resour. Bull. SO-85. New Orleans, LA: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 65 p.

Brandeis, T.J.; Helmer, E.H.; Oswalt, S.N. 2007. The status of Puerto Rico's forests, 2003. Resour. Bull. SRS-119. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 72 p.

Brandeis, T.J.; Turner, J.A. 2013. Puerto Rico's forests, 2009. Resour. Bull. SRS-RB-191. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 85 p.

Caldwell, P.; Muldoon, C.; Ford-Miniat, C. [and others]. 2014. Quantifying the role of National Forest System lands in providing surface drinking water supply for the Southern United States. Gen. Tech. Rep. SRS-197. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 135 p.

Caldwell, P.; Sun, G.; McNulty, S. [and others]. 2012. Impacts of impervious cover, water withdrawals, and climate change on river flows in the conterminous U.S. Hydrology and Earth System Sciences. 16: 2839-2857.

Caribbean Landscape Conservation Cooperative. 2016. Puerto Rico Protected Areas Database [version of December 2016]. GIS data. San Juan, Puerto Rico. https://caribbeanlcc.org/puerto-ricos-protected-areas-map-and-inventory-updated/. [Date accessed: June 2017].

Daly, C.; Helmer, E.H.; Quinones, M. 2003. Mapping the climate of Puerto Rico, Vieques, and Culebra. International Journal of Climatology. 23: 1359-1381.

Franco, P.A.; Weaver, P.L.; Eggen-McIntosh, S. 1997. Forest resources of Puerto Rico, 1990. Resour. Bull. SRS-22. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 45 p.

Gómez-Gómez, F.; Rodríguez-Martínez, J.; Santiago, M. 2014. Hydrogeology of Puerto Rico and the outlying islands of Vieques, Culebra, and Mona: U.S. Geological Survey Scientific Investigations Map 3296. 40 p. plus 2 pls. https://dx.doi.org/10.3133/sim3296. [Published online: August 19, 2014].

Gould, W.A.; Alarcon, C.; Fevold, B. [and others]. 2008. The Puerto Rico Gap Analysis Project Volume 1: land cover, vertebrate species distributions, and land stewardship. Gen. Tech. Rep. IITF-39. Río Piedras, Puerto Rico: U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry. 165 p.

Gould, W.A.; Quinones, M.; Solorzano, M. [and others]. 2011. Protected Natural Areas of Puerto Rico. 1:240,000. Res. Map IITF-RMAP-02. Rio Piedras, Puerto Rico: U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry.

Harris, N.L.; Lugo, A.E.; Brown, S.; Heartsill Scalley, T., eds. 2012. Luquillo Experimental Forest: research history and opportunities. Experimental Forests and Ranges EFR-1. Washington, DC: U.S. Department of Agriculture Forest Service. 152 p.

Helmer, E.H. 2004. Forest conservation and land development in Puerto Rico. Landscape Ecology. 19: 29–40.

Kennaway, T.; Helmer, E.H. 2007. The forest types and ages cleared for land development in Puerto Rico. GIScience & Remote Sensing. 44(4): 356–382.

Larsen, M.C. 2008. Luquillo WEBB site location map. https://pr.water.usgs.gov/public/webb/webb_map.html. [Date accessed: March 17, 2017].

Lockaby, G.; Nagy, C.; Vose, J. [and others]. 2013. Forests and water. In: Wear, D.N.; Greis, J.G., eds. The Southern Forest Futures Project: technical report. Gen. Tech. Rep. SRS-GTR-178. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 309-339.

Lu, J.; Sun, G.; McNulty, S.G; Amatya, D.M. 2005. A comparison of six potential evapotranspiration methods for regional use in the Southeastern United States. Journal of the American Water Resources Association (JAWRA). 41(3): 621–633.

Marion, D.A.; Sun, G.; Caldwell, P.V. [and others]. 2013. Managing forest water quantity and quality under climate change. In: Vose, J.M.; Klepzig, K.D., eds. Climate Change Adaptation and Mitigation Management Options: A Guide for Natural Resource Managers in Southern Forest Ecosystems. Boca Raton, FL: CRC Press: 249–305.

McDowell, W.H.; Scatena, F.N.; Waide, R.B. [and others]. 2012. Geographic and ecological setting of the Luquillo Mountains. In: Brokaw, N.; Crowl, T.A.; Lugo, A.E. [and others], eds. A Caribbean forest tapestry: the multidimensional nature of disturbance and response. New York: Oxford University Press: 72–163.

Quinones, M.; Gould, W.A.; Castro-Prieto, J.; Martinuzzi, S. 2013. Spatial analysis of Puerto Rico's terrestrial protected areas [1:240 000]. Res. Map IITF-RMAP-03. Rio Piedras, Puerto Rico: U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry.

Sun, G.; Alstad, K.; Chen, J.Q. [and others]. 2011a. A general predictive model for estimating monthly ecosystem evapotranspiration. Ecohydrology. 4: 245–255.

Sun, G.; Caldwell, P.; Noormets, A. [and others]. 2011b. Upscaling key ecosystem functions across the conterminous United States by a water-centric ecosystem model. Journal of Geophysical Research-Biogeosciences. 116: G00J05.

Sun, G.; Caldwell, P.V.; Georgakakos, A.P. [and others]. 2013. Impacts of climate change and variability on water resources in the Southeastern U.S. Chapter 10. In: Ingram, K.T.; Dow, K.; Carter, L., eds. Southeastern Regional Technical Report to the National Climate Change Assessment, Water Resources. [Place of publication unknown]: Island Press: 204–234.

Sun, G.; McNulty, S.G.; Myers, J.A.M.; Cohen, E.C. 2008. Impacts of multiple stresses on water demand and supply across the Southeastern United States. Journal of the American Water Resources Association. 44: 1441-1457.

Tavernia, B.G.; Nelson, M.D.; Caldwell, P.V.; Sun, G. 2013. Water stress projections in the Northeastern and Midwestern United States in 2060: anthropogenic and ecological consequences. Journal of the American Water Resources Association. 49: 15.

Weaver, P.L. 2012. The Luquillo Mountains: forest resources and their history. Gen. Tech. Rep. IITF-GTR-44. Rio Piedras, Puerto Rico: U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry. 159 p.

Vörösmarty, C.J.; Federer, C.A.; Schloss, A. 1998. Potential evaporation functions compared on U.S. watersheds: implications for global-scale water balance and terrestrial ecosystem modeling. Journal of Hydrology. 207: 147–69.

U.S. Census Bureau. 2012. 2010 Census of population and housing, summary population and housing characteristics, CPH-1-53, Puerto Rico. Washington, DC: U.S. Government Printing Office. 475p.

U.S. Geological Survey (USGS) and U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS). 2013. Federal Standards and Procedures for the National Watershed Boundary Dataset (WBD) (4 ed.): U.S. Geological Survey Techniques and Methods 11–A3, 63 p. https://pubs.usgs.gov/tm/11/a3. [Published online: September 2013].

Zhang, L.; Sun, G.; Cohen, E. [and others]. [In review]. An improved water budget for the El Yunque National Forest, Puerto Rico as determined by an integrated ecohydrological modeling approach. Submitted to Forest Science. On file with Liangxia Zhang: brightzlx@126.com.

Cohen, Erika; Sun, Ge; Zhang, Liangxia; Caldwell, Peter; and Krieger, Suzanne. 2017.
Quantifying the role of forested lands in providing surface drinking water supply for Puerto Rico. Gen. Tech. Rep. SRS-197-Addendum. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 20 p.

The Forest Service, U.S. Department of Agriculture published a General Technical Report (GTR-SRS-197) in 2014 that quantified the role that water originating on National Forest System lands contributed to the drinking water supply and determined what population and communities were being served in the 13 Southern States of Region 8 of the Forest Service. The Commonwealth of Puerto Rico is included in Region 8, but it was not included in the results of GTR-SRS-197 because at the time of that report the Water Supply Stress Index (WaSSI) model used for the assessment was not parameterized for Puerto Rico. The goal of this project was to implement the same methodology used in GTR-SRS-197 for the mainland of Puerto Rico. WaSSI is a monthly water balance and flow routing model that can quantify the amount of water at a watershed outlet. Water intake location data from the U.S. Geological Survey (USGS) and population served data from the Puerto Rico Aqueduct and Sewer Authority were used to quantify the amount of population being served by water originating on forested land. Puerto Rico has a total land area of 8,900 km^2, and 38 percent of that land area is forested with 1.2 percent in National Forest System land and 37.1 percent in commonwealth and private forest land. We estimated that all lands in mainland Puerto Rico produced 6.5 billion m^3/year of water. Of that total, National Forest System lands provided 219 million m^3/year of water (3.3 percent of total land), and commonwealth and private forest lands provided 2.6 billion m^3/year of water (40 percent of total land). A population of 3.6 million people was served by 113 intakes located downstream of commonwealth and private forest land, and 13 of those intakes were also located downstream of El Yunque National Forest and served a population of 780,000. National Forest System land and commonwealth and private forest land play an unequal role in providing water for the people of Puerto Rico. More than 2.1 million people receive at least 30 percent of their water from commonwealth and private forest land. In comparison, more than 139,000 people receive at least 30 percent of their water from National Forest System land. Our analysis provides quantitative information on water yield from forest lands and sources of water supply in Puerto Rico. This study is an addendum to GTR-SRS-197.

Keywords: commonwealth and private forest lands, drinking water, hydrologic modeling, National Forest System, Puerto Rico, State and private forest lands, WaSSI, water supply.

How do you rate this publication?

Scan this code to submit your feedback
or go to www.srs.fs.usda.gov/pubeval