Prepared in cooperation with the Puerto Rico Aqueduct and Sewer Authority and the Puerto Rico Environmental Quality Board

Estimated Water Withdrawals and Use in Puerto Rico, 2015

Open-File Report 2021–1060

U.S. Department of the Interior
U.S. Geological Survey

Cover. Background photograph: Farm irrigated by a sprinkler system in the south coast of Puerto Rico. Photograph by Marcos Quiñones, February 24, 2014. Inset photograph: Irrigation well in Santa Isabel, Puerto Rico. Photograph by José A. Santiago-Sáez, U.S. Geological Survey.

Estimated Water Withdrawals and Use in Puerto Rico, 2015

By Wanda L. Molina-Rivera and Michelle M. Irizarry-Ortiz

Prepared in cooperation with the Puerto Rico Aqueduct and Sewer Authority and the Puerto Rico Environmental Quality Board

Open-File Report 2021–1060

U.S. Department of the Interior
U.S. Geological Survey

U.S. Geological Survey, Reston, Virginia: 2021

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit https://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit https://store.usgs.gov.

Suggested citation:
Molina-Rivera, W.L., and Irizarry-Ortiz, M.M., 2021, Estimated water withdrawals and use in Puerto Rico, 2015: U.S. Geological Survey Open-File Report 2021-1060, 38 p., https://doi.org/10.3133/ofr20211060.

Associated data for this publication:
Dixon, J.F., Molina-Rivera, W.L., Irizarry-Ortiz, M.M., and Christesson, K.R., 2021, Spatial and tabular datasets of water withdrawals and use in Puerto Rico, 2015: U.S. Geological Survey data release, https://doi.org/10.5066/P9POVNC6.

ISSN 2331-1258 (online)

Acknowledgments

The authors gratefully acknowledge the following Commonwealth agencies for their cooperation and for providing the water-use data: the Puerto Rico Aqueduct and Sewer Authority, Puerto Rico Department of Natural and Environmental Resources, the Puerto Rico Electric Power Authority, and the Puerto Rico Department of Health. The authors also thank John Stamm and Richard L. Marella of the U.S. Geological Survey (USGS) for their guidance on the agricultural water withdrawals section, and Kyle Christesson (USGS contractor) for his assistance digitizing golf courses and agricultural fields in Puerto Rico. We would like to thank Eric Harmsen from the University of Puerto Rico-Mayagüez for his technical suggestions on the use of a soil moisture model for estimating agricultural water withdrawals and for providing access to the GOES-PRWEB dataset used in this report. Finally, many thanks to Richard L. Marella (USGS) and Melissa A. Harris (USGS) for their useful comments and suggestions when reviewing this manuscript.

Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow rate	
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
gallon per day per acre (gal/d-acre)	0.003785	cubic meter per day acre (m^3/d-acre)
	Energy	
gigawatthour (GWh)	3.6×10^{12}	Joule (J)

Abbreviations

ET	evapotranspiration
NAICS	North American Industry Classification System Code
NCA	North Coast Aqueduct
NEXRAD	Next-Generation Weather Radar
NWUSP	National Water-Use Science Project
PRAGWATER	Puerto Rico Agricultural Water Management
PRASA	Puerto Rico Aqueduct and Sewer Authority
PRDNER	Puerto Rico Department of Natural and Environmental Resources
PREPA	Puerto Rico Electric Power Authority
USGS	U.S. Geological Survey
WSA	water service area
WTP	water treatment plant

Estimated Water Withdrawals and Use in Puerto Rico, 2015

By Wanda L. Molina-Rivera and Michelle M. Irizarry-Ortiz

Abstract

Water withdrawals and use in Puerto Rico for 2015 were estimated at 2,372 million gallons per day (Mgal/d), which was 21 percent less than withdrawals and use for 2010. The 2015 total water withdrawal and use estimates were the lowest since 1990 and coincided with a substantial decline of 25 percent in saline-water withdrawals for thermoelectric-power cooling processes from 2010 to 2015. Freshwater withdrawals were 671 Mgal/d, or 28 percent of total water withdrawals, and saline-water withdrawals were 1,701 Mgal/d, or 72 percent of total withdrawals. Fresh surface-water withdrawals were estimated at 548 Mgal/d, 10 percent less than in 2010, whereas fresh groundwater withdrawals were estimated at 122 Mgal/d, 2 percent less than in 2010. Saline surface-water withdrawals were 25 percent less than in 2010.

Freshwater withdrawals were greatest for public-supply water and irrigation in 2015 and, combined, accounted for 98 percent of Puerto Rico's total freshwater withdrawals. Withdrawals in 2015 for public-supply water (576 Mgal/d) were 14 percent lower and withdrawals for irrigation (78 Mgal/d) were 104 percent greater than in 2010, possibly because of drought conditions in agricultural counties along the south and southeast coasts in 2015. The sources for public-supply water withdrawals in 2015 included surface water (88 percent) and groundwater (12 percent). Withdrawals for other uses, which account for the remaining 2 percent of Puerto Rico's total freshwater withdrawals, were lower in 2015 than in 2010; specifically, withdrawals for domestic self-supplied use decreased by 78 percent, industrial withdrawals decreased by 15 percent, and withdrawals for livestock decreased by 25 percent. Freshwater withdrawals for thermoelectric power and mining were greater in 2015 than in 2010, increasing by 23 percent and 5 percent, respectively.

The total population of Puerto Rico decreased by 7 percent from 2010 to 2015, from 3.73 million people in 2010 to 3.47 million people in 2015. The number of people who obtained potable water from public-supply water facilities in 2015 was about 3.47 million, or about 100 percent of the population of Puerto Rico.

Public-supply water deliveries for domestic use accounted for 338 Mgal/d in 2015, which is 47 percent greater than in 2010, indicating an increase in domestic per capita use from 62 to 98 gallons per person per day from 2010 to 2015. Domestic self-supplied withdrawals were estimated at 0.52 Mgal/d in 2015, for an estimated 4,708 people (less than 1 percent of Puerto Rico's population). All domestic self-supplied withdrawals were assumed to be from groundwater sources.

Irrigation freshwater withdrawals were 78 Mgal/d in 2015 and accounted for 12 percent of the total freshwater withdrawals for all uses. Surface-water deliveries from irrigation districts accounted for 44 percent of total irrigation withdrawals, whereas groundwater withdrawals accounted for 56 percent. About 37,000 acres were irrigated in 2015, a decrease of 11 percent or about 4,000 acres compared to 2010. About 99 percent of the acreage was irrigated by micro-irrigation and sprinkler systems in 2015. About 65 percent of the irrigation withdrawals were accounted for by four municipalities: Santa Isabel, Salinas, Lajas, and Juana Díaz.

Altogether, freshwater withdrawals for livestock, industrial, mining, and thermoelectric power accounted for 2 percent (16.2 Mgal/d) of freshwater withdrawals for all uses, 9 percent less than in 2010. About 71 percent of the freshwater withdrawn for these categories was from groundwater sources.

In 2015, 50 percent of the total freshwater withdrawn in Puerto Rico was apportioned to six municipalities: Arecibo, Trujillo Alto, Toa Alta, Villalba, Aguada, and Mayagüez. Arecibo accounted for about 18 percent of the total freshwater withdrawals, predominantly for public-supply water use. Trujillo Alto, Toa Alta, Villalba, Aguada, and Mayagüez accounted for about 32 percent (213 Mgal/d) of the total freshwater withdrawals, which were predominantly for public-supply water uses. Withdrawals in some of these municipalities are subsequently distributed to other municipalities such as those in the San Juan metro area. The Puerto Rico Aqueduct and Sewer Authority water service area for the San Juan metro area (referred to as W–102) accounted for about 28 percent of the total water delivered from public-supply water facilities to domestic users, which includes about 34 percent of the total population of Puerto Rico.

Introduction

The National Water-Use Science Project (NWUSP) is a cooperative program of the U.S. Geological Survey (USGS) with the primary purpose to collect, compile, store, and disseminate water-use information both locally and nationally (further details provided at https://www.usgs.gov/mission-areas/water-resources/science/national-water-use-science-project). At 5-year intervals since 1950, the USGS has compiled water-use data, including water withdrawn for drinking, irrigation, manufacturing, and power generation, among other uses in the United States, and has described how these uses have changed over time. The program was implemented in Puerto Rico in 1980 to provide data for the management of the Commonwealth's water resources. Water-use data reports for Puerto Rico by municipality were published for 1986–87 (Molina-Rivera and Dopazo-Rodríguez, 1995); 1988–89 (Dopazo-Rodríguez and Molina-Rivera, 1995); 1995 (Molina-Rivera, 1998); 2000 (Molina-Rivera, 2005); 2005 (Molina-Rivera and Gómez-Gómez, 2008), and 2010 (Molina-Rivera, 2014).

Water-resources planners and managers often require information regarding the amount of water withdrawn, as well as where and how it is used, to assess many of the critical water problems facing Puerto Rico. The USGS maintains cooperative agreements with the Puerto Rico Aqueduct and Sewer Authority (PRASA) and the Puerto Rico Environmental Quality Board to compile and disseminate water-use data for major use categories in Puerto Rico. Data used to compile and tabulate water use and withdrawal values were either obtained from online sources or by contacting local agencies across Puerto Rico directly.

Purpose and Scope

The purpose of this report is to provide detailed information about water withdrawals and use in Puerto Rico for 2015. A withdrawal is defined as water that is pumped or diverted from groundwater or surface-water sources for public supply, domestic self-supplied, irrigation, livestock, industrial, mining, thermoelectric power, and other uses (Maupin and others, 2014). Withdrawals were estimated in millions of gallons per day (Mgal/d) for the following water-use categories: (1) public-supply water, (2) domestic (including deliveries from public-supply water systems and self-supplied domestic), (3) irrigation, (4) livestock, (5) industrial, (6) mining, and (7) thermoelectric power. All categories are freshwater withdrawals except thermoelectric power, which includes both saline and freshwater withdrawals. Categories are discussed in terms of water withdrawals (which, in turn, can be associated with multiple uses) and (or) water uses. Estimated water use was aggregated by municipality (equivalent to a county in the United States) (fig. 1) and source for most of the water-use categories presented in this report. Public-supply water withdrawals were aggregated by water service areas (WSAs) (fig. 2). Sources of water include groundwater, surface water, and seawater (defined as saline surface water by the USGS).

Data Compilation Procedures

The sources of data and the methods used to compile data differ for each of the seven water-use categories and are described in the following sections.

Public-Supply Water Withdrawals

In this report, public-supply water withdrawal is defined as water withdrawn by public and private suppliers that provides water for at least 15 service connections or serves an average of 25 people or more for at least 60 days a year (U.S. Environmental Protection Agency, 2018). Raw data used to compile and tabulate freshwater withdrawals from PRASA surface-water facilities and wells by municipalities and PRASA WSAs during 2015 were not available online and were obtained directly from PRASA. Contact PRASA for more information. Also, the raw data used to compile and tabulate public-supply water withdrawals from non-PRASA systems were not available online and were obtained directly from the Puerto Rico Department of Health (Puerto Rico Department of Health, 2015). Public-supply water withdrawals were compiled and apportioned at the municipality in which the withdrawals took place, although the water subsequently may have been distributed and used in other municipalities. Public-supply water withdrawal data were aggregated for the 78 municipalities in Puerto Rico and for the sources of water and were categorized as PRASA or non-PRASA systems.

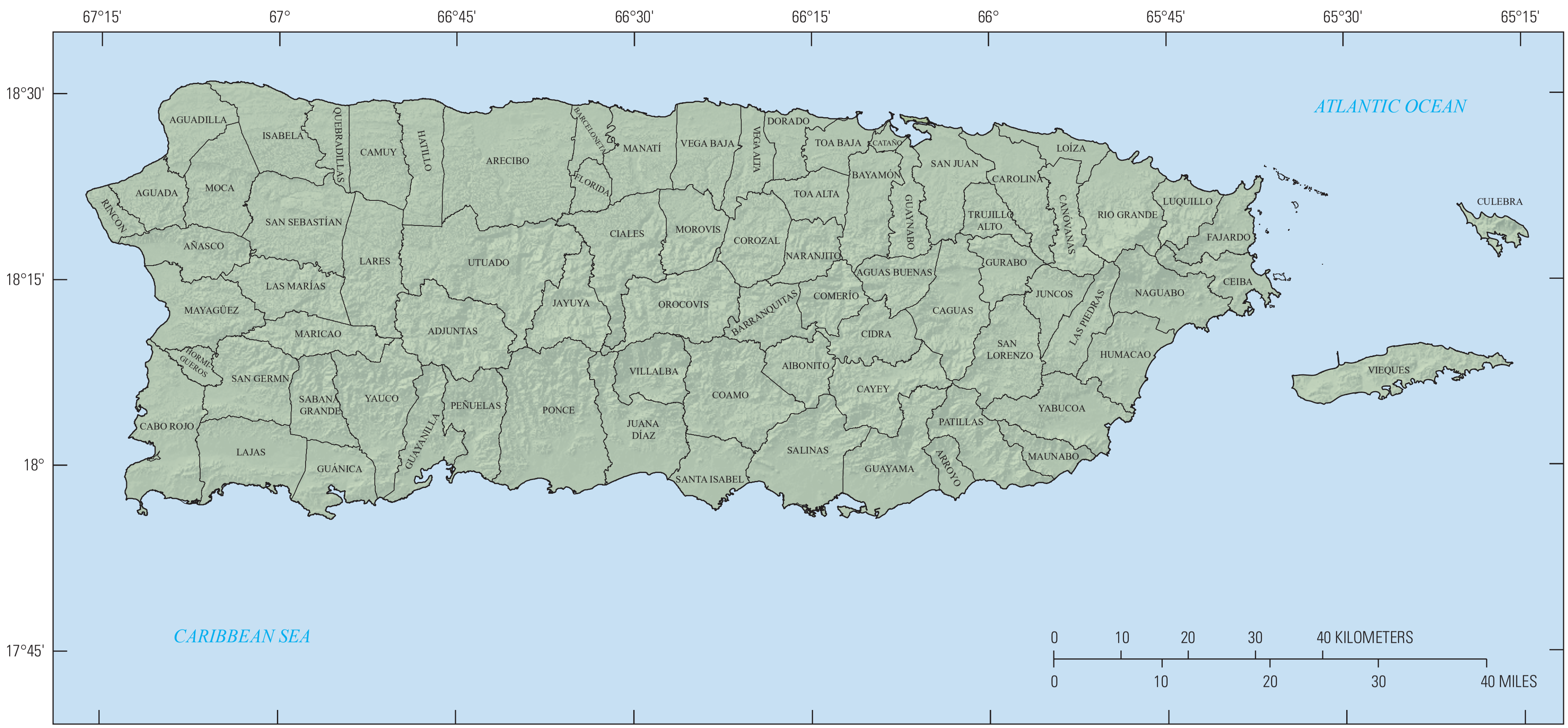
Population Served

Estimates of the population served by PRASA public-supply water systems were derived using spatial analysis to determine the percentage of the population served within the WSAs. The population served from non-PRASA community systems was defined as the resident population within a municipality that receives water from a public-supply system on a year-round basis and excludes seasonal residents (U.S. Environmental Protection Agency, 2018). In this report, the population served was estimated in the municipality where the water was delivered, which is not necessarily the municipality where the withdrawal took place. The combined total number of users of public-supply water served by PRASA, non-PRASA, and domestic self-supplied users was considered in this report to equal the 2015 total population estimate obtained by the U.S. Census Bureau (2015). Public-supply water use per capita was obtained by dividing the average daily total public-supply water use by the population served.

Domestic Deliveries From Public-Supply Water Systems

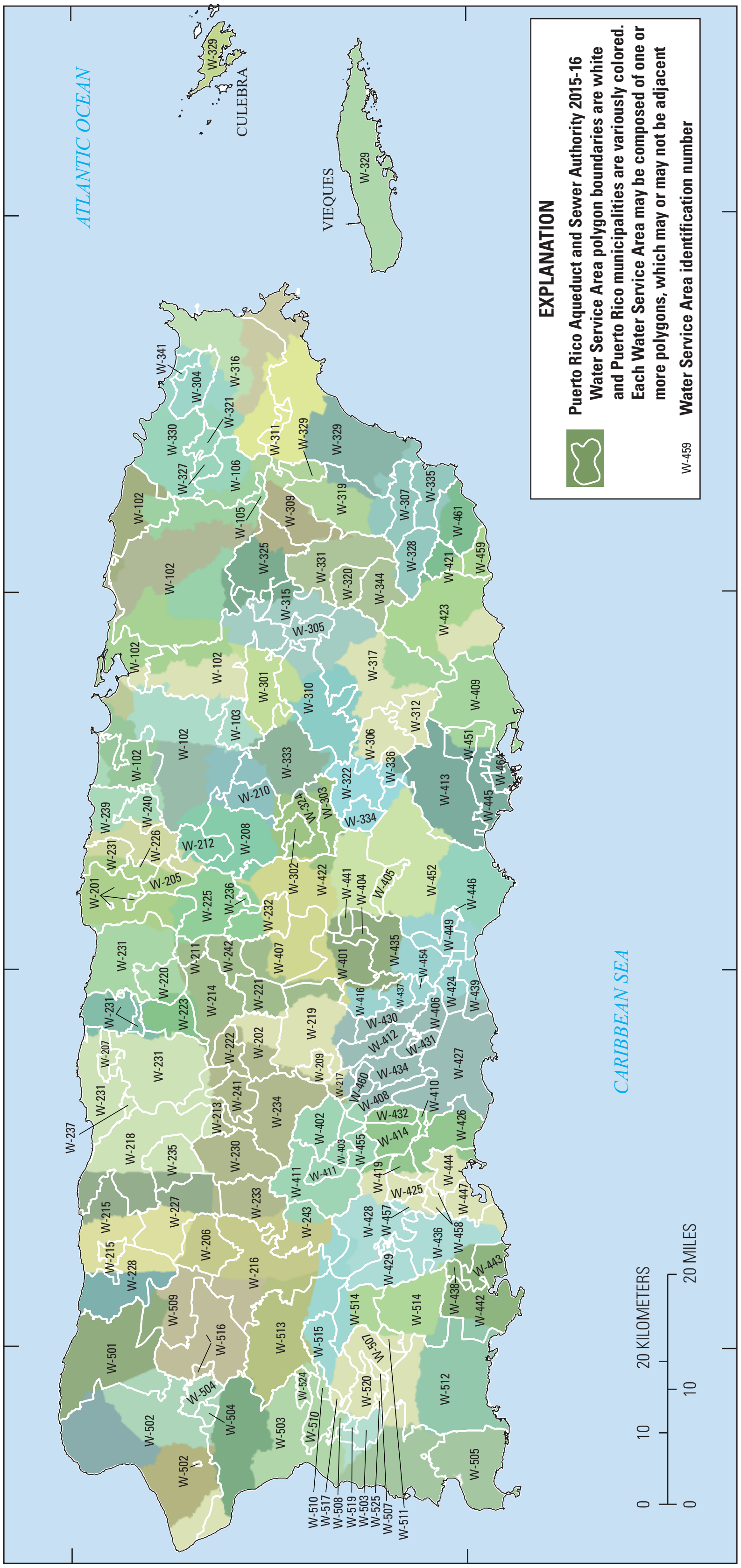
Domestic delivery represents water distributed by a public-supply facility to residential customers for domestic purposes, both indoor (drinking, washing, flushing, and other uses) and outdoor (lawn watering, car washing, replenishing swimming pools, sidewalk washing, and other uses). Data have limited availability owing to restrictions (sensitivity concern). Contact PRASA for more information. Data were aggregated by PRASA WSAs and by municipalities.

A domestic per capita water-use coefficient was calculated for each public-supply water system in Puerto Rico; this coefficient can be multiplied by the domestic population to estimate



Base modified from the U.S. Geological Survey digital data

Figure 1. Boundaries of municipalities in Puerto Rico.



Base modified from the U.S. Geological Survey digital data

Figure 2. Locations of Puerto Rico Aqueduct and Sewer Authority Water Service Areas, 2015–16.

the total domestic water use for a given area. Residential use varies; however, households served by the same public-supply water system often have a common pattern of use affected by factors such as water cost rates, water conservation patterns, customer affluence, climate, and topography (Marella, 1992). As a result, a public-supply domestic per capita water-use coefficient can be determined for a specific system but varies from one system to another within Puerto Rico.

Domestic Self-Supplied Water Withdrawals

Domestic self-supplied water withdrawals refer to water used by individual households that are not served by PRASA and non-PRASA public-supply water systems. Self-supplied domestic withdrawals were estimated for municipalities by multiplying the self-supplied population by the associated public-supply domestic per capita water-use coefficient. The self-supplied population is calculated by subtracting the total resident population served by public-supply water systems in a municipality from the total 2015 Census of Population (U.S. Census Bureau, 2015) in the same municipality.

In the United States, the water source for about 98 percent of self-supplied domestic withdrawals was groundwater (Hutson and others, 2004). On the basis of estimates for the United States, it is assumed that domestic self-supplied withdrawals in Puerto Rico are mainly from groundwater sources.

Irrigation Water Use and Withdrawals

Irrigation water use includes water applied by an irrigation system to sustain plant growth in agricultural and horticultural practices, along with water used to irrigate golf courses. Consumptive use is the part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment (Dieter and others, 2018). In addition to consumptive use, estimates of irrigation withdrawals typically include water that is lost in conveyance prior to application on fields, as well as water that may subsequently return to a surface-water body as runoff after application, water consumed as evapotranspiration (ET) from plants and ground surfaces, or water that recharges aquifers as it seeps past the root zone. The difficulty in estimating conveyance losses and return flows for the various sources of water was documented by Molina-Rivera (2015). Irrigation withdrawals exclude any water obtained from municipal wastewater facilities that is used for irrigation. In Puerto Rico, irrigation withdrawals can be from surface-water and groundwater sources.

Surface-water withdrawal data for crop irrigation purposes in agricultural areas served by four irrigation districts (fig. 3) managed by the Puerto Rico Electric Power Authority (PREPA) were obtained from the districts. The four irrigation districts within Puerto Rico are the Guayama and Juana Diaz Irrigation Districts in the southeast, the Valle de Lajas Irrigation District in the southwest, and the Isabela Irrigation District in the northwest. These surface-water withdrawals include conveyance losses in the irrigation canals that range from 10 to 20 percent for the irrigation districts in the south (Puerto Rico Department of Natural and Environmental Resources, 2008). No reliable estimates of conveyance losses exist for the Isabela Irrigation District (Puerto Rico Department of Natural and Environmental Resources, 2008).

The Guayama Irrigation District withdraws water from the Lago Patillas and Lago Melania reservoirs, the Río Guamaní, and from an interbasin transfer from Lago Carite to the Río Guamaní (fig. 3). These streams and reservoirs provide water to agricultural lands in the municipalities of Arroyo, Guayama, Patillas, and Salinas (fig. 1). In 2015, water conveyed by the Guayama Irrigation District was also the source of public-supply water to three PRASA water treatment plants (WTPs) that filter raw water and deliver potable water to the municipalities of Arroyo, Guayama, Maunabo, Patillas and Salinas. The Guayama Urbano WTP is supplied from the Patillas irrigation canal, the Farallón WTP from Lago Carite, and the Patillas Urbano WTP from Lago Patillas (fig. 3). Also, the Guayama Irrigation District delivers fresh surface water to a private thermoelectric power facility in the area.

The Juana Díaz Irrigation District withdraws water exclusively from the Lago Guayabal reservoir located in the municipalities of Juana Díaz and Villalba and conveys the water to agricultural lands in the municipalities of Juana Díaz, Santa Isabel, and the part of Salinas west of Río Nigua (figs. 1 and 3).

The Valle de Lajas Irrigation District withdraws water from the Lago Loco and Lago Luchetti reservoirs of the municipality of Yauco and conveys the water to agricultural lands in the municipalities of Cabo Rojo, Guánica, Lajas, Sabana Grande, and Yauco (figs. 1 and 3). Water diversion from Lago Loco and Lago Luchetti to the Valle de Lajas Irrigation District provided the surface water withdrawn by the PRASA to WTPs in the municipalities of Sabana Grande, Lajas, and Cabo Rojo (Máginas WTP, Lajas WTP, and Betances WTP, respectively).

The Isabela Irrigation District withdraws water exclusively from the Lago Guajataca reservoir, located in the municipalities of Isabela and San Sebastián, and conveys the water to agricultural lands in the municipalities of Aguadilla, Isabela, and Moca (figs. 1 and 3). Diversion of water from Lago Guajataca, which is conveyed through the Canal de Moca and the Canal de Aguadilla, provided the surface water withdrawn by Aguadilla Nueva and Isabela Urbano PRASA WTPs. These public-supply WTPs serve the municipalities of Aguada, Aguadilla, Moca, and Rincón.

Groundwater withdrawals for crop and golf course irrigation purposes were estimated for 32 municipalities with irrigation activity, mostly located within the irrigation districts. Coffee farms and other farms in the interior mountainous regions of Puerto Rico, which depend predominantly on rainfall as their source of water (Southern Integrated Pest Management Center, 2002; Puerto Rico Department of Natural and Environmental Resources, 2016), were excluded from the analysis. Total irrigation water use at each farm and golf course was assumed to be equal to the crop consumptive use, which was estimated using a modified version of a soil moisture model developed by Harmsen (2018). This assumption is made on the basis of farms in the south of Puerto Rico

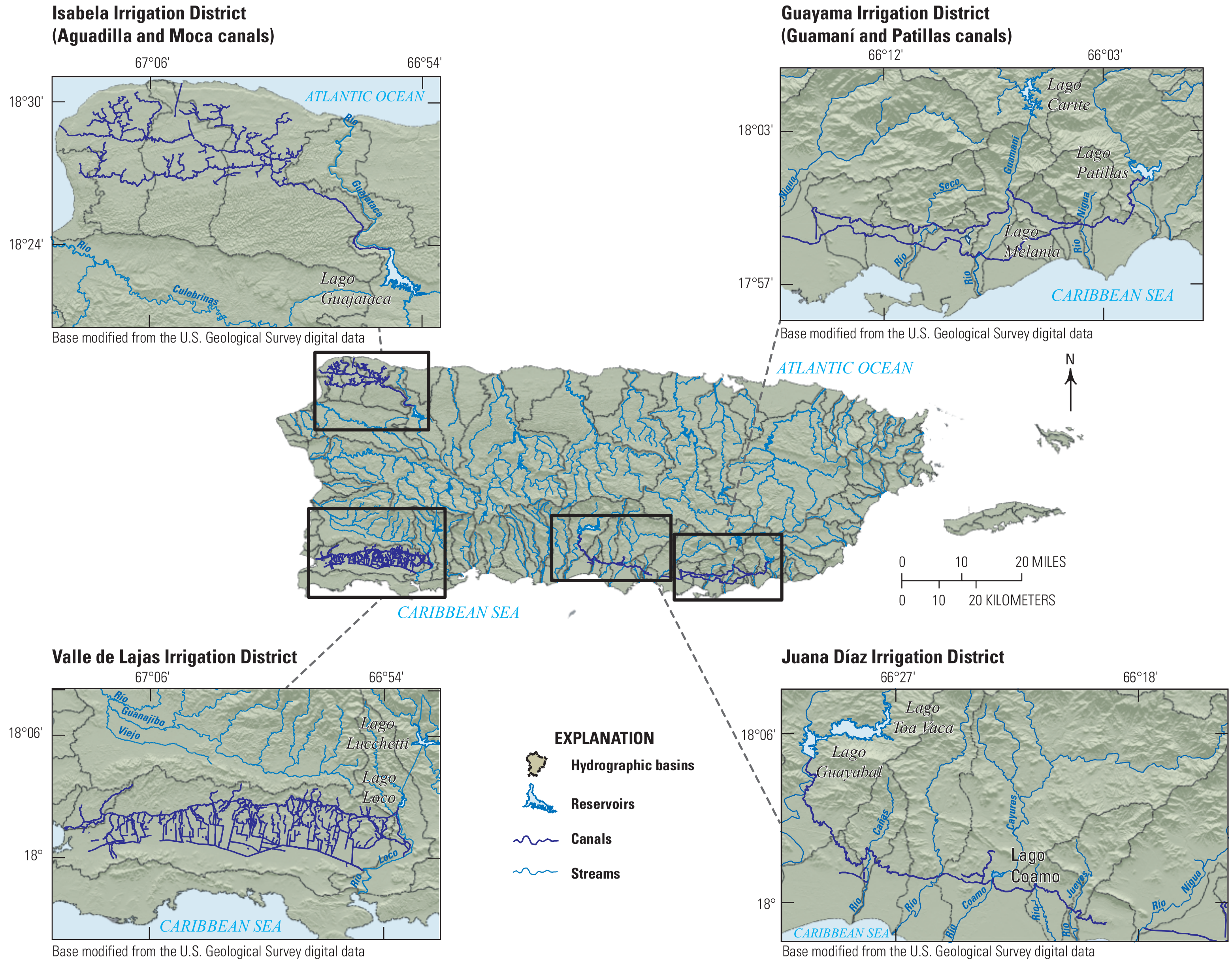


Figure 3. Locations of the Puerto Rico Electric Power Authority irrigation districts in Puerto Rico, 2015. See figure 1 for the names of the municipalities.

predominantly using more efficient micro-irrigation methods (Ramos-Ginés, 1994) as well as the difficulty in estimating conveyance losses and return flows for the various sources of water (Molina-Rivera, 2015). Total water use was then aggregated at the municipality level, and the reported surface-water withdrawals were subtracted from these values to estimate self-supplied groundwater withdrawals by municipality. The reported surface-water withdrawals exceeded the estimated total water use in five municipalities. In such cases, it was assumed that the total water use equaled the reported surface-water withdrawals and that there were no groundwater withdrawals for irrigation in these municipalities.

According to the Puerto Rico Institute for Water and Health (2017), the following golf courses in Puerto Rico use treated wastewater for irrigation purposes: Complejo Palmas del Mar in Humacao, Hotel Dorado Beach in Dorado, Grand Meliá PR Golf Resort in Río Grande, and Wyndham Grand Río Mar Beach Resort in Río Grande/Luquillo. It was assumed that all of the irrigation water used at these four golf resorts was obtained from municipal wastewater reuse in 2015 and that no additional water was withdrawn at these resorts for irrigation purposes; therefore, these golf courses are excluded from analyses of water withdrawals but their water reuse amounts are estimated as a separate water use category.

Puerto Rico experienced long and intense drought conditions between 2014 and 2016, especially in the eastern and southeastern regions. These dry conditions resulted in natural disaster declarations for 20 impacted municipalities during the summer months of 2015 (U.S. Department of Agriculture, 2015). The drought resulted in crop losses associated with pasture grass, livestock fodder, and plantains accounting for 85 percent of the $14 million in income losses in 2015 (Holupchinski and others, 2019). According to the Puerto Rico Department of Natural and Environmental Resources (2016), the most affected agricultural sector was improved pastures with over $3.6 million in losses, followed by cattle. Inspection of Google Earth aerial imagery for 2015 indicated dry conditions existed in pasture lands in the southern portion of the island especially during the summer months of 2015. Producers of farinaceous crops (containing starch, such as plantains) were unable to plant their crops because of the dryness of the soil. Seeds were planted later than usual in the year, and plants and fruits did not develop (Puerto Rico Department of Natural and Environmental Resources, 2016). For example, in the municipality of Yabucoa (fig. 1), 70 percent of plantain farmers lost their crops (Puerto Rico Department of Natural and Environmental Resources, 2016). This is confirmed by inspection of Google Earth aerial imagery, which shows decreased crop cover at most plantain farms in this municipality during the months of August–September, 2015.

Flow-meter readings were available for a selected number of irrigation wells during all or part of January 2015 through February 2016 primarily along the south coast of Puerto Rico. In previous water-use compilations for Puerto Rico, these metered data provided an estimate of water application rates that were then used to calculate water needs per crop type throughout the island. Most farms where flow-meter readings were performed are in municipalities located in the semiarid southern coast of Puerto Rico and were subjected to severe drought conditions in 2015. Because of differences in the response of individual farmers to drought conditions, potential restrictions on irrigation declared by the local government (Puerto Rico Scientific Committee on Droughts, 2015), and uncertainties regarding the crop types and planting cycles served by each well, the applicability of water application rates derived from these farms to farms in other areas of the island that experienced a different set of meteorological conditions in 2015 is not appropriate. Therefore, in the absence of farm-specific withdrawal data, a soil moisture model that estimates water application requirements to keep the soil moisture on a farm above a specific threshold was implemented in R programming software (https://www.R-project.org/) for 2015.

Harmsen (2018) developed a simple spreadsheet method for scheduling irrigation based on the methodology by the United Nations Food and Agriculture Organization (Allen and others, 1998). The model maintains soil moisture content between field capacity and a threshold soil moisture content in order to emulate agricultural practices that seek to avoid water stress on crops and maximize yields on a daily timestep. The spreadsheet model was modified for the purpose of computing the water application requirement to maintain the soil moisture above a threshold within each farm on the island. The soil moisture threshold is computed based on a management-allowed deficit factor between the soil's field capacity and wilting point:

$$\theta_{threshold} = \theta_{fc} - MAD * \left(\theta_{fc} - \theta_{pwp}\right) \quad (1)$$

where

$\theta_{threshold}$ is the threshold volumetric soil moisture to be maintained, as a fraction;

θ_{fc} is the volumetric soil moisture at field capacity, as a fraction;

MAD is the management allowed deficit factor, as a fraction; and

θ_{pwp} is the volumetric soil moisture at the permanent wilting point, as a fraction.

The irrigation need is computed by means of the soil water balance equation:

$$I_t = \max\left[0; D_t\left(\theta_{threshold} - \theta_{t-1}\right) - P_t + ET_{c,t}\right] \quad (2)$$

where

I_t is the irrigation need on day *t* in millimeters;

D_t is the root depth for the crop on day *t*, in millimeters;

θ_{t-1} is the previous day's volumetric soil moisture, as a fraction;

P_t is the precipitation on day *t*, in millimeters; and

$ET_{c,t}$ is the crop *c* potential evapotranspiration on day *t*, in millimeters.

Equation 2 assumes that the crop is well watered at all times so that its actual evapotranspiration rate equals its potential evaporation rate. The crop potential evapotranspiration rate is computed as the product of a crop coefficient and the Penman-Monteith grass-reference evapotranspiration (Allen and others, 1998; Allen and others, 2005):

$$ET_{c,t} = K_{c,t} ET_{o,t} \tag{3}$$

where

$K_{c,t}$ is the crop *c* coefficient on day *t*, in millimeters; and

$ET_{o,t}$ is the Penman-Monteith grass-reference evapotranspiration (*ETo*) on day *t*, in millimeters.

An intermediate water balance term is computed for crop *c* and day *t* based on the soil water balance equation:

$$B_t = \left(\theta_{t-1} - \frac{\left(ET_{c,t} - P_t - I_t \right)}{D_t} \right) \tag{4}$$

where

B_t is the intermediate water balance term on day *t*, as a fraction.

Any excess soil moisture above field capacity as a result of rainfall during the current day is assumed to leave the root zone as runoff and groundwater recharge within a relatively short time, so that at the end of the day the soil moisture does not exceed field capacity:

$$\theta_t = min\left[\theta_{fc}; \left(\max(0, B_t \right) \right] \tag{5}$$

$$RR_t = max\left[0; D_t * \left(B_t - \theta_{fc} \right) \right] \tag{6}$$

where

θ_t is the volumetric soil moisture at the end of day *t*, as a fraction; and

RR_t is the soil moisture in excess of field capacity that is lost to runoff and groundwater recharge on day *t*, in millimeters.

Equations 1–6 are applied starting on the first day of the year for perennial crops and based on an assumed growing season for annual crops, which can be discontinuous. The initial soil moisture is assumed to equal the threshold soil moisture ($\theta_t = \theta_{threshold}$) prior to the first day of irrigation. The predominant crop type planted at each farm was assigned from six principal types of crops (*c*) based on field visit observations from January to September 2015. Perennial crops include grasses for pasture and hay, and turf grasses on golf courses; mangoes; and plantains and bananas. Seasonal crops include vegetables, tomatoes, and corn (seed).

According to the Agricultural Extension Service of the University of Puerto Rico (2017), tomatoes are produced on the island between October and March. Based on an assumed 3-month period from planting to harvest (Fornaris, 2007), two back-to-back growing seasons were assumed between October and March for tomatoes. Corn seed is also assumed to be produced on the southern part of the island predominantly between October and March. Two back-to-back growing seasons for corn are assumed for this period. Although there is evidence in the media of a potential third growing season for corn in Puerto Rico (possibly between March and June; for example, see Mayer [2020]), inspection of Google Earth aerial imagery over corn seed farms did not provide evidence of widespread plant growth during this period.

Vegetables grown on the island include calabaza (a winter squash), peppers, coriander, sweet peppers, onions, and lettuce. Many of these vegetables can be grown year round and farms tend to rotate among different vegetable types. Since the exact type of vegetable grown at each farm during a particular period is unknown, a generic vegetable crop is assumed to be grown at these farms. Inspection of Google Earth imagery for 2015 indicated that vegetable crops were generally grown from January through March and from July through December in municipalities in the northwestern region of the island including Isabela, Moca, and Aguadilla. In the towns of Guayama and Salinas, evidence of vegetable crops was found from January through March and from October through December, whereas on the rest of the island, vegetables appeared to be grown year round.

Daily timeseries of rainfall (P_t) and Penman-Monteith grass-reference evapotranspiration ($ET_{o,t}$) (Allen and others, 2005) at 1-kilometer spatial resolution over Puerto Rico for 2015 were obtained from the GOES-PRWEB dataset (Harmsen and others, 2010) downloaded from the Puerto Rico Agricultural Water Management (PRAGWATER) website (Puerto Rico Agricultural Water Management, 2020). GOES-PRWEB rainfall was obtained from the National Weather Service's Advanced Hydrologic Prediction Service and is based on rainfall measured by Next-Generation Weather Radar (NEXRAD) in Cayey, which the National Weather Service adjusts as necessary. Daily integrated solar radiation, which is the main component used in estimating grass-reference evapotranspiration in GOES-PRWEB, was derived from a physical model for estimating incident solar radiation at the surface from the National Oceanic and Atmospheric Administration's Geostationary and Operational Environmental Satellite data. A description of the other sources of meteorological data used in $ET_{o,t}$ estimation can be found on the PRAGWATER website (Harmsen, 2020).

The irrigated land area within each farm was estimated by digitizing land that appeared cultivated during at least some portion of 2015 using 2015 Google Earth aerial imagery (accessed in May 2020). The methodology differs from that used for previous water-use compilations for Puerto Rico in that it was assumed that the entire farm was cultivated. Cultivated areas in the interior mountainous region of the island are generally rain fed and were excluded from the analysis. In the remaining areas, it was assumed that the entire cultivated area was irrigated, as determined by the soil moisture model based on the assumed growing season for the predominant crop type assigned to the farm. For golf courses, only fairways and greens were digitized. Total irrigated acreages were aggregated by municipality.

The irrigated land areas on farms and golf courses were intersected with daily rainfall and reference evapotranspiration grids to obtain spatially averaged daily values. Soil properties, such as soil moisture at field capacity (θ_{fc}) and at the permanent wilting point (θ_{pwp}), were also obtained from GOES-PRWEB. Crop parameters include the management allowed deficit (*MAD*), root depth (D_t), and crop coefficient ($K_{c,t}$). Because of the lack of crop parameter data for Puerto Rico, values for some of these parameters were based on data for the State of Florida and other national and international sources (tables 1 and 2).

It is worth noting that although the crop coefficient used for “grasses for pasture and hay, and turf grasses on golf courses” in this study (table 1) corresponds to turf grasses in Puerto Rico (Paulino-Paulino and others, 2008), crop coefficients for pasture in Smajstrala (1990) are of a similar magnitude with slightly higher values (up to 0.90–0.95) during summer months. There is uncertainty regarding the extent to which different types of grasses are actually irrigated in Puerto Rico. Viqueira-Ríos and others (2012) state that in the Lajas Valley Agricultural Reserve, most hay is being produced with a minimum of irrigation. According to a study by the Puerto Rico Water Resources and Environmental Research Institute (2005), pasture grass and forage agriculture in Puerto Rico increased substantially between 1996–97 and 2000–01, owing to the establishment of modern irrigation systems and an increase in improved pasture lands. Pasture grasses tend to have deeper roots than turf grasses (Smajstrala, 1990). In order to limit the potential overestimation of water withdrawals for irrigation in pasture farms, a root depth characteristic of turf grasses (0.46 meters) was assigned to all grass types in this study.

Inspection of Google Earth aerial imagery for 2015 indicated that about two-thirds of farms assigned a grass crop were left fallow during the months of May through August. It is likely that these are hay farms that may have stopped growing hay during what is traditionally the rainy season when excessive moisture during harvest can damage the crop.

Table 1. Crop parameters for vegetables; mangoes; plantains and bananas; and grasses for pasture and hay, and turf grasses on golf courses.

[MAD, management allowed deficit factor; m, meter]

Crop parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Vegetables (MAD = [1]0.5)												
Crop coefficient[2,3]	0.53	0.69	0.81	0.92	0.95	0.97	0.84	0.72	0.53	0.69	0.81	0.92
Root depth[4] (m)	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Mangoes (MAD = [5]0.5)												
Crop coefficient[2,6]	0.60	0.50	0.45	0.45	0.50	0.50	0.60	0.80	0.80	0.70	0.70	0.60
Root depth[5] (m)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Plantains and bananas (MAD = [7]0.35)												
Crop coefficient[3]	0.40	0.40	0.45	0.50	0.60	0.70	0.85	1.00	1.10	1.10	0.90	0.80
Root depth[7] (m)	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Grasses for pasture and hay, and turf grasses on golf courses (MAD = [8]0.5)												
Crop coefficient[2,9]	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Root depth[8] (m)	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46

[1]Value for generic annual crop from Smajstrala (1990).

[2]Crop coefficients assumed applicable to the first day of the month and linearly interpolated throughout the year.

[3]Table 5 of Puerto Rico Water Resources and Environmental Research Institute (2005).

[4]Maximum root depth from Smajstrala (1990) for vegetables typically grown in Puerto Rico.

[5]Averge value from Pereira and Alves (2013).

[6]De Azevedo and others (2003).

[7]Allen and others (1998).

[8]Average value for turf grasses from Smajstrala (1990).

[9]Paulino-Paulino and others (2008).

Table 2. Crop parameters for tomatoes and corn (seed).

[MAD, management allowed deficit factor; m, meter]

Crop parameter	Growth stage 1	Growth stage 2	Growth stage 3	Growth stage 4
Tomatoes (MAD = [1]0.4)				
Stage length[2] (days)	20	28	28	17
Crop coefficient[3]	0.40–0.40	0.40–1.05	1.05–1.05	1.05–0.75
Root depth[3] (m)	0.23–0.23	0.23–0.30	0.30–0.30	0.30–0.30
Corn (seed) (MAD = [1]0.6)				
Stage length[2] (days)	15	26	29	22
Crop coefficient[3]	0.40–0.40	0.40–1.05	1.05–1.05	1.05–0.55
Root depth[3] (m)	0.30–0.30	0.30–0.46	0.46–0.46	0.46–0.46

[1]Smajstrala (1990).

[2]Fractional stage duration from Smajstrala (1990) multiplied by assumed total duration of growing season.

[3]Values from Smajstrala (1990) for tomatoes and field corn, respectively. Initial and final values are varied linearly during the stage.

These farms were assigned a growing season from September through April. All other farms and golf courses classified as grass were assumed to be irrigated year round.

Equations 1–6 were applied to each individual farm to obtain the irrigation need for each day of the year (I_t). To validate the soil moisture model, water requirements for each type of crop were estimated based on readings of well-flow meters during all or part of January 2015 through February 2016 at farms mostly located along the south coast of Puerto Rico and were compared against simulated values (table 3). These farms were assumed to only be irrigated from groundwater; therefore, the well-meter readings represent the total irrigation water use at these farms, which generally compared favorably with the estimated consumptive use based on the soil moisture model. For this reason, no additional irrigation-system efficiency factors or conveyance-loss estimates were applied to the simulated values. Simulated consumptive-use values were within plus or minus (±) 10 percent of application rates derived from well-meter readings, except for vegetables and corn (seed), where simulated values overestimated metered values by 82 percent and 39 percent, respectively.

Inspection of Google Earth aerial imagery for 2015 indicated that the vegetable farm at which well metering had been performed in 2015 had crops covering its entire area during the months of January, July, and December. Only two records of well-meter data were available at this farm, one in early 2015 and one in early 2016; the data did not allow temporally varying application rates to be derived and crop-growing patterns to be informed. On the basis of the limited number of aerial imagery snapshots available, it was assumed that vegetables on this farm were grown year round, which may have not been the case and could explain the overestimation of irrigation withdrawals. It is also possible that during periods of harvesting, the entire field may still have been irrigated despite only part of the crop being present. The response of individual farmers to the severe drought conditions in 2015 (that is, potential overwatering when water is available and underwatering when not) is also unpredictable and could also help explain some of these differences. The type of vegetable grown during different months is also unknown. There is also some level of uncertainty in the assumed model parameters such as crop coefficients, root depths, and others. Another potential limitation is that the model attempts to constrain the soil moisture to stay within a narrow range every day. In particular, it assumes that any excess soil moisture beyond the field capacity leaves the crop root zone during a given day. In reality, the process of soil moisture redistribution to field capacity may take a few days during which any excess water in the soil could meet the evapotranspiration requirement. This would reduce the estimated irrigation requirements. As a sensitivity test, the soil moisture model was modified to allow for a delay in the soil moisture redistribution to field capacity, similar to the methodology employed by the Agricultural Field Scale Irrigation Requirements Simulation model (Smajstrala, 1990). This resulted in a small decline in the total annual irrigation requirements; however, the decline was very minor compared to the level of overestimation of irrigation requirements at these two farms.

Finally, total water use for irrigation was estimated by multiplying the acres irrigated by the water demand for crops, the latter value obtained from the soil moisture model and aggregated at the municipality level. The reported surface-water withdrawals were subtracted from these values to estimate groundwater withdrawals by municipality. All crops except grasses were assumed to be irrigated by micro-irrigation, as is common in the southern part of the island where most farms are located. Sprinkler irrigation was assumed for "grasses for pasture and hay, and turf grasses on golf courses."

Livestock Water Withdrawals

Livestock water use is associated with livestock watering, feedlots, dairy operations, and on-farm needs within the border of an individual farm that is not used for crop irrigation. Livestock includes dairy cows and heifers, beef cattle and calves, sheep and lambs, goats, swine, horses, and poultry. Other uses include water withdrawn for climate control (mostly cooling), dairy operations (sanitation and cleaning), and animal-waste disposal. All withdrawals for livestock were considered self-supplied.

The livestock freshwater withdrawals were estimated by the NWUSP. Estimates of livestock withdrawals were primarily derived by using animal population data and water-use coefficients, in gallons per head per day, for each animal type. The 2015 withdrawals for livestock were estimated according to methods described by Lovelace (2009), using livestock population data compiled for the 2012 Census of Agriculture (U.S. Department of Agriculture, 2014).

Table 3. Water use for tomatoes, vegetables, mangoes, corn (seed), and plantains and bananas based on water-use meter observations at wells in 2014, 2015, and early 2016, and simulated values.

[Some fields were served by two or three wells. For example, estimates for tomatoes include three wells serving one field of 334 acres and two wells serving one field of 351 acres. Simulated values shown in the last column]

Meter reading date (mm/dd/yyyy)	Water use (gallons)	Time interval (days)	Water use (gallons per day)	Field size (acres)	Water use for field (gallons per day per acre)	Water use for crop (gallons per day per acre)	Water use for field (gallons per day per acre) as simulated
			Tomatoes				
01/21/2015 02/23/2016	77,797,499	398	195,471	334	1,640	1,512	1,465
01/21/2015 09/09/2015	31,143,499	231	134,820				
01/21/2015 02/01/2016	81,829,299	376	217,631				
01/21/2015 02/23/2016	62,667,099	398	157,455	351	1,384		1,460
02/17/2015 02/23/2016	121,797,299	371	328,295				
			Vegetables				
01/21/2015 02/23/2016	160,290,000	398	402,739	200	2,014	2,014	3,656
			Mangoes				
01/21/2015 12/28/2015	132,064,199	341	387,285	170	2,278	2,278	2,468
			Corn (seed)				
01/17/2014 10/16/2014	125,254,999	272	460,496	438	1,110	1,110	1,544
01/21/2016 07/21/2016	4,700,000	182	25,824				
			Plantains and bananas				
01/27/2015 12/16/2015	49,857,899	323	154,359	122	3,220	3,680	3,283
01/27/2015 12/16/2015	77,039,299	323	238,512				
03/23/2016 06/24/2016	45,663,000	93	491,000	160	4,140		3,287
03/23/2016 06/24/2016	15,946,000	93	171,462				

Industrial Water Withdrawals

Industrial self-supplied withdrawals refer to water used for manufacturing purposes such as pharmaceutical production, chemical and allied products preparation, food processing, and petroleum refining. In Puerto Rico, most of the self-supplied industries are located along the north coast and can be grouped by the North American Industry Classification System Code (NAICS) number 325412 (U.S. Census Bureau, 2017), which refers to pharmaceutical preparation manufacturing.

The withdrawal estimates for industrial self-supplied use are limited to groundwater withdrawals and were provided by the Puerto Rico Department of Natural and Environmental Resources (PRDNER) Permits and Water Franchise Division. Data have limited availability owing to restrictions (sensitivity concern). Contact PRDNER for more information.

Mining Water Withdrawals

Mining water use includes the water used for the extraction of minerals; solids, such as coal and ores; liquids, such as crude petroleum; and gases, such as natural gas. Estimates for mining water-use withdrawals were provided by the NWUSP. Data have limited availability owing to restrictions (sensitivity concern). Contact NWUSP for more information.

In 2015, the primary mining water-use activity in Puerto Rico was sand and gravel extraction. All mining withdrawals were considered self-supplied.

Thermoelectric-Power Water Withdrawals

The largest use of water in thermoelectric power generation is for the cooling process, whereby water is used to condense and cool the steam used to drive generators (Dieter and others, 2018). Water used for power generation can be self-supplied or obtained from a public-supply water system. Two main types of cooling systems are used by thermoelectric power facilities: once-through systems and recirculating systems. The primary cooling method used in Puerto Rico is once-through (also known as open-loop) cooling in which the water is withdrawn from a source, circulated through heat exchangers, and then returned to a body of water at higher temperatures. Recirculating cooling systems (also known as closed-loop systems) circulate water through heat exchangers, cool the water using ponds or towers, and then recirculate the water. In Puerto Rico, seawater is the source for all saline-water withdrawals used for once-through cooling purposes, and freshwater withdrawals and (or) public-supply water deliveries are the source for boiler feed and domestic use within the facilities. In 2015, Puerto Rico had six active thermoelectric power facilities, four of which are operated by PREPA and two by private companies; these facilities provided the estimates of water withdrawals for this report. Raw data for estimating thermoelectric-power water withdrawals were not available online and were obtained directly from PREPA and the private companies (Ecoeléctrica and AES Corporation). Data have limited availability owing to restrictions (sensitivity concern). Contact PRDNER, Ecoeléctrica, or AES Corporation for more information.

Total Water Withdrawals and Use

Aggregated water use and withdrawal estimates generated as part of this publication are available in Dixon and others (2021). Total water withdrawals in Puerto Rico for 2015 were estimated for seven categories of use: public-supply water, domestic self-supplied, irrigation (including golf course irrigation), livestock, industrial, mining, and thermoelectric power (table 4). The two largest uses of freshwater were public-supply water and irrigation, accounting for 98 percent of the total freshwater withdrawn in Puerto Rico. The domestic self-supplied, livestock, industrial, mining, and thermoelectric-power categories accounted for the remaining 2 percent of the total freshwater withdrawals. Arecibo accounted for about 18 percent of the total freshwater withdrawals, predominantly for public-supply water use. Trujillo Alto, Toa Alta, Villalba, Aguada, and Mayagüez accounted for about 32 percent (213 Mgal/d) of the total freshwater withdrawals, which were predominantly for public-supply water uses.

Table 4. Water withdrawals by category in Puerto Rico, 2015.

[Data source: U.S. Geological Survey, Caribbean-Florida Water Science Center; all values in million gallons per day]

Puerto Rico	Freshwater			Saline water			All water		
	Ground	Surface	Total	Ground	Surface	Total	Ground	Surface	Total
Public-supply water	66.62	509.78	576.40	0.00	0.00	0.00	66.62	509.78	576.40
Domestic self-supplied	0.52	0.00	0.52	0.00	0.00	0.00	0.52	0.00	0.52
Irrigation	43.48	34.10	77.58	0.00	0.00	0.00	43.48	34.10	77.58
Livestock	4.23	1.60	5.83	0.00	0.00	0.00	4.23	1.60	5.83
Industrial	3.67	0.00	3.67	0.00	0.00	0.00	3.67	0.00	3.67
Mining	1.84	0.18	2.02	0.00	0.00	0.00	1.84	0.18	2.02
Thermoelectric power	1.82	2.83	4.65	0.00	1,701.11	1,701.11	1.82	1,703.94	1,705.76
Total	**122.18**	**548.49**	**670.67**	**0.00**	**1,701.11**	**1,701.11**	**122.18**	**2,249.60**	**2,371.78**

Total withdrawals were estimated at 2,372 Mgal/d. Freshwater withdrawals accounted for 671 Mgal/d (28 percent) and saline-water withdrawals composed the remaining 1,701 Mgal/d (72 percent) of the total withdrawals. Seawater is the source of all saline-water withdrawals and was used for cooling processes at thermoelectric power facilities. Total surface-water withdrawals (saline and freshwater) were estimated at 2,250 Mgal/d, or 95 percent of the total water withdrawn. About 24 percent (548 Mgal/d) of total surface-water withdrawals were freshwater. Total groundwater withdrawals were estimated at 122 Mgal/d, all of which was freshwater (table 4).

Public-supply water withdrawals totaled 576 Mgal/d or 86 percent of the total freshwater withdrawals. Fifty-eight percent of total freshwater withdrawals for public-supply water in Puerto Rico were apportioned among six municipalities: Arecibo, Trujillo Alto, Toa Alta, Villalba, Aguada, and Mayagüez (table 5). Note that reported withdrawals in table 5 are each for the municipality from which the withdrawal occurred. Withdrawals might have subsequently been distributed to other municipalities such as San Juan. Irrigation withdrawals (fig. 4) totaled 78 Mgal/d or 12 percent of total freshwater withdrawals. About 65 percent of the total freshwater withdrawals for irrigation occurred at four municipalities: Santa Isabel, Salinas, Lajas, and Juana Díaz (table 5).

In 2015, public-supply surface-water withdrawals accounted for 93 percent (510 Mgal/d) of the total fresh surface-water withdrawals (548 Mgal/d). Of the total fresh groundwater withdrawals in 2015 (122 Mgal/d), public-supply water accounted for 55 percent (67 Mgal/d), followed by irrigation withdrawals, which accounted for 36 percent (43 Mgal/d) (table 4). Fresh groundwater withdrawals for public-supply water in the municipalities of Arecibo, Santa Isabel, Manatí, Vega Baja, and Ponce accounted for 41 percent of the total fresh groundwater withdrawals (table 6).

Public-Supply Water Withdrawals and Population Served

Withdrawals for public-supply water accounted for 576 Mgal/d of all water uses in Puerto Rico in 2015. This amount is 14 percent less than the estimated amount of public-supply water withdrawn in 2010. During 2015, public-supply water distributed by PRASA was provided by intakes, active public WTPs, and wells. Non-PRASA surface-water systems and domestic wells served communities with 15 or more connections. PRASA and non-PRASA systems withdrew 510 Mgal/d (88 percent) from surface-water sources, such as reservoirs, canals, and streams, and 67 Mgal/d (12 percent) from groundwater sources (table 6). The largest public-supply surface-water withdrawal was in the municipality of Arecibo, where public-supply water accounted for 109 Mgal/d or 21 percent of the total fresh surface-water withdrawals. The municipalities of Trujillo Alto and Toa Alta withdrew about 25 percent less surface water for public-supply water uses in 2015 than in 2010, mostly because of the drought that affected the metropolitan area in 2015.

An estimated 3,469,474 people relied on public-supply water for their household needs in 2015 (table 7). The combined total of (1) all users of public-supply water served by PRASA and non-PRASA systems and (2) domestic self-supplied users was considered in this report to equal the 2015 total population estimate (3,474,182 people).

Most of the public-supply water withdrawals are delivered to customers for domestic uses, representing indoor and outdoor water uses at occupied residences. In 2015, domestic deliveries accounted for 59 percent (338 Mgal/d) of the total public-supply water withdrawals in Puerto Rico (576 Mgal/d) (table 6). The remaining 238 Mgal/d was distributed for commercial, industrial, and thermoelectric power, and all other users (government facilities, schools, hospitals, firefighting, and systems losses). Domestic deliveries were also estimated for the 139 PRASA WSAs. The PRASA WSA identified as the metropolitan area, W–102, accounted for about 28 percent of the total water delivered from public-supply water facilities to domestic users. About 34 percent of the total population of Puerto Rico was served in the W–102 PRASA WSA (table 7).

The North Coast Aqueduct (NCA), commonly referred to as the “Superaqueduct,” is a major public-supply water facility that began operation in 2000 and transfers water from the Río Grande de Arecibo Basin to the San Juan metropolitan area. The NCA distributes water through seven interconnections along the system: Miraflores-Arecibo, Sabana Hoyos-Arecibo, Barceloneta, Manatí, Vega Baja, Dorado/Vega Alta, and Bayamón (fig. 5). In 2015, the NCA delivered 107 Mgal/d to municipalities primarily located in the north-central part of Puerto Rico. The Bayamón interconnection accounted for 71 percent (76 Mgal/d) of the water transfers (fig. 5).

Domestic Deliveries from Public-Supply Water Systems and Self-Supplied

Domestic water use includes indoor and outdoor uses at residences. Common indoor water uses include drinking, food preparation, washing clothes and dishes, bathing, and toilet flushing. Common outdoor uses include lawn and garden watering, maintaining swimming pools and ponds, sidewalk cleaning, and other domestic water uses that are either provided by a public supplier or are self-supplied.

In 2015, public-supply water systems delivered 338 Mgal/d for domestic water use (served from PRASA and non-PRASA systems). The domestic per capita water use in Puerto Rico was estimated at 98 gallons per day (gal/d) in 2015 (table 8). This per capita use varies between PRASA WSAs and between municipalities; however, households served by the same public-supply water system often have a common pattern of use affected by factors such as household income, climate, and topography (Marella, 1992). The estimated public-supply water deliveries to domestic users are presented by PRASA WSA and by municipality in tables 7 and 8, respectively. These deliveries combined with the self-supplied domestic withdrawals represent the total amount of water withdrawn for human consumption.

Table 5. Estimated total freshwater withdrawals by water-use category and municipality in Puerto Rico, 2015.

[Data source: Raw data used to compile and tabulate withdrawal data were obtained directly from State agencies. Mgal/d, million gallons per day]

Municipality	Public supply	Domestic	Irrigation	Livestock	Industrial	Mining	Thermoelectric power	Total
Adjuntas	2.07	0.02	0.00	0.02	0.00	0.00	0.00	2.11
Aguada	22.48	0.00	0.40	0.05	0.07	0.00	0.00	23.00
Aguadilla	3.83	0.07	0.54	0.05	0.11	0.08	0.00	4.68
Aguas Buenas	14.15	0.00	0.00	0.02	0.00	0.00	0.00	14.17
Aibonito	2.35	0.00	0.00	0.17	0.02	0.00	0.00	2.54
Añasco	1.46	0.00	0.00	0.04	0.00	0.00	0.00	1.50
Arecibo	121.88	0.01	0.00	0.63	0.13	0.10	0.00	122.75
Arroyo	0.48	0.00	0.59	0.00	0.00	0.00	0.00	1.07
Barceloneta	2.66	0.00	0.00	0.02	1.29	0.00	0.00	3.97
Barranquitas	4.34	0.00	0.00	0.10	0.02	0.00	0.00	4.46
Bayamón	0.73	0.00	0.03	0.00	0.05	0.24	0.00	1.05
Cabo Rojo	4.33	0.00	1.29	0.13	0.14	0.00	0.00	5.89
Caguas	9.86	0.00	0.14	0.09	0.06	0.00	0.00	10.15
Camuy	0.52	0.00	0.00	0.05	0.00	0.00	0.00	0.57
Canóvanas	5.32	0.00	0.00	0.03	0.01	0.00	0.00	5.36
Carolina	1.10	0.00	0.00	0.06	0.00	0.00	0.00	1.16
Cataño	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cayey	2.95	0.00	0.00	0.05	0.16	0.00	0.00	3.16
Ceiba	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.04
Ciales	3.19	0.00	0.00	0.05	0.00	0.00	0.00	3.24
Cidra	4.13	0.02	0.00	0.09	0.04	0.00	0.00	4.28
Coamo	0.84	0.00	0.64	0.27	0.00	0.00	0.00	1.75
Comerio	3.37	0.00	0.00	0.05	0.00	0.00	0.00	3.42
Corozal	4.10	0.00	0.00	0.09	0.00	0.00	0.00	4.19
Culebra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dorado	3.01	0.04	0.00	0.03	0.03	0.00	0.00	3.11
Fajardo	9.32	0.00	0.11	0.04	0.08	0.04	0.00	9.59
Florida	1.62	0.00	0.00	0.04	0.00	0.00	0.00	1.66
Guánica	2.53	0.00	5.94	0.03	0.00	0.00	0.00	8.50
Guayama	10.68	0.00	2.49	0.01	0.21	0.28	1.75	15.42
Guayanilla	2.60	0.00	3.57	0.03	0.00	0.00	1.17	7.37
Guaynabo	5.10	0.00	0.03	0.00	0.07	0.00	0.00	5.20
Gurabo	2.65	0.00	0.04	0.05	0.01	0.00	0.00	2.75
Hatillo	3.96	0.00	0.00	0.65	0.08	0.00	0.00	4.69
Hormigueros	1.16	0.00	0.00	0.04	0.04	0.00	0.00	1.24
Humacao	0.00	0.00	0.00	0.13	0.12	0.32	0.00	0.57
Isabela	6.75	0.00	1.12	0.18	0.04	0.00	0.00	8.09
Jayuya	2.67	0.00	0.00	0.00	0.07	0.00	0.00	2.74
Juana Díaz	2.56	0.01	9.33	0.03	0.00	0.00	0.00	11.93
Juncos	1.44	0.00	0.03	0.16	0.15	0.00	0.00	1.78
Lajas	4.32	0.00	12.97	0.16	0.00	0.00	0.00	17.45
Lares	3.69	0.01	0.00	0.02	0.00	0.00	0.00	3.72

Table 5. Estimated total freshwater withdrawals by water-use category and municipality in Puerto Rico, 2015.—Continued

[Data source: Raw data used to compile and tabulate withdrawal data were obtained directly from State agencies. Mgal/d, million gallons per day]

Municipality	Public supply	Domestic	Irrigation	Livestock	Industrial	Mining	Thermoelectric power	Total
Las Marías	1.61	0.00	0.00	0.01	0.00	0.00	0.00	1.62
Las Piedras	5.75	0.00	0.00	0.11	0.07	0.00	0.00	5.93
Loíza	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03
Luquillo	2.12	0.00	0.00	0.01	0.01	0.00	0.00	2.14
Manatí	3.34	0.00	0.07	0.06	0.18	0.22	0.00	3.87
Maricao	1.47	0.00	0.00	0.00	0.03	0.00	0.00	1.50
Maunabo	1.40	0.00	0.71	0.01	0.00	0.00	0.00	2.12
Mayagüez	21.95	0.00	0.00	0.05	0.02	0.09	0.00	22.11
Moca	0.60	0.00	0.10	0.13	0.00	0.00	0.00	0.83
Morovis	3.61	0.00	0.00	0.07	0.00	0.00	0.00	3.68
Naguabo	12.79	0.00	0.00	0.13	0.00	0.00	0.00	12.92
Naranjito	0.69	0.00	0.00	0.08	0.00	0.00	0.00	0.77
Orocovis	4.08	0.00	0.00	0.05	0.00	0.00	0.00	4.13
Patillas	5.40	0.00	0.73	0.04	0.00	0.00	0.00	6.17
Peñuelas	2.59	0.00	0.21	0.02	0.00	0.00	1.03	3.85
Ponce	4.04	0.00	1.91	0.04	0.05	0.28	0.00	6.32
Quebradillas	3.93	0.00	0.00	0.20	0.00	0.00	0.00	4.13
Rincón	0.95	0.00	0.00	0.03	0.00	0.00	0.00	0.98
Rio Grande	10.47	0.00	0.13	0.03	0.00	0.00	0.00	10.63
Sabana Grande	3.14	0.00	2.02	0.02	0.00	0.00	0.00	5.18
Salinas	3.08	0.00	12.43	0.03	0.00	0.00	0.70	16.24
San Germán	1.50	0.00	0.00	0.06	0.00	0.00	0.00	1.56
San Juan	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.07
San Lorenzo	5.09	0.00	0.00	0.05	0.00	0.00	0.00	5.14
San Sebastián	6.71	0.00	0.00	0.26	0.00	0.00	0.00	6.97
Santa Isabel	5.12	0.00	15.93	0.01	0.03	0.20	0.00	21.29
Toa Alta	61.65	0.00	0.00	0.03	0.00	0.00	0.00	61.68
Toa Baja	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.23
Trujillo Alto	75.58	0.00	0.00	0.01	0.00	0.00	0.00	75.59
Utuado	3.92	0.21	0.00	0.04	0.00	0.00	0.00	4.17
Vega Alta	0.70	0.00	0.00	0.03	0.00	0.00	0.00	0.73
Vega Baja	4.38	0.13	0.00	0.06	0.03	0.03	0.00	4.63
Vieques	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Villalba	30.61	0.00	0.00	0.02	0.00	0.00	0.00	30.63
Yabucoa	3.73	0.00	1.97	0.37	0.01	0.00	0.00	6.08
Yauco	4.20	0.00	2.11	0.03	0.00	0.08	0.00	6.42
Total	**576.40**	**0.52**	**77.58**	**5.83**	**3.67**	**2.02**	**4.65**	**670.67**

Figure 4. Irrigation well in Santa Isabel, Puerto Rico. Photograph by José A. Santiago-Sáez, U.S. Geological Survey.

Water for self-supplied domestic use is typically obtained from a private source, such as a well, or from rainwater captured in a cistern. Less than 1 percent of the population (4,708 people) in Puerto Rico provided their own water for domestic use in 2015 (table 8). Self-supplied withdrawals were estimated at 0.52 Mgal/d, less than 1 percent of all uses in 2015. All self-supplied withdrawals reported herein were from fresh groundwater sources. Self-supplied domestic withdrawals are rarely metered or reported, and this usage is usually calculated by multiplying an estimate of the population not served by public-supply water by a per capita coefficient. The per capita coefficients were estimated on the basis of the average derived from the non-PRASA community systems. The average self-supplied domestic per capita use in 2015 was 110 gal/d and ranged from 53 to 160 gal/d in the municipalities where it occurred. Generally, the self-supplied domestic per capita use is greatest in the southern municipalities, where outdoor watering is most common (table 8).

In 2015, the 98-gal/d per capita water use for domestic public-supply deliveries (table 8) was a 58 percent increase when compared to 2010. Overall, about 36 gal/d more water per capita was distributed among the resident population for household uses in 2015 than in 2010. The per capita use was generally lower in municipalities located primarily on the eastern side of the island, which were affected by the drought and were subject to a water rationing control plan (table 8). Although the domestic delivery per capita use in the municipalities affected by the drought was less in comparison to the rest of the municipalities, it remained high in comparison to use in 2010. Possible explanations may include one or more of the following:

- Although the residents were asked to conserve water, they did not alter their water-use behavioral patterns and continued with the same practices, mostly for such outdoor uses as landscaping irrigation, car washing, sidewalk cleaning, or collecting more water as a reserve for indoor uses during the cutoff days.
- A decrease in population and increase in water available for distribution, mostly to the domestic sector.
- More accurate accounting of the domestic deliveries from the public suppliers.

Table 6. Estimated public-supply water withdrawals in Puerto Rico by source of water and municipality, 2015.

[Data source: Raw data used to compile and tabulate withdrawal data were obtained by contacting the Puerto Rico Aqueduct and Sewer Authority (PRASA) and Puerto Rico Department of Health directly. Withdrawals are accounted in the municipalities where the intakes are located. Non-PRASA community water systems refers to water systems that supply water to the same population year round. SW, surface water; GW, groundwater; Mgal/d, million gallons per day]

Municipality	PRASA			Non-PRASA (community water systems)			Total withdrawals		
	GW withdrawals (Mgal/d)	SW withdrawals (Mgal/d)	Total withdrawals (Mgal/d)	GW withdrawals (Mgal/d)	SW withdrawals (Mgal/d)	Total withdrawals (Mgal/d)	GW withdrawals (Mgal/d)	SW withdrawals (Mgal/d)	Total withdrawals (Mgal/d)
Adjuntas	0.10	1.78	1.88	0.17	0.02	0.19	0.27	1.80	2.07
Aguada	0.23	21.76	21.99	0.49	0.00	0.49	0.72	21.76	22.48
Aguadilla	0.34	3.47	3.81	0.02	0.00	0.02	0.36	3.47	3.83
Aguas Buenas	0.00	13.92	13.92	0.23	0.00	0.23	0.23	13.92	14.15
Aibonito	0.60	1.66	2.26	0.09	0.00	0.09	0.69	1.66	2.35
Añasco	0.00	1.40	1.40	0.06	0.00	0.06	0.06	1.40	1.46
Arecibo	12.74	109.10	121.84	0.04	0.00	0.04	12.78	109.10	121.88
Arroyo	0.48	0.00	0.48	0.00	0.00	0.00	0.48	0.00	0.48
Barceloneta	2.66	0.00	2.66	0.00	0.00	0.00	2.66	0.00	2.66
Barranquitas	0.55	3.51	4.06	0.27	0.01	0.28	0.82	3.52	4.34
Bayamón	0.00	0.73	0.73	0.00	0.00	0.00	0.00	0.73	0.73
Cabo Rojo	3.12	1.21	4.33	0.00	0.00	0.00	3.12	1.21	4.33
Caguas	0.00	9.38	9.38	0.41	0.07	0.48	0.41	9.45	9.86
Camuy	0.52	0.00	0.52	0.00	0.00	0.00	0.52	0.00	0.52
Canóvanas	0.00	5.32	5.32	0.00	0.00	0.00	0.00	5.32	5.32
Carolina	0.00	1.10	1.10	0.00	0.00	0.00	0.00	1.10	1.10
Cataño	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cayey	0.00	2.89	2.89	0.03	0.03	0.06	0.03	2.92	2.95
Ceiba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ciales	0.00	3.16	3.16	0.02	0.01	0.03	0.02	3.17	3.19
Cidra	0.00	4.07	4.07	0.06	0.00	0.06	0.06	4.07	4.13
Coamo	0.00	0.75	0.75	0.05	0.04	0.09	0.05	0.79	0.84
Comerio	0.29	2.96	3.25	0.12	0.00	0.12	0.41	2.96	3.37
Corozal	0.00	3.87	3.87	0.09	0.14	0.23	0.09	4.01	4.10
Culebra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dorado	3.01	0.00	3.01	0.00	0.00	0.00	3.01	0.00	3.01
Fajardo	0.00	9.31	9.31	0.00	0.01	0.01	0.00	9.32	9.32
Florida	1.62	0.00	1.62	0.00	0.00	0.00	1.62	0.00	1.62

Table 6. Estimated public-supply water withdrawals in Puerto Rico by source of water and municipality, 2015.—Continued

[Data source: Raw data used to compile and tabulate withdrawal data were obtained by contacting the Puerto Rico Aqueduct and Sewer Authority (PRASA) and Puerto Rico Department of Health directly. Withdrawals are accounted in the municipalities where the intakes are located. Non-PRASA community water systems refers to water systems that supply water to the same population year round. SW, surface water; GW, groundwater; Mgal/d, million gallons per day]

Municipality	PRASA			Non-PRASA (community water systems)			Total withdrawals		
	GW withdrawals (Mgal/d)	SW withdrawals (Mgal/d)	Total withdrawals (Mgal/d)	GW withdrawals (Mgal/d)	SW withdrawals (Mgal/d)	Total withdrawals (Mgal/d)	GW withdrawals (Mgal/d)	SW withdrawals (Mgal/d)	Total withdrawals (Mgal/d)
Guánica	2.53	0.00	2.53	0.00	0.00	0.00	2.53	0.00	2.53
Guayama	0.60	10.06	10.66	0.00	0.02	0.02	0.60	10.08	10.68
Guayanilla	2.36	0.18	2.54	0.01	0.05	0.06	2.37	0.23	2.60
Guaynabo	0.00	5.09	5.09	0.01	0.00	0.01	0.01	5.09	5.10
Gurabo	0.00	2.65	2.65	0.00	0.00	0.00	0.00	2.65	2.65
Hatillo	0.37	3.59	3.96	0.00	0.00	0.00	0.37	3.59	3.96
Hormigueros	1.16	0.00	1.16	0.00	0.00	0.00	1.16	0.00	1.16
Humacao	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isabela	0.00	6.75	6.75	0.00	0.00	0.00	0.00	6.75	6.75
Jayuya	0.00	2.30	2.30	0.00	0.37	0.37	0.00	2.67	2.67
Juana Díaz	2.42	0.00	2.42	0.00	0.14	0.14	2.42	0.14	2.56
Juncos	0.00	1.44	1.44	0.00	0.00	0.00	0.00	1.44	1.44
Lajas	0.00	4.32	4.32	0.00	0.00	0.00	0.00	4.32	4.32
Lares	0.04	3.54	3.58	0.09	0.02	0.11	0.13	3.56	3.69
Las Marías	0.00	1.60	1.60	0.00	0.01	0.01	0.00	1.61	1.61
Las Piedras	0.22	5.34	5.56	0.13	0.06	0.19	0.35	5.40	5.75
Loíza	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Luquillo	0.12	2.00	2.12	0.00	0.00	0.00	0.12	2.00	2.12
Manatí	3.34	0.00	3.34	0.00	0.00	0.00	3.34	0.00	3.34
Maricao	0.00	1.46	1.46	0.00	0.01	0.01	0.00	1.47	1.47
Maunabo	1.03	0.35	1.38	0.00	0.02	0.02	1.03	0.37	1.40
Mayagüez	1.01	20.94	21.95	0.00	0.00	0.00	1.01	20.94	21.95
Moca	0.60	0.00	0.60	0.00	0.00	0.00	0.60	0.00	0.60
Morovis	0.06	3.55	3.61	0.00	0.00	0.00	0.06	3.55	3.61
Naguabo	0.00	12.52	12.52	0.00	0.27	0.27	0.00	12.79	12.79
Naranjito	0.00	0.00	0.00	0.61	0.08	0.69	0.61	0.08	0.69
Orocovis	0.00	3.70	3.70	0.29	0.09	0.38	0.29	3.79	4.08
Patillas	0.97	4.26	5.23	0.10	0.07	0.17	1.07	4.33	5.40

Table 6. Estimated public-supply water withdrawals in Puerto Rico by source of water and municipality, 2015.—Continued

[Data source: Raw data used to compile and tabulate withdrawal data were obtained by contacting the Puerto Rico Aqueduct and Sewer Authority (PRASA) and Puerto Rico Department of Health directly. Withdrawals are accounted in the municipalities where the intakes are located. Non-PRASA community water systems refers to water systems that supply water to the same population year round. SW, surface water; GW, groundwater; Mgal/d, million gallons per day]

Municipality	PRASA			Non-PRASA (community water systems)			Total withdrawals		
	GW withdrawals (Mgal/d)	SW withdrawals (Mgal/d)	Total withdrawals (Mgal/d)	GW withdrawals (Mgal/d)	SW withdrawals (Mgal/d)	Total withdrawals (Mgal/d)	GW withdrawals (Mgal/d)	SW withdrawals (Mgal/d)	Total withdrawals (Mgal/d)
Peñuelas	0.25	2.17	2.42	0.02	0.15	0.17	0.27	2.32	2.59
Ponce	3.00	0.84	3.84	0.13	0.07	0.20	3.13	0.91	4.04
Quebradillas	0.14	3.79	3.93	0.00	0.00	0.00	0.14	3.79	3.93
Rincón	0.95	0.00	0.95	0.00	0.00	0.00	0.95	0.00	0.95
Rio Grande	0.00	10.43	10.43	0.00	0.04	0.04	0.00	10.47	10.47
Sabana Grande	0.06	3.08	3.14	0.00	0.00	0.00	0.06	3.08	3.14
Salinas	3.08	0.00	3.08	0.00	0.00	0.00	3.08	0.00	3.08
San Germán	1.28	0.19	1.47	0.01	0.02	0.03	1.29	0.21	1.50
San Juan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
San Lorenzo	0.00	4.82	4.82	0.24	0.03	0.27	0.24	4.85	5.09
San Sebastián	0.18	6.41	6.59	0.12	0.00	0.12	0.30	6.41	6.71
Santa Isabel	5.12	0.00	5.12	0.00	0.00	0.00	5.12	0.00	5.12
Toa Alta	0.00	61.65	61.65	0.00	0.00	0.00	0.00	61.65	61.65
Toa Baja	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trujillo Alto	0.00	75.58	75.58	0.00	0.00	0.00	0.00	75.58	75.58
Utuado	0.00	3.69	3.69	0.05	0.18	0.23	0.05	3.87	3.92
Vega Alta	0.70	0.00	0.70	0.00	0.00	0.00	0.70	0.00	0.70
Vega Baja	3.19	1.19	4.38	0.00	0.00	0.00	3.19	1.19	4.38
Vieques	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Villalba	0.03	30.27	30.30	0.02	0.29	0.31	0.05	30.56	30.61
Yabucoa	1.18	2.15	3.33	0.39	0.01	0.40	1.57	2.16	3.73
Yauco	0.00	4.14	4.14	0.00	0.06	0.06	0.00	4.20	4.20
Total	**62.25**	**507.39**	**569.64**	**4.37**	**2.39**	**6.76**	**66.62**	**509.78**	**576.40**

Table 7. Estimated domestic deliveries, population served, and domestic per capita use in Puerto Rico by Puerto Rico Aqueduct and Sewer Authority Water Service Areas, 2015.

[Data source: Raw data used to compile and tabulate domestic delivery data were obtained directly from the Puerto Rico Aqueduct and Sewer Authority (PRASA); ID, identifier; PWS, public water system; Mgal/d, million gallons per day; gal/d, gallon per day; WTP, water treatment plant]

PRASA water service area ID	Municipalities served	PRASA water service area name	PWS ID	Domestic deliveries (Mgal/d)	Total population served	Domestic per capita use (gal/d)
W-102 and Carolina WTP[1]	Aguas Buenas, Bayamón, Caguas, Canóvanas, Carolina, Cataño, Corozal, Dorado, Guaynabo, Gurabo, Loíza, Naranjito, San Juan, Toa Alta, Toa Baja, Trujillo Alto	Metropolitano	PR0002591, PR0002000	93.13	1,164,329	80
W-103	Aguas Buenas, Bayamón, Comerío	Barrio Nuevo	PR0005557	0.36	6,826	53
W-105	Canóvanas	Cubuy	PR0002611	0.25	2,304	109
W-106	Canóvanas, Las Piedras, Río Grande	Guzmán Arriba	PR0005356	0.64	11,740	55
W-201	Manatí, Morovis, Vega Baja	Vega Baja Urbano, Pugnado, Ciudad Real	PR0002772, PR0002972, PR0003812	4.96	45,541	109
W-202	Jayuya, Utuado	Mameyes Arriba	PR0003062	0.44	2,959	149
W-205	Vega Alta, Vega Baja	Almirante Sur	PR0002982	0.35	3,079	114
W-206	Camuy, Lares	Lares Urbano	PR0002692	1.41	11,934	118
W-207	Arecibo, Barceloneta	Garrochales	PR0002782	2.20	14,329	154
W-208	Barranquitas, Corozal, Naranjito, Vega Alta	Negros	PR0005537	2.09	22,245	94
W-209	Jayuya, Utuado	Canalizo	PR0003212	0.09	1,527	59
W-210	Barranquitas, Naranjito	Cedro Arriba	PR0005517	1.25	12,363	101
W-211	Ciales, Morovis	Ciales Urbano	PR0002752	0.97	3,183	305
W-212	Corozal, Vega Alta	Corozal Urbano	PR0005487	1.16	12,584	92
W-213	Arecibo, Utuado	Río Arriba	PR0002842	0.25	1,051	238
W-214	Ciales, Utuado	Frontón	PR0003012	0.40	6,244	64
W-215	Camuy, Hatillo	Hatillo-Camuy, Ciénaga	PR0003862, PR0002662	3.27	36,357	90
W-216	Lares, Las Marias, Maricao, San Sebastián	Lares Espino	PR0003872	1.96	17,261	114
W-217	Jayuya, Ponce, Utuado	La Pica	PR0003042	0.08	550	145
W-218	Arecibo Hatillo	Arecibo Urbano	PR0002652	9.11	57,219	159
W-219	Ciales, Jayuya, Ponce, Utuado	Jayuya Urbano	PR0002712	1.60	13,444	119
W-220	Florida, Manatí	Monte Bello	PR0002942	0.48	4,920	98
W-221	Ciales	Las Delicias	PR0003732	0.32	1,933	166
W-222	Utuado	Mameyes Abajo	PR0003122	0.14	1,367	102
W-223	Florida	Florida Urbano	PR0002732	1.46	10,116	144
W-225	Morovis	Morovis Urbano	PR0002762	2.83	24,610	115
W-226	Vega Alta, Vega Baja	Almirante Norte	PR0003722	0.22	6,562	34
W-227	Camuy, Hatillo, Utuado	Quebrada	PR0002872	1.02	9,832	104
W-228	Camuy, Quebradillas	Quebradillas Urbano	PR0002682	3.00	28,824	104
W-230	Utuado	Roncador	PR0003142	0.44	5,617	78

Table 7. Estimated domestic deliveries, population served, and domestic per capita use in Puerto Rico by Puerto Rico Aqueduct and Sewer Authority Water Service Areas, 2015.—Continued

[Data source: Raw data used to compile and tabulate domestic delivery data were obtained directly from the Puerto Rico Aqueduct and Sewer Authority (PRASA); ID, identifier; PWS, public water system; Mgal/d, million gallons per day; gal/d, gallon per day; WTP, water treatment plant]

PRASA water service area ID	Municipalities served	PRASA water service area name	PWS ID	Domestic deliveries (Mgal/d)	Total population served	Domestic per capita use (gal/d)
W-231	Arecibo, Barceloneta, Manatí, Vega Alta, Vega Baja	Barceloneta Urbano, Sabana Hoyos, Cimarrona, Santana, Manatí East	PR0002822, PR0002832, PR0002722, PR0003832, PR0003262, PR0005587	12.79	108,087	118
W-232	Morovis, Orocovis	Sanamuerto	PR0003022	0.32	4,445	72
W-233	Lares, Utuado	Santa Isabel	PR0003712	0.53	4,222	126
W-234	Utuado	Utuado Urbano	PR0002702	1.69	13,475	125
W-235	Arecibo, Hatillo	Esperanza	PR0002792	0.40	5,302	75
W-236	Morovis	Arraijanes	PR0003822	0.06	213	282
W-237	Arecibo	Bajadero	PR0003222	0.56	1,772	316
W-239	Dorado, Vega Alta	Dorado Urbano	PR0005607	8.91	47,931	186
W-240	Dorado, Vega Alta	Maguayo	PR0005597	1.22	14,461	84
W-241	Utuado	Sabana Grande	PR0003192	0.18	2,121	85
W-242	Ciales	Jaguas Pozas	PR0003802	0.50	5,297	94
W-243	Adjuntas, Lares, Maricao	Indiera Alta	PR0003232	0.28	3,383	83
W-301	Aguas Buenas	Aguas Buenas Urbano	PR0005046	1.80	16,905	106
W-302	Barranquitas	Barrancas Nuevo	PR0004625	0.58	3,560	163
W-303	Barranquitas, Comerio	Barranquitas Urbano	PR0004605	0.57	8,805	65
W-304	Fajardo, Luquillo	Luquillo Urbano	PR0005316	1.58	9,772	162
W-305	Caguas	Caguas Sur	PR0005066	2.92	25,212	116
W-306	Aibonito, Cayey, Cidra	Cayey Urbano	PR0004635	1.74	20,580	85
W-307	Yabucoa	La Grua	PR0005496	1.08	8,170	132
W-309	Juncos, Las Piedras, San Lorenzo	Juncos - Ceiba Sur	PR0005166	1.84	28,203	65
W-310	Aguas Buenas, Caguas, Cidra	Cidra Urbano	PR0004695	2.95	57,637	51
W-311	Naguabo	Cubuy Maizales	PR0005286	0.26	918	283
W-312	Cayey	Culebras	PR0004665	0.21	1,943	108
W-315	Caguas, Gurabo, San Lorenzo	Caguas Norte	PR0005086	8.59	60,609	142
W-316	Ceiba, Fajardo, Luquillo, Naguabo, Rio Grande	Fajardo Ceiba	PR0005306	6.98	50,241	139
W-317	Caguas, Cayey, Cidra, Guayama	Farallón	PR0004925	3.73	47,286	79
W-319	Humacao, Juncos, Las Piedras, Yabucoa	Las Piedras Humacao	PR0005376	2.85	42,672	67
W-320	San Lorenzo	Jagual	PR0005416	0.45	5,542	81
W-321	Rio Grande	Jiménez	PR0005336	0.08	1,478	54
W-322	Aibonito	Aibonito La Plata	PR0004545	1.20	15,313	78
W-324	Barranquitas	Las Bocas	PR0004945	0.50	11,609	43
W-325	Gurabo, Juncos	Gurabo Urbano	PR0005096	2.18	44,074	49
W-327	Rio Grande	Morovis	PR0005486	0.29	2,472	117
W-328	Yabucoa	Guayabota	PR0005186	0.17	5,576	30

Table 7. Estimated domestic deliveries, population served, and domestic per capita use in Puerto Rico by Puerto Rico Aqueduct and Sewer Authority Water Service Areas, 2015.—Continued

[Data source: Raw data used to compile and tabulate domestic delivery data were obtained directly from the Puerto Rico Aqueduct and Sewer Authority (PRASA); ID, identifier; PWS, public water system; Mgal/d, million gallons per day; gal/d, gallon per day; WTP, water treatment plant]

PRASA water service area ID	Municipalities served	PRASA water service area name	PWS ID	Domestic deliveries (Mgal/d)	Total population served	Domestic per capita use (gal/d)
W-329	Ceiba, Culebra, Humacao, Las Piedras, Naguabo, Vieques, Yabucoa	Río Blanco, Vieques, Culebra, Boquerón	PR0005236, PR0005386	7.04	90,270	78
W-330	Loíza, Luquillo, Río Grande	El Yunque	PR0005296	6.67	46,522	143
W-331	Caguas, Juncos, San Lorenzo	San Lorenzo Urbano	PR0005106	3.24	30,098	108
W-333	Aguas Buenas, Barranquitas, Cidra, Comerío, Naranjito	Comerío Urbano	PR0004705	2.73	25,834	106
W-334	Aibonito	Aibonito Urbano	PR0004955	0.47	6,446	73
W-335	Yabucoa	Yabucoa Urbano	PR0005196	1.61	12,044	134
W-336	Aibonito, Cayey	Cuyon	PR0004555	0.17	957	178
W-341	Luquillo	Paisaje del Lago	PR0005466	0.09	389	231
W-344	San Lorenzo	Espino	PR0005136	0.47	4,549	103
W-401	Ciales, Orocovis, Villalba	Aceitunas	PR0004654	2.57	15,607	165
W-402	Adjuntas	Garzas	PR0004584	0.45	5,655	80
W-403	Adjuntas	Adjuntas Urbano	PR0004204	0.67	3,866	173
W-404	Villalba	Apeadero	PR0003944	0.18	1,634	110
W-405	Coamo	Coamo Urbano	PR0003914	0.59	4,449	133
W-406	Juana Díaz, Ponce	Coto Laurel	PR0004524	1.24	10,731	116
W-407	Ciales, Orocovis	Matrullas	PR0004564	0.52	5,021	104
W-408	Adjuntas, Ponce	Guaraguao	PR0004114	0.15	5,571	27
W-409	Guayama	Guayama Urbano	PR0004745	2.88	34,549	83
W-410	Peñuelas	Guayanés	PR0004324	0.53	2,125	249
W-411	Adjuntas	Yahuecas, Guilarte	PR0004494, PR0004684	0.49	5,442	90
W-412	Ponce	Hogares Seguros	PR0004514	0.07	934	75
W-413	Salinas	Cocos	PR0004895	0.99	13,625	73
W-414	Peñuelas	Jagua Ceiba	PR0004624	0.18	4,957	36
W-419	Guayanilla, Peñuelas	Malpaso	PR0004464	0.15	3,062	49
W-421	Maunabo, Patillas	Matuyas	PR0004825	0.04	1,058	38
W-422	Barranquitas, Coamo, Corozal, Morovis, Orocovis	Orocovis Urbano	PR0004044	2.79	22,230	126
W-423	Arroyo, Guayama, Patillas	Patillas Urbano	PR0004835	3.75	38,115	98
W-424	Juana Díaz	Experimental	PR0004604	0.22	9,638	23
W-425	Guayanilla	Jaguas Pasto	PR0004244	0.16	1,292	124
W-426	Guayanilla, Peñuelas	Peñuelas Urbano	PR0004324	1.00	10,254	98
W-427	Peñuelas, Ponce	Ponce Urbano	PR0003824	14.19	118,391	120
W-428	Guayanilla, Maricao, Yauco	Duey	PR0004234	0.44	4,385	100
W-429	Yauco	Rancheras	PR0004334	0.09	2,977	30
W-430	Ponce	Real Anón	PR0004454	0.34	4,506	75
W-431	Ponce	Cerrillos	PR0004634	0.67	9,145	73

Table 7. Estimated domestic deliveries, population served, and domestic per capita use in Puerto Rico by Puerto Rico Aqueduct and Sewer Authority Water Service Areas, 2015.—Continued

[Data source: Raw data used to compile and tabulate domestic delivery data were obtained directly from the Puerto Rico Aqueduct and Sewer Authority (PRASA); ID, identifier; PWS, public water system; Mgal/d, million gallons per day; gal/d, gallon per day; WTP, water treatment plant]

PRASA water service area ID	Municipalities served	PRASA water service area name	PWS ID	Domestic deliveries (Mgal/d)	Total population served	Domestic per capita use (gal/d)
W-432	Peñuelas	Rucio	PR0004614	0.18	1,532	117
W-435	Juana Diaz, Villalba	Regional Villalba Toa Vaca	PR0004664	4.95	24,712	200
W-436	Guánica, Guayanilla, Sabana Grande, Yauco	Yauco	PR0004314	2.83	33,646	84
W-437	Juana Diaz, Villalba	Agustinillo	PR0004644	0.22	4,536	49
W-438	Guánica	Arenas	PR0004374	0.35	974	359
W-439	Juana Díaz, Ponce	Aruz	PR0003834	0.42	6,268	67
W-442	Guánica, Lajas	Ensenada	PR0004084	0.71	6,498	109
W-443	Guánica	Guanica Urbano	PR0004074	1.22	8,844	138
W-444	Guayanilla, Peñuelas	Guayanilla Urbano	PR0004054	0.84	7,623	110
W-445	Guayama, Salinas	Salinas Urbano	PR0004885	1.02	14,314	71
W-447	Guayanilla	Piedras Blancas	PR0004474	0.49	3,044	161
W-449	Juana Diaz	Amelia	PR0004344	0.39	3,658	107
W-452	Aibonito, Coamo, Juana Diaz, Santa Isabel	Santa Isabel Urbano	PR0003904	3.88	55,992	69
W-454	Juana Diaz	Jacaguas	PR0004534	0.37	3,696	100
W-455	Adjuntas	Saltillo Vaca	PR0004134	0.12	2,086	58
W-457	Guayanilla, Yauco	Consejo	PR0004484	0.40	1,139	351
W-458	Guayanilla	Quebrada, Deportivo	PR0004444	0.42	4,215	100
W-459	Patillas	Jacaboas	PR0004845	0.83	2,820	294
W-460	Adjuntas, Ponce	La Mocha	PR0004214	0.03	798	38
W-461	Maunabo	Maunabo Urbano	PR0004815	1.24	11,989	103
W-464	Salinas	Coqui	PR0004915	0.25	3,036	82
W-501	Aguadilla, Isabela, Moca	Isabela	PR0002672	3.81	46,640	82
W-502	Aguada, Aguadilla, Moca, Rincón	Aguadilla Urbano, Rafael Matías	PR0003293, PR0003294	17.96	130,732	137
W-503	Añasco, Cabo Rojo, Hormigueros, Mayagüez, Moca, Rincón, San Germán	Hormigueros, Mayagüez Urbano	PR0003383, PR0003283	15.00	155,606	96
W-504	Moca	Plata I y II, Ramón Valentín	PR0003296	0.32	4,973	64
W-505	Cabo Rojo	Cabo Rojo	PR0003373	1.00	8,673	115
W-507	San Germán	Caín Alto, Capriles	PR0003533	0.24	4,997	48
W-508	Hormigueros, Mayagüez	El Rosario	PR0003423	0.18	1,320	136
W-509	Isabela, San Sebastián	Lago Guajataca	PR0003772	0.88	8,015	110
W-510	Mayagüez	Ponce de León, Las Vegas	PR0003643, PR0003495	1.75	11,462	153
W-512	Cabo Rojo, Lajas, San Germán	Lajas Urbano	PR0003343	3.51	41,802	84
W-513	Las Marías, Maricao, Mayagüez	Las Marías	PR0003363	1.17	9,262	126

Table 7. Estimated domestic deliveries, population served, and domestic per capita use in Puerto Rico by Puerto Rico Aqueduct and Sewer Authority Water Service Areas, 2015.—Continued

[Data source: Raw data used to compile and tabulate domestic delivery data were obtained directly from the Puerto Rico Aqueduct and Sewer Authority (PRASA); ID, identifier; PWS, public water system; Mgal/d, million gallons per day; gal/d, gallon per day; WTP, water treatment plant]

PRASA water service area ID	Municipalities served	PRASA water service area name	PWS ID	Domestic deliveries (Mgal/d)	Total population served	Domestic per capita use (gal/d)
W-514	Lajas, Maricao, Sabana Grande, San Germán	Sabana Grande Urbano, Monte del Estado	PR0003333, PR0003523	2.60	26,313	99
W-515	Las Marias, Maricao, San Germán	Maricao Urbano	PR0003353	0.38	4,469	85
W-516	San Sebastián	San Sebastián Urbano, Wilfredo Valentín	PR0003303, PR0003435	3.66	27,895	131
W-517	San Germán	El Japones	PR0003425	0.10	991	101
W-519	Hormigueros	Lavadero	PR0003453	0.23	2,071	111
W-520	Hormigueros, San Germán	Duey	PR0003553	0.50	4,455	112
W-524	Mayagüez	Consumo	PR0003403	0.11	1,362	81
W-525	San Germán	Pedregal	PR0003633	0.08	552	145
Total				**338.35**	**3,469,474**	**98**

[1]Carolina WTP is a municipal plant.

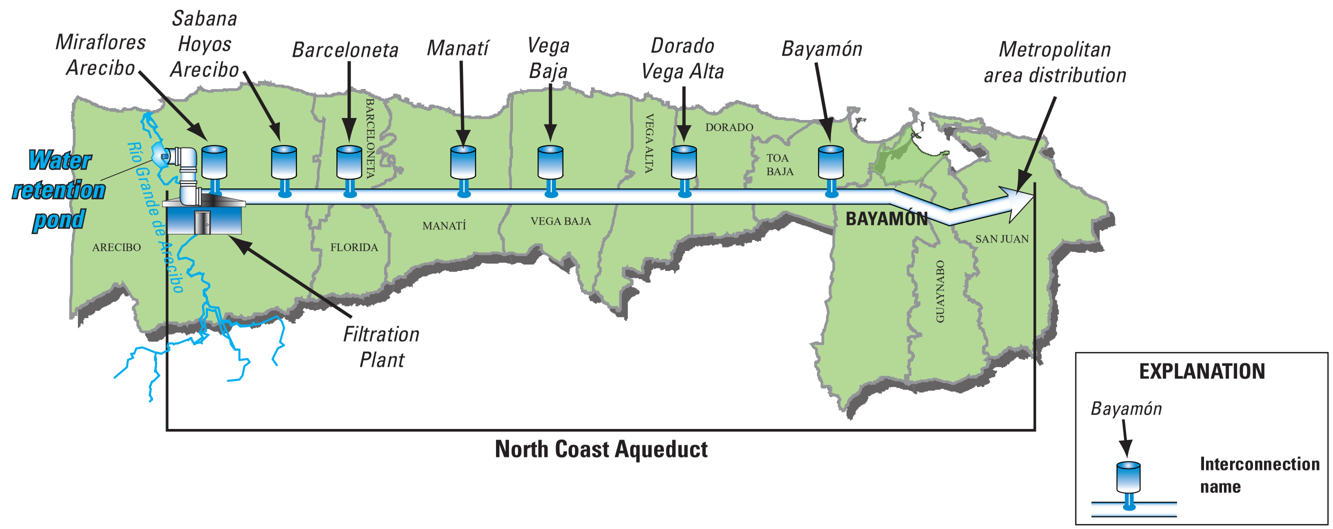
Irrigation Water Use and Withdrawals

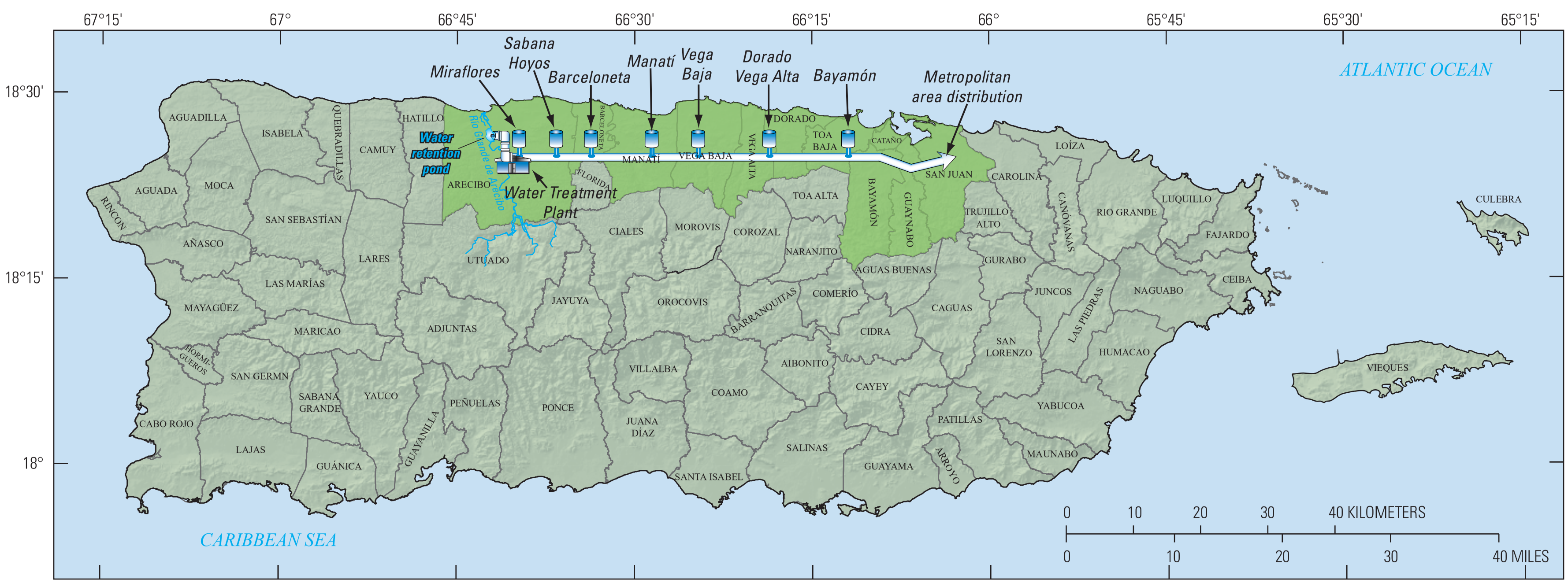
As described in the "Data Compilation Procedures-Irrigation Water Use and Withdrawals" section, total irrigation water use at each farm was assumed to be equal to the crop consumptive use estimated based on a soil moisture model (table 9). Self-supplied withdrawals from wells (that is, groundwater withdrawals) were estimated by subtracting estimated surface-water deliveries from irrigation districts from the total water use after aggregation to the municipality level.

During 2015, the estimated irrigation water use in Puerto Rico was 79.1 Mgal/d for all sources. This estimate includes 1.5 Mgal/d from wastewater reuse (table 9); therefore, withdrawals for irrigation were reported as 77.6 Mgal/d (79.1 minus 1.5). From this 79.1 Mgal/d total, 3.5 Mgal/d was for golf course irrigation, while the remaining 75.6 Mgal/d was for crop irrigation. Total water use by crop was 22.5 Mgal/d for plantains and bananas, 19.0 Mgal/d for grasses for pasture and hay, 11.4 Mgal/d for vegetables, 8.1 Mgal/d for corn (seed), 8.0 Mgal/d for mangoes, and 4.4 Mgal/d for tomatoes. The sum of the total water use for the different crops equals 73.4 Mgal/d, which is 2.2 Mgal/d lower than the 75.6 Mgal/d crop irrigation reported earlier. This 2.2-Mgal/d difference can be attributed to five municipalities where the reported surface-water deliveries exceed the estimated total water use from the soil moisture model. As previously discussed for such cases, it was assumed that the total water use equaled the reported surface-water withdrawals and superseded our estimates from the soil moisture model. This difference between reported and simulated total water use can be attributed to uncertainties in the soil moisture model due to the limited data available for validation.

Freshwater sources included surface-water deliveries from irrigation districts estimated at 34.1 Mgal/d (44 percent) and groundwater withdrawals estimated at 43.5 Mgal/d (56 percent) (table 9). Wastewater obtained from municipal facilities accounted for 1.5 Mgal/d applied to golf courses. About 37,000 acres were irrigated in 2015, including the lands cultivated for crop production and maintained for golf course activities. In 1995, the number of acres irrigated using more water-efficient irrigation systems began to increase, which continued in 2015. About 25,000 acres were irrigated by micro-irrigation systems, accounting for 68 percent of the total irrigated acres. Micro-irrigation systems directly wet only the soil surface in the immediate vicinity of the plant's root zone. About 11,000 acres (31 percent) were irrigated by sprinkler systems, whereby water is applied by means of perforated pipes or nozzles operated under pressure to form a spray pattern. About 500 acres (1 percent) were irrigated using surface (flood) irrigation systems, which cover the entire soil surface with ponded water. About 72 percent of all irrigation use occurred in five municipalities: Santa Isabel, Salinas, Lajas, Juana Díaz, and Guánica (table 9). These municipalities, located along the south coast of Puerto Rico, typically are in areas where average annual rainfall (about 40–45 inches [in.]) is less than the normal average annual rainfall in Puerto Rico (70–72 in.) (National Oceanic and Atmospheric Administration, 2017). In 2015, these municipalities received 37 in. of rainfall, which was about 15 in. less annual rainfall than the total accumulated for mainland Puerto Rico (52 in.). This necessitated the application of supplemental water to support crops in this part of Puerto Rico.

Interconnection name	Water transferred (million gallons per day)
Miraflores-Arecibo	5.31
Sabana Hoyos-Arecibo	2.41
Barceloneta	1.79
Manatí	5.74
Vega Baja	3.71
Dorado/Vega Alta	12.18
Bayamón	75.51





Base modified from the U.S. Geological Survey digital data

Figure 5. Locations of North Coast Aqueduct interconnections and water transferred, in million gallons per day (Mgal/d), 2015.

Table 8. Estimated domestic self-supplied withdrawals, public-supply deliveries, population served, and domestic per capita use in Puerto Rico by municipality, 2015.

[Data source: U.S. Geological Survey; Mgal/d, million gallons per day; gal/d, gallon per day]

Municipality	Self-supplied use			Public-supply deliveries		Total use		
	Population	Groundwater withdrawals (Mgal/d)	Per capita use (gal/d)	Population	Deliveries (Mgal/d)	Population	Withdrawals and deliveries (Mgal/d)	Per capita use (gal/d)
Adjuntas	211	0.02	80	18,368	1.80	18,579	1.82	98
Aguada	0	0.00	0	39,530	5.43	39,530	5.43	137
Aguadilla	616	0.07	121	55,188	7.51	55,804	7.58	136
Aguas Buenas	0	0.00	0	26,915	2.40	26,915	2.40	89
Aibonito	0	0.00	0	24,040	1.92	24,040	1.92	80
Añasco	0	0.00	0	27,989	2.70	27,989	2.70	96
Arecibo	76	0.01	114	89,572	12.64	89,648	12.65	141
Arroyo	0	0.00	0	18,546	1.82	18,546	1.82	98
Barceloneta	0	0.00	0	24,650	3.08	24,650	3.08	125
Barranquitas	0	0.00	0	29,323	2.26	29,323	2.26	77
Bayamón	0	0.00	0	189,159	14.90	189,159	14.90	79
Cabo Rojo	0	0.00	0	49,762	4.95	49,762	4.95	99
Caguas	0	0.00	0	134,481	13.90	134,481	13.90	103
Camuy	0	0.00	0	32,995	3.11	32,995	3.11	94
Canóvanas	0	0.00	0	46,972	3.72	46,972	3.72	79
Carolina	0	0.00	0	161,884	13.25	161,884	13.25	82
Cataño	0	0.00	0	25,641	2.04	25,641	2.04	80
Cayey	0	0.00	0	45,490	3.78	45,490	3.78	83
Ceiba	0	0.00	0	12,218	1.49	12,218	1.49	122
Ciales	0	0.00	0	17,349	2.16	17,349	2.16	125
Cidra	356	0.02	53	40,869	2.45	41,225	2.47	60
Coamo	0	0.00	0	39,862	3.33	39,862	3.33	84
Comerío	0	0.00	0	19,983	2.07	19,983	2.07	104
Corozal	0	0.00	0	35,037	3.19	35,037	3.19	91
Culebra	0	0.00	0	1,806	0.14	1,806	0.14	78
Dorado	256	0.04	150	37,622	5.65	37,878	5.69	150
Fajardo	0	0.00	0	33,102	4.60	33,102	4.60	139
Florida	0	0.00	0	12,188	1.66	12,188	1.66	136
Guánica	0	0.00	0	17,386	2.36	17,386	2.36	136
Guayama	0	0.00	0	42,721	3.61	42,721	3.61	85
Guayanilla	0	0.00	0	19,604	2.37	19,604	2.37	121
Guaynabo	0	0.00	0	90,879	7.24	90,879	7.24	80
Gurabo	0	0.00	0	47,265	3.75	47,265	3.75	79
Hatillo	0	0.00	0	41,047	5.23	41,047	5.23	127
Hormigueros	0	0.00	0	16,478	1.62	16,478	1.62	98
Humacao	0	0.00	0	54,827	4.18	54,827	4.18	76
Isabela	0	0.00	0	43,398	3.59	43,398	3.59	83
Jayuya	0	0.00	0	15,328	1.80	15,328	1.80	117
Juana Díaz	41	0.01	160	48,019	5.79	48,060	5.80	121

Table 8. Estimated domestic self-supplied withdrawals, public-supply deliveries, population served, and domestic per capita use in Puerto Rico by municipality, 2015.—Continued

[Data source: U.S. Geological Survey; Mgal/d, million gallons per day; gal/d, gallon per day]

Municipality	Self-supplied use			Public-supply deliveries		Total use		
	Population	Groundwater withdrawals (Mgal/d)	Per capita use (gal/d)	Population	Deliveries (Mgal/d)	Population	Withdrawals and deliveries (Mgal/d)	Per capita use (gal/d)
Juncos	0	0.00	0	39,754	2.40	39,754	2.40	60
Lajas	0	0.00	0	23,935	2.04	23,935	2.04	85
Lares	84	0.01	107	27,288	3.10	27,372	3.11	114
Las Marías	0	0.00	0	8,881	1.11	8,881	1.11	125
Las Piedras	0	0.00	0	38,290	2.59	38,290	2.59	68
Loíza	0	0.00	0	27,251	2.27	27,251	2.27	83
Luquillo	0	0.00	0	19,004	2.92	19,004	2.92	154
Manatí	0	0.00	0	40,700	4.75	40,700	4.75	117
Maricao	0	0.00	0	5,903	0.55	5,903	0.55	93
Maunabo	0	0.00	0	11,315	1.11	11,315	1.11	98
Mayagüez	0	0.00	0	79,510	8.35	79,510	8.35	105
Moca	0	0.00	0	37,746	4.59	37,746	4.59	122
Morovis	0	0.00	0	31,866	3.73	31,866	3.73	117
Naguabo	0	0.00	0	26,632	2.50	26,632	2.50	94
Naranjito	0	0.00	0	29,181	2.68	29,181	2.68	92
Orocovis	0	0.00	0	21,957	2.55	21,957	2.55	116
Patillas	0	0.00	0	17,819	2.30	17,819	2.30	129
Peñuelas	0	0.00	0	21,731	2.08	21,731	2.08	96
Ponce	0	0.00	0	149,028	16.48	149,028	16.48	111
Quebradillas	0	0.00	0	24,605	2.56	24,605	2.56	104
Rincón	0	0.00	0	14,551	1.77	14,551	1.77	122
Río Grande	0	0.00	0	51,725	6.59	51,725	6.59	127
Sabana Grande	0	0.00	0	23,555	2.33	23,555	2.33	99
Salinas	0	0.00	0	29,351	2.14	29,351	2.14	73
San Germán	0	0.00	0	32,976	2.79	32,976	2.79	85
San Juan	0	0.00	0	355,074	28.30	355,074	28.30	80
San Lorenzo	0	0.00	0	38,721	4.00	38,721	4.00	103
San Sebastián	0	0.00	0	39,007	4.90	39,007	4.90	126
Santa Isabel	0	0.00	0	22,517	1.56	22,517	1.56	69
Toa Alta	0	0.00	0	74,368	5.93	74,368	5.93	80
Toa Baja	0	0.00	0	82,065	6.54	82,065	6.54	80
Trujillo Alto	0	0.00	0	69,615	5.55	69,615	5.55	80
Utuado	1,793	0.21	119	28,495	3.24	30,288	3.45	114
Vega Alta	0	0.00	0	38,640	5.91	38,640	5.91	153
Vega Baja	1,275	0.13	102	53,517	5.45	54,792	5.58	102
Vieques	0	0.00	0	8,950	0.70	8,950	0.70	78
Villalba	0	0.00	0	23,697	3.75	23,697	3.75	158
Yabucoa	0	0.00	0	35,082	3.57	35,082	3.57	102
Yauco	0	0.00	0	37,679	3.18	37,679	3.18	84
Total	**4,708**	**0.52**	**110**	**3,469,474**	**338.35**	**3,474,182**	**338.87**	**98**

Table 9. Estimated irrigation water use, consumptive use, cultivated and (or) irrigated acres, principal type of crop, and irrigation methods in Puerto Rico by source of water and municipality, 2015.

[Data Source: U.S. Geological Survey; Mgal/d, million gallons per day; TA, thousands of acres; SW, surface water; GW, groundwater; MI, micro-irrigation]

Municipality	Irrigation water use (Mgal/d)				Consumptive use (Mgal/d)	Cultivated and irrigated area (TA)	Principal type of crop	Area of irrigation methods (TA)		
	SW withdrawal	GW withdrawal	Reuse	Total				MI	Sprinkler	Surface
Aguada	0.40	0.00	0.00	0.40	0.40	0.611	Grasses	0.000	0.611	0.000
Aguadilla	0.54	0.00	0.00	0.54	0.54	0.993	Vegetables, grasses	0.695	0.298	0.000
Arroyo	0.59	0.00	0.00	0.59	0.59	0.183	Grasses, vegetables	0.081	0.103	0.000
Bayamón	0.00	0.03	0.00	0.03	0.03	0.026	Grasses	0.000	0.026	0.000
Cabo Rojo	0.57	0.72	0.00	1.29	1.29	1.021	Grasses	0.000	1.021	0.000
Caguas	0.00	0.14	0.00	0.14	0.14	0.083	Grasses	0.000	0.083	0.000
Coamo	0.00	0.64	0.00	0.64	0.64	0.412	Grasses	0.000	0.412	0.000
Dorado	0.00	0.00	0.58	0.58	0.58	0.366	Grasses	0.000	0.366	0.000
Fajardo	0.00	0.11	0.00	0.11	0.11	0.072	Grasses	0.000	0.072	0.000
Guánica	3.88	2.06	0.00	5.94	5.94	2.159	Vegetables, bananas, grasses, rice	1.065	0.612	0.481
Guayama	1.86	0.63	0.00	2.49	2.49	1.560	Bananas, grasses, vegetables, and seeds	1.372	0.187	0.000
Guayanilla	0.00	3.57	0.00	3.57	3.57	1.069	Bananas, grasses, vegetables, and seeds	0.866	0.203	0.000
Guaynabo	0.00	0.03	0.00	0.03	0.03	0.030	Grasses	0.000	0.030	0.000
Gurabo	0.00	0.04	0.00	0.04	0.04	0.027	Grasses	0.000	0.027	0.000
Humacao	0.00	0.00	0.51	0.51	0.51	0.199	Grasses	0.000	0.199	0.000
Isabela	1.12	0.00	0.00	1.12	1.12	0.484	Vegetables, grasses	0.421	0.063	0.000
Juana Díaz	4.02	5.31	0.00	9.33	9.33	4.571	Mango, seeds, grasses, bananas	4.251	0.320	0.000
Juncos	0.00	0.03	0.00	0.03	0.03	0.017	Grasses	0.000	0.017	0.000
Lajas	7.70	5.27	0.00	12.97	12.97	4.674	Grasses, vegetables	1.823	2.851	0.000
Luquillo	0.00	0.00	0.03	0.03	0.03	0.025	Grasses	0.000	0.025	0.000
Manatí	0.00	0.07	0.00	0.07	0.07	0.486	Coffee	0.486	0.000	0.000
Maunabo	0.00	0.71	0.00	0.71	0.71	0.414	Plantains	0.414	0.000	0.000
Moca	0.00	0.10	0.00	0.10	0.10	0.200	Vegetables	0.200	0.000	0.000
Patillas	0.67	0.06	0.00	0.73	0.73	0.396	Grasses	0.000	0.396	0.000
Peñuelas	0.00	0.21	0.00	0.21	0.21	0.124	Grasses	0.000	0.124	0.000
Ponce	0.00	1.91	0.00	1.91	1.91	1.120	Grasses	0.000	1.120	0.000
Río Grande	0.00	0.13	0.41	0.54	0.54	0.374	Grasses	0.000	0.374	0.000
Sabana Grande	2.02	0.00	0.00	2.02	2.02	0.472	Vegetables, bananas	0.472	0.000	0.000
Salinas	5.10	7.33	0.00	12.43	12.43	4.453	Bananas, vegetables, sorghum, papaya, pumpkins, seeds, grasses	3.340	1.113	0.000

Table 9. Estimated irrigation water use, consumptive use, cultivated and (or) irrigated acres, principal type of crop, and irrigation methods in Puerto Rico by source of water and municipality, 2015.—Continued

[Data Source: U.S. Geological Survey; Mgal/d, million gallons per day; TA, thousands of acres; SW, surface water; GW, groundwater; MI, micro-irrigation]

Municipality	Irrigation water use (Mgal/d)				Consumptive use (Mgal/d)	Cultivated and irrigated area (TA)	Principal type of crop	Area of irrigation methods (TA)		
	SW withdrawal	GW withdrawal	Reuse	Total				MI	Sprinkler	Surface
Santa Isabel	5.63	10.30	0.00	15.93	15.93	7.876	Bananas, vegetables, mango, seeds, tomatoes, grasses, palms	7.640	0.236	0.000
Yabucoa	0.00	1.97	0.00	1.97	1.97	1.309	Plantains, grasses	1.021	0.288	0.000
Yauco	0.00	2.11	0.00	2.11	2.11	0.726	Bananas	0.726	0.000	0.000
Total	**34.10**	**43.48**	**1.53**	**79.11**	**79.11**	**36.530**		**24.873**	**11.176**	**0.481**

Livestock Water Withdrawals

Data on livestock water use, specifically, water associated with livestock watering, feedlots, daily operations, and other on-farm needs were compiled by municipality (table 10). During 2015, withdrawals for livestock water use were estimated at about 6 Mgal/d, less than 1 percent of the total freshwater withdrawals. Fresh groundwater was the source for about 73 percent of total self-supplied livestock water-use withdrawals. The municipalities of Hatillo, Arecibo, and Yabucoa together accounted for 28 percent of total livestock withdrawals in 2015 (table 10). Estimated total withdrawals for livestock decreased 25 percent from 2010 to 2015.

Industrial Water Withdrawals

Industrial withdrawals provide water for such purposes as fabricating, processing, washing, diluting, cooling, or transporting a product; incorporating water into a product; or for sanitation needs within the manufacturing facility. In this report, industrial use refers to self-supplied industrial fresh groundwater withdrawals only.

In 2015, industrial self-supplied groundwater withdrawals were estimated at 3.7 Mgal/d. Industrial groundwater withdrawals were less than 1 percent of the total freshwater withdrawals. For the municipality of Barceloneta, fresh groundwater withdrawals were estimated at 1.3 Mgal/d, 35 percent of the total industrial groundwater withdrawals for Puerto Rico. Industrial self-supplied withdrawals from groundwater sources in Puerto Rico were compiled by municipality (table 11). The amount of groundwater withdrawn for industrial uses decreased 15 percent from 2010 to 2015.

Mining Water Withdrawals

Mining water use is water used for the extraction of minerals that may be in the form of solids, liquids, or gases. Mining withdrawals were compiled by municipality (table 12). During 2015, withdrawals for mining use were estimated at 2 Mgal/d, or less than 1 percent of the total freshwater withdrawals. Fresh groundwater was the source for 91 percent of total self-supplied mining water-use withdrawals. The municipalities of Humacao, Guayama, Ponce, Bayamón and Manatí together accounted for 1.34 Mgal/d or 66 percent of total mining withdrawals in 2015 (table 12). Estimated total withdrawals for mining increased 5 percent from 2010 to 2015.

Thermoelectric-Power Water Withdrawals

Although some water is converted to steam to power turbines and generate electricity, most water for thermoelectric power is used during the cooling process. In 2015, Puerto Rico had four thermoelectric power facilities in the municipalities of Cataño, Guayanilla, Salinas, and San Juan, equipped with once-through cooling systems, and two power facilities in the municipalities of Guayama and Peñuelas equipped with recirculating cooling systems.

Withdrawals and public-supply water deliveries for thermoelectric power in 2015 totaled 1,707 Mgal/d. Thermoelectric-power withdrawals were compiled by source of water and by municipality for 2015 (table 13). Saline surface-water withdrawals (seawater) accounted for 1,701 Mgal/d or 99.7 percent of total saline surface-water withdrawals for all uses in 2015. About 1,689 Mgal/d of saline water was withdrawn by thermoelectric power facilities equipped with

Table 10. Estimated livestock water withdrawals in Puerto Rico by source of water and municipality, 2015.

[Data source: U.S. Geological Survey, Caribbean-Florida Water Science Center; Mgal/d, million gallons per day]

Municipality	Water withdrawals (Mgal/d)		
	Groundwater	Surface water	Total
Adjuntas	0.00	0.02	0.02
Aguada	0.05	0.00	0.05
Aguadilla	0.05	0.00	0.05
Aguas Buenas	0.00	0.02	0.02
Aibonito	0.17	0.00	0.17
Añasco	0.04	0.00	0.04
Arecibo	0.63	0.00	0.63
Arroyo	0.00	0.00	0.00
Barceloneta	0.02	0.00	0.02
Barranquitas	0.00	0.10	0.10
Bayamón	0.00	0.00	0.00
Cabo Rojo	0.13	0.00	0.13
Caguas	0.09	0.00	0.09
Camuy	0.05	0.00	0.05
Canóvanas	0.03	0.00	0.03
Carolina	0.00	0.06	0.06
Cataño	0.00	0.00	0.00
Cayey	0.05	0.00	0.05
Ceiba	0.00	0.04	0.04
Ciales	0.05	0.00	0.05
Cidra	0.00	0.09	0.09
Coamo	0.27	0.00	0.27
Comerio	0.00	0.05	0.05
Corozal	0.00	0.09	0.09
Culebra	0.00	0.00	0.00
Dorado	0.03	0.00	0.03
Fajardo	0.00	0.04	0.04
Florida	0.04	0.00	0.04
Guánica	0.03	0.00	0.03
Guayama	0.01	0.00	0.01
Guayanilla	0.03	0.00	0.03
Guaynabo	0.00	0.00	0.00
Gurabo	0.05	0.00	0.05
Hatillo	0.65	0.00	0.65
Hormigueros	0.04	0.00	0.04
Humacao	0.13	0.00	0.13
Isabela	0.18	0.00	0.18
Jayuya	0.00	0.00	0.00
Juana Díaz	0.03	0.00	0.03
Juncos	0.16	0.00	0.16
Lajas	0.16	0.00	0.16
Lares	0.00	0.02	0.02
Las Marías	0.00	0.01	0.01
Las Piedras	0.00	0.11	0.11
Loiza	0.00	0.03	0.03
Luquillo	0.00	0.01	0.01
Manatí	0.06	0.00	0.06
Maricao	0.00	0.00	0.00
Maunabo	0.00	0.01	0.01
Mayagüez	0.05	0.00	0.05
Moca	0.00	0.13	0.13
Morovis	0.00	0.07	0.07
Naguabo	0.00	0.13	0.13
Naranjito	0.00	0.08	0.08
Orocovis	0.00	0.05	0.05
Patillas	0.04	0.00	0.04
Peñuelas	0.02	0.00	0.02
Ponce	0.04	0.00	0.04
Quebradillas	0.20	0.00	0.20
Rincón	0.03	0.00	0.03
Rio Grande	0.00	0.03	0.03
Sabana Grande	0.02	0.00	0.02
Salinas	0.03	0.00	0.03
San Germán	0.06	0.00	0.06
San Juan	0.00	0.00	0.00
San Lorenzo	0.00	0.05	0.05
San Sebastián	0.00	0.26	0.26
Santa Isabel	0.01	0.00	0.01
Toa Alta	0.00	0.03	0.03
Toa Baja	0.00	0.00	0.00
Trujillo Alto	0.00	0.01	0.01
Utuado	0.00	0.04	0.04
Vega Alta	0.03	0.00	0.03
Vega Baja	0.06	0.00	0.06
Vieques	0.01	0.00	0.01
Villalba	0.00	0.02	0.02
Yabucoa	0.37	0.00	0.37
Yauco	0.03	0.00	0.03
Total	**4.23**	**1.60**	**5.83**

Table 11. Estimated industrial water withdrawals in Puerto Rico by municipality, 2015.

[Data source: Raw data used to compile and tabulate water withdrawal data were obtained directly from State agencies. Mgal/d, million gallons per day]

Municipality	Self-supplied fresh groundwater withdrawals
Aguada	0.07
Aguadilla	0.11
Aibonito	0.02
Arecibo	0.13
Barceloneta	1.29
Barranquitas	0.02
Bayamón	0.05
Cabo Rojo	0.14
Caguas	0.06
Canóvanas	0.01
Cayey	0.16
Cidra	0.04
Dorado	0.03
Fajardo	0.08
Guánica	0.00
Guayama	0.21
Guaynabo	0.07
Gurabo	0.01
Hatillo	0.08
Hormigueros	0.04
Humacao	0.12
Isabela	0.04
Jayuya	0.07
Juncos	0.15
Las Piedras	0.07
Luquillo	0.01
Manatí	0.18
Maricao	0.03
Mayagüez	0.02
Ponce	0.05
Quebradillas	0.00
San Juan	0.01
Santa Isabel	0.03
Toa Alta	0.00
Toa Baja	0.23
Vega Baja	0.03
Yabucoa	0.01
Yauco	0.00
Total	**3.67**

Table 12. Estimated mining water withdrawals in Puerto Rico by source of water and municipality, 2015.

[Data source: U.S. Geological Survey, Caribbean-Florida Water Science Center; Mgal/d, million gallons per day]

Municipality	Water withdrawals (Mgal/d)		
	Groundwater	Surface water	Total
Adjuntas	0.00	0.00	0.00
Aguada	0.00	0.00	0.00
Aguadilla	0.06	0.02	0.08
Aguas Buenas	0.00	0.00	0.00
Aibonito	0.00	0.00	0.00
Añasco	0.00	0.00	0.00
Arecibo	0.10	0.00	0.10
Arroyo	0.00	0.00	0.00
Barceloneta	0.00	0.00	0.00
Barranquitas	0.00	0.00	0.00
Bayamón	0.24	0.00	0.24
Cabo Rojo	0.00	0.00	0.00
Caguas	0.00	0.00	0.00
Camuy	0.00	0.00	0.00
Canóvanas	0.00	0.00	0.00
Carolina	0.00	0.00	0.00
Cataño	0.00	0.00	0.00
Cayey	0.00	0.00	0.00
Ceiba	0.00	0.00	0.00
Ciales	0.00	0.00	0.00
Cidra	0.00	0.00	0.00
Coamo	0.00	0.00	0.00
Comerío	0.00	0.00	0.00
Corozal	0.00	0.00	0.00
Culebra	0.00	0.00	0.00
Dorado	0.00	0.00	0.00
Fajardo	0.04	0.00	0.04
Florida	0.00	0.00	0.00
Guánica	0.00	0.00	0.00
Guayama	0.25	0.03	0.28
Guayanilla	0.00	0.00	0.00
Guaynabo	0.00	0.00	0.00
Gurabo	0.00	0.00	0.00
Hatillo	0.00	0.00	0.00
Hormigueros	0.00	0.00	0.00
Humacao	0.32	0.00	0.32
Isabela	0.00	0.00	0.00
Jayuya	0.00	0.00	0.00
Juana Díaz	0.00	0.00	0.00
Juncos	0.00	0.00	0.00
Lajas	0.00	0.00	0.00
Lares	0.00	0.00	0.00
Las Marías	0.00	0.00	0.00
Las Piedras	0.00	0.00	0.00
Loíza	0.00	0.00	0.00
Luquillo	0.00	0.00	0.00
Manatí	0.22	0.00	0.22
Maricao	0.00	0.00	0.00
Maunabo	0.00	0.00	0.00
Mayagüez	0.06	0.03	0.09
Moca	0.00	0.00	0.00
Morovis	0.00	0.00	0.00
Naguabo	0.00	0.00	0.00
Naranjito	0.00	0.00	0.00
Orocovis	0.00	0.00	0.00
Patillas	0.00	0.00	0.00
Peñuelas	0.00	0.00	0.00
Ponce	0.28	0.00	0.28
Quebradillas	0.00	0.00	0.00
Rincón	0.00	0.00	0.00
Río Grande	0.00	0.00	0.00
Sabana Grande	0.00	0.00	0.00
Salinas	0.00	0.00	0.00
San Germán	0.00	0.00	0.00
San Juan	0.04	0.02	0.06
San Lorenzo	0.00	0.00	0.00
San Sebastián	0.00	0.00	0.00
Santa Isabel	0.14	0.06	0.20
Toa Alta	0.00	0.00	0.00
Toa Baja	0.00	0.00	0.00
Trujillo Alto	0.00	0.00	0.00
Utuado	0.00	0.00	0.00
Vega Alta	0.00	0.00	0.00
Vega Baja	0.03	0.00	0.03
Vieques	0.00	0.00	0.00
Villalba	0.00	0.00	0.00
Yabucoa	0.00	0.00	0.00
Yauco	0.06	0.02	0.08
Total	**1.84**	**0.18**	**2.02**

Table 13. Estimated withdrawals and deliveries from public-supply water by thermoelectric power facilities, by source of water and municipality in Puerto Rico, 2015.

[Data source: Raw data used to compile and tabulate water use and withdrawal data were obtained directly from the Puerto Rico Electric and Power Authority. Mgal/d, million gallons per day; GWh, gigawatthour]

Municipality	Cooling system type	Fresh groundwater withdrawals (Mgal/d)	Fresh surface-water withdrawals (Mgal/d)	Total freshwater withdrawals (Mgal/d)	Saline surface-water withdrawals (Mgal/d)	Public supply deliveries (Mgal/d)	Withdrawals and deliveries (Mgal/d)	Net power generation (GWh)	Reclaimed wastewater (Mgal/d)
Cataño	Once through	0.00	0.00	0.00	192.58	0.11	192.69	1,479.00	0.00
Guayama	Recirculating	0.19	1.56	1.75	0.00	0.00	1.75	3,260.00	2.69
Guayanilla	Once through	0.93	0.24	1.17	572.35	0.00	573.52	1,127.00	0.00
Peñuelas	Recirculating	0.00	1.03	1.03	11.97	0.00	13.00	2,936.00	0.00
Salinas	Once through	0.70	0.00	0.70	469.06	0.00	469.76	3,847.00	0.00
San Juan	Once through	0.00	0.00	0.00	455.15	0.86	456.01	1,642.00	0.00
Total		**1.82**	**2.83**	**4.65**	**1,701.11**	**0.97**	**1,706.73**	**14,291.00**	**2.69**

once-through cooling systems; only 12 Mgal/d of saline water was withdrawn by one of the facilities equipped with recirculating cooling systems. PRASA delivered an estimated total of 0.97 Mgal/d of freshwater to the Cataño and San Juan power facilities. Groundwater withdrawals by the power facilities located in the municipalities of Guayama, Guayanilla, and Salinas totaled 1.82 Mgal/d. The thermoelectric power facility located in Guayama reported using 2.69 Mgal/d of reclaimed wastewater in 2015. Reclaimed wastewater is a supplemental source of water for thermoelectric power operations, especially in areas where additional water sources are needed (table 13). Total saline-water withdrawals associated with cooling processes decreased 25 percent from 2010 to 2015. Also, net power generation associated with thermoelectric-power withdrawals decreased 28 percent from 2010 to 2015.

Trends in Water Withdrawals and Use, 1990–2015

The year-by-year population totals of Puerto Rico and the withdrawal estimates by category of use were summarized in 5-year increments from 1990 to 2015 (table 14). Total withdrawals for all categories of use in 2015 were estimated at 2,372 Mgal/d, the lowest estimated amount since 1990. Total withdrawals in 2015 were 21 percent less than in 2010, coinciding with a substantial decline of 25 percent in the saline-water withdrawals for thermoelectric-power cooling processes. This might be associated with reduced power generation in 2015. Irrigation, mining, and thermoelectric power were the only categories with larger freshwater withdrawals in 2015 than in 2010. Freshwater withdrawals for thermoelectric power and mining were greater in 2015 than in 2010, increasing by 23 percent and 5 percent, respectively. In 2015 irrigation use increased from its lowest levels in 2005 and 2010 because of the drought conditions experienced by the southern and eastern portions of the island in 2015.

Public-supply water withdrawal estimates from 1990 to 2010 indicated an increasing trend in conjunction with the total population growth up to 2005 and the people served by public-supply water facilities (table 14). Public-supply withdrawals in 2015 were 14 percent less than in 2010, decreasing from 670 to 576 Mgal/d, marking the first decline since 1990. Also, a decreasing trend in the population served was observed as population declined from 3.69 million in 2010 to 3.47 million in 2015—a 6-percent decline. The total population of Puerto Rico decreased by 7 percent from 2010 to 2015, from 3.73 million people in 2010 to 3.47 million people in 2015. The decline in the population served is in accordance with the decline in the island's population over the last decade. Public-supply deliveries for domestic use and the average domestic per capita use increased 47 and 58 percent, respectively, between 2010 and 2015. Increased domestic use might be related to the drought of 2015.

The magnitude of domestic self-supplied use was fairly steady from 2000 to 2010, but a large change was observed in 2015 (table 14). Domestic self-supplied withdrawals declined 78 percent between 2010 and 2015, from 2.41 to 0.52 Mgal/d, respectively. The decrease in the domestic self-supplied withdrawals is inferred to be a function of the 7-percent decline in the total population from 2010 to 2015.

Irrigation deliveries and withdrawals were 104 percent higher in 2015 (78 Mgal/d) than in 2010 (38 Mgal/d), likely caused in large part by the severe drought conditions experienced along the south and southeastern coasts of the island in 2015. The highest estimated irrigation use (140 Mgal/d) occurred in 1990. From 1995 to 2010, a decline of more than 60 percent for irrigation use was observed. Total irrigated acreage was 11 percent lower in 2015 than in 2010, a decline of about 4,000 acres. Some of these apparent changes may be partly due to differing methodologies for estimating irrigated acreages and withdrawals through time. Changes in irrigation practices have caused a decline in coverage by the surface (flood) irrigation systems from about 14,300 acres in 1990 to about 500 acres in 2015. Ramos-Ginés (1994) indicated that the standard irrigation method in the Santa Isabel-Juana Díaz area was furrow irrigation until about 1985. Micro-irrigation, which more effectively uses available groundwater resources and is more suitable for the new type of crops grown in the area, began to gradually replace furrow irrigation in the 1970s.

Freshwater withdrawals for livestock, industrial, mining, and thermoelectric power uses were 16.2 Mgal/d in 2015, or about 9 percent less than in 2010 (17.8 Mgal/d). In 2015, about 71 percent of the freshwater withdrawn for these categories was from groundwater sources. The most noticeable decreasing trend for these uses from 1990 to 2015 was observed for industrial withdrawals. Total industrial freshwater withdrawals decreased by 67 percent between 1990 and 2015, from 11.1 Mgal/d in 1990 to 3.7 Mgal/d in 2015. Industrial freshwater withdrawals decreased 15 percent between 2010 and 2015. Declines in industrial withdrawals in Puerto Rico may be due in part to the net loss of patents on certain pharmaceutical products, the escalation of manufacturing production costs (labor and electricity), emphasis on water reuse and (or) recycling within the industrial facilities, and the effect of local economic decline (Department of Labor and Human Resources, 2014). Declines in total withdrawals for livestock of 25 percent from 2010 to 2015 are also noticeable. Further analysis of causal relationships is beyond the scope of this report.

An increasing trend in total surface freshwater withdrawals was observed from 1990 to 2010, from 419 Mgal/d in 1990 to 611 Mgal/d in 2010; however, a decrease of 10 percent was observed from 2010 to 2015. Total groundwater withdrawals declined by 22 percent between 1990 and 2015, from 157 Mgal/d in 1990 to 122 Mgal/d in 2015; a slight reduction of 2 percent was observed from 2010 to 2015. Also, total saline surface-water withdrawals decreased 31 percent from 1990 to 2015, from 2,465 to 1,701 Mgal/d, and decreased 25 percent from 2010 to 2015.

Table 14. Trends in estimated water withdrawals in Puerto Rico, 1990–2015.

[Data source: U.S. Geological Survey. Withdrawals are in million gallons per day; domestic per capita use is in gallons per day; areas for irrigation methods are in thousands of acres; net power generation is in gigawatt-hours. Values may not sum to totals because of independent rounding. Negative values are shown in italics. N/A, information not available]

Data elements	Year						Percentage change 2010 to 2015
	1990	1995	2000	2005	2010	2015	
Water withdrawals by source of water							
Surface water							
Fresh	418.52	420.33	486.16	575.16	610.66	548.49	*–10*
Saline	2,465	2,262	2,191	2,288	2,270	1,701	*–25*
Groundwater							
Fresh	157.05	153.42	146.75	146.54	124.62	122.18	*–2*
Saline	0.00	0.00	0.00	0.00	0.00	0.00	
Total withdrawals	**3,040.24**	**2,837.57**	**2,825.96**	**3,009.10**	**2,998.23**	**2,371.78**	***–21***
Freshwater withdrawals by water-use category							
Public-supply water	404.00	430.00	513.00	652.00	670.00	576.40	*–14*
Domestic self-supplied	6.66	11.91	[1]2.09	2.11	2.41	0.52	*–78*
Irrigation	140.00	107.00	95.00	45.00	38.00	77.58	104
Livestock	8.33	6.21	9.64	7.79	7.81	5.83	*–25*
Industrial	11.13	11.12	11.16	9.41	4.30	3.67	*–15*
Mining	2.56	4.17	3.29	1.98	1.93	2.02	5
Thermoelectric power	2.56	2.16	[1]1.78	2.81	3.78	4.65	23
Total freshwater withdrawals	**575.24**	**572.57**	**635.96**	**721.10**	**728.23**	**670.67**	***–8***
Saline-water withdrawals by water-use category							
Thermoelectric power (all surface water)	2,465	2,265	2,190	2,288	2,270	1,701	*–25*
Population statistics							
Population served, in millions	3.371	3.538	3.796	3.881	3.688	3.469	*–6*
Domestic self-supplied population, in millions	0.150	0.217	0.013	0.031	0.038	0.005	*–87*
Total population, in millions	**3.521**	**3.755**	**3.809**	**3.912**	**3.726**	**3.474**	***–7***
Domestic water use							
Public-supply water deliveries to domestic users	161.52	171.19	N/A	346.78	229.77	338.35	47
Domestic per capita use	48	48	69	89	62	98	58
Irrigated acreage by irrigation method							
Sprinkler	21.25	0	14.56	0	8.17	11.18	37
Micro-irrigation (drip)	0	17.45	32.98	54.46	32.66	24.87	*–24*
Surface (flood)	14.29	20.62	5.35	0	0	0.48	
Total irrigated acreage	**35.54**	**38.07**	**52.89**	**54.46**	**40.83**	**36.53**	***–11***
Net power generation							
Thermoelectric power facilities	14,510	15,762	16,214	21,333	19,904	14,291	*–28*

[1]Values obtained from Molina-Rivera (2005).

References Cited

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M., 1998, Crop evapotranspiration—Guidelines for computing crop water requirements: Rome, Food and Agriculture Organization of the United Nations [FAO], FAO Irrigation and Drainage Paper 56, 300 p., accessed May 15, 2020, at http://www.fao.org/docrep/X0490E/x0490e00.htm.

Allen, R.G., Walter, I.A, Elliott, R., Howell, T., Itenfisu, D., Jensen, M., and Snyder, R.L., 2005, The ASCE standardized reference evapotranspiration equation: Technical Committee on Standardization of Reference Evapotranspiration, Environmental and Water Resources Institute of the American Society of Civil Engineers [ASCE], 59 p.

De Azevedo, P.V., da Silva, B.B., and da Silva, V.P.R., 2003, Water requirements of irrigated mango orchards in northeast Brazil: Agricultural Water Management, v. 58, no. 33, p. 241–254.

Department of Labor and Human Resources, 2014, Puerto Rico economic analysis report, 2012–2013: Commonwealth of Puerto Rico, Department of Labor and Human Resources, Bureau of Labor Statistics, 28 p., accessed March 31, 2017, at https://www.doleta.gov/performance/results/annualreports/PY2012/PREconomicAnalysis2012.pdf.

Dieter, C.A., Maupin, M.A., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2018, Estimated use of water in the United States in 2015: U.S. Geological Survey Circular 1441, 65 p., https://doi.org/10.3133/cir1441. [Supersedes USGS Open-File Report 2017–1131.]

Dixon, J.F., Molina-Rivera, W.L., Irizarry-Ortiz, M.M., and Christesson, K.R., 2021, Spatial and tabular datasets of water withdrawals and use in Puerto Rico, 2015: U.S. Geological Survey data release, https://doi.org/10.5066/P9POVNC6.

Dopazo-Rodríguez, T., and Molina-Rivera, W.L., 1995, Estimated water use in Puerto Rico, 1988–89: U.S. Geological Survey Open-File Report 95–380, 31 p.

Fornaris, G.J., 2007, Conjunto tecnológico para la producción de tomate—Suelo y preparación del terreno [Technological set for tomato production—Soil and land preparation]: University of Puerto Rico, Agricultural Experiment Station, 7 p., accessed May 10, 2020, at https://www.upr.edu/eea/wp-content/uploads/sites/17/2016/03/TOMATE-Suelo-y-Preparaci%C3%B3n-del-Terreno-v2007.pdf.

Harmsen, E.W., 2018, Simple spreadsheet method for scheduling irrigation, chap. 1 *of* Goyal, M.R., Nambuthiri, S.S., and Koech, R., eds., Technological interventions in management of irrigated agriculture: Ontario, Canada, Apple Academic Press, p. 4–17.

Harmsen, E.W., 2020, Water and energy balance results for Puerto Rico (1-km spatial resolution): Puerto Rico Agricultural Water Management [PRAGWATER] web page, accessed in April 7, 2020, at https://pragwater.com/goes-puerto-rico-water-and-energy-balance-goes-web-algorithm/.

Harmsen, E.W., Mecikalski, J., Mercado, A., and Tosado Cruz, P., 2010, Estimating evapotranspiration in the Caribbean region using satellite remote sensing *in* American Water Resources Association 2010 Summer Specialty Conference, San Juan, Puerto Rico, August 30–September 1, 2010: American Water Resources Association, 6 p., accessed March 24, 2020, at http://academic.uprm.edu/abe/PRAGWATER/EricHarmsen_et_al_AWRA_2010_Summer%20Specialty_Conference_San_Juan_PR.pdf.

Holupchinski, E., Álvarez-Berríos, N., Gould, M., and Fain, J., 2019, Drought in the U.S. Caribbean—Impacts on crops: National Climate Adaptation Science Centers fact sheet, 2 p., accessed May 13, 2020, at https://www.sciencebase.gov/catalog/item/5d42e866e4b01d82ce8daf19.

Hutson, S.S., Barber, N.L., Kenny, J.F., Linsey, K.S., Lumia, D.S., and Maupin, M.A., 2004, Estimated use of water in the United States in 2000: U.S. Geological Survey Circular 1268, 46 p.

Lovelace, J.K., 2009, Method for estimating water withdrawals for livestock in the United States, 2005: U.S. Geological Survey Scientific Investigations Report 2009–5041, 7 p., accessed March 7, 2017, at https://pubs.usgs.gov/sir/2009/5041/.

Marella, R.L., 1992, Factors that affect public-supply water use in Florida with a section on projected water use to the year 2020: U.S. Geological Survey Water-Resources Investigations Report 91–4123, 35 p.

Mayer, A., 2017, Puerto Rico's hurricane recovery hinders farm businesses' seed research: National Public Radio website, accessed June 10, 2020, at https://www.npr.org/sections/thesalt/2017/11/29/567254037/puerto-ricos-hurricane-recovery-complicates-ag-businesses-seed-research.

Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2014, Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405, 56 p., accessed March 16, 2017, at https://doi.org/10.3133/cir1405.

Molina-Rivera, W.L., 1998, Estimated water use in Puerto Rico, 1995: U.S. Geological Survey Open-File Report 98–276-A, 29 p., accessed March 21, 2017, at https://pubs.usgs.gov/of/1998/0276a/report.pdf.

Molina-Rivera, W.L., 2005, Estimated water use in Puerto Rico, 2000: U.S. Geological Survey Open-File Report 2005–1201, 26 p., accessed March 21, 2017, at https://pubs.usgs.gov/of/2005/1201/OFR2005_1201.pdf.

Molina-Rivera, W.L., 2014, Estimated water use in Puerto Rico, 2010: U.S. Geological Survey Open-File Report 2014–1117, 35 p., accessed March 21, 2017, at https://doi.org/10.3133/ofr20141117.

Molina-Rivera, W.L., 2015, Source, use, and disposition of freshwater in Puerto Rico, 2010: U.S. Geological Survey Fact Sheet 2015–3044, 6 p., accessed June 25, 2020, at https://doi.org/10.3133/fs20153044.

Molina-Rivera, W.L., and Dopazo-Rodríguez, T., 1995, Estimated water use in Puerto Rico, 1986–87: U.S. Geological Survey Open-File Report 95–358, 30 p., accessed March 21, 2017, at https://pubs.er.usgs.gov/publication/ofr95358.

Molina-Rivera, W.L., and Gómez-Gómez, F., 2008, Estimated water use in Puerto Rico, 2005: U.S. Geological Survey Open-File Report 2008–1286, 37 p., accessed March 21, 2017, at https://pubs.usgs.gov/of/2008/1286/OFR_2008_1286.pdf.

National Oceanic and Atmospheric Administration, 2017, National Weather Service—Average rainfall statistic: National Oceanic and Atmospheric Administration, National Weather Service web page, accessed June 21, 2021, at https://w2.weather.gov/climate/local_data.php?wfo=sju.

Paulino-Paulino, J., Harmsen, E.W., Sotomayor-Ramírez, D., and Rivera, L.E., 2008, Nitrate leaching under different levels of irrigation for three turfgrasses in southern Puerto Rico: Journal of Agriculture of the University of Puerto Rico, v. 92, no. 3–4, p. 135–152.

Pereira, L.S., and Alves, I., 2013, Crop water requirements: Elsevier, Reference Module in Earth Systems and Environmental Science, p. 322–334, accessed May 15, 2020, at https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/crop-coefficient.

Puerto Rico Agricultural Water Management [PRAGWATER], 2020, GOES–PRWEB data: University of Puerto Rico at Mayagüez, Puerto Rico Agricultural Water Management [PRAGWATER] web page, accessed April 27, 2020, at http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/.

Puerto Rico Department of Health, 2015, Inventario sistemas non-PRASA: Puerto Rico Department of Health, División de Agua Potable [Potable Water Division], 75 p.

Puerto Rico Department of Natural and Environmental Resources, 2008, Plan integral de recursos de agua de Puerto Rico: Estado Libre Asociado de Puerto Rico, Departmento de Recursos Naturales y Ambientales [Puerto Rico Comprehensive Water Resource Plan: Commonwealth of Puerto Rico, Department of Natural and Environmental Resources] report, 595 p., accessed June 26, 2020, at https://estadisticas.pr/files/BibliotecaVirtual/estadisticas/biblioteca/DRNA_PlanIntegraldeRecursosdeAgua_2008.pdf.

Puerto Rico Department of Natural and Environmental Resources, 2016, Informe sobre la sequía 2014–16 en Puerto Rico [Report on the 2014–16 drought in Puerto Rico]: Departmento de Recursos Naturales y Ambientales, División Monitoreo del Plan de Aguas [Department of Natural and Environmental Resources, Water Plan Monitoring Division], 100 p.

Puerto Rico Institute for Water and Health, 2017, Reutilización de aguas residuals en Puerto Rico [Wastewater reuse in Puerto Rico]: Metropolitan University of Puerto Rico, College of Environmental Affairs, 2 p., accessed July 13, 2020, at https://cupey.uagm.edu/sites/umet.suagm.edu/files/public/u216/idas_reuso_agua_pr.pdf.

Puerto Rico Scientific Committee on Droughts, 2015, Protocolo para el manejo de sequía en Puerto Rico [Protocol for the management of drought in Puerto Rico], March 2015: Departmento de Recursos Naturales y Ambientales [Department of Natural and Environmental Resources], 31 p., accessed June 25, 2020, at https://drought.unl.edu/archive/plans/Drought/state/PR_2015.pdf.

Puerto Rico Water Resources and Environmental Research Institute, 2005, Estudio sobre el uso de agua agrícola en Puerto Rico [Study on agricultural water use in Puerto Rico]—Plan integral de conservación, desarrollo y uso de los recursos de agua de Puerto Rico, informe final al Departamento de Recursos Naturales y Ambientales [Comprehensive plan for the conservation, development and use of Puerto Rico's water resources, final report to the Department of Natural and Environmental Resources]: Mayagüez, P.R., University of Puerto Rico, Puerto Rico Water Resources and Environmental Research Institute, 86 p.

Ramos-Ginés, O., 1994, Effects of changing irrigation practices on the groundwater hydrology of the Santa Isabel-Juana Díaz area, south central Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 91–4183, 22 p., accessed May 24, 2018, at https://pubs.usgs.gov/wri/1991/4183/report.pdf.

Southern Integrated Pest Management Center, 2002, Crop profile for coffee in Puerto Rico: National Integrated Pest Management database, accessed May 13, 2020, at https://ipmdata.ipmcenters.org/documents/cropprofiles/PRcoffee.pdf.

Smajstrala, A.G., 1990, Technical manual—Agricultural field scale irrigation requirements simulation (AFSIRS) model, version 5.5: Saint Johns River Water Management District Special Publication SJ2008–SP17, 251 p.

University of Puerto Rico, Agricultural Extension Service, 2017, Tomate de ensalada [Salad tomato]: Hoja Informativa [Fact Sheet] HORT–04–17, 3 p., accessed May 6, 2020, at http://www.ermitahernandez.com/uploads/5/3/7/6/53761975/hoja_informativa_tomate_rev18.pdf.

U.S. Census Bureau, 2015, Annual estimates of the resident population—April 1, 2010 to July 1, 2015: U.S. Census Bureau online database, accessed March 21, 2017, at https://data.census.gov/cedsci/table?q=puerto%20rico%202015&tid=ACSDT1Y2015.B01003.

U.S. Census Bureau, 2017, North American industry classification system: Executive Office of the President, Office of Budget and Management, 963 p., accessed March 16, 2018, at https://www.census.gov/eos/www/naics/2017NAICS/2017_NAICS_Manual.pdf.

U.S. Department of Agriculture, 2014, 2012 Census of agriculture—Puerto Rico, island and municipio data: United States Department of Agriculture [USDA], Geographic Area Series, v. 1, no. 52, AC–12–A–52, 350 p., accessed February 21, 2017, at https://www.nass.usda.gov/Publications/AgCensus/2012/Full_Report/Outlying_Areas/prv1.pdf.

U.S. Department of Agriculture, 2015, News release—USDA declares drought disaster in Puerto Rico: U.S. Department of Agriculture, Natural Resources Conservation Service Caribbean Area web page, accessed May 13, 2020, at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/?navtype=SUBNAVIGATION&ss=161043&cid=NRCSEPRD385827&navid=105100000000000&pnavid=105000000000000&position=News&ttype=detail.

U.S. Environmental Protection Agency [EPA], 2018, Drinking water requirement for States and public water systems—Information about public water systems: U.S. Environmental Protection Agency web page, accessed March 9, 2018, at https://water.epa.gov/infrastructure/drinkingwater/pws/factioids/cfm.

Viqueira-Rios, R., Comas, L.M., and Sturm, P., 2012, Lajas Valley Agricultural Reserve—Farm inventory of the Guánica Lagoon, El Anegado, and adjacent areas, Guánica, Puerto Rico: Ellicott City, Maryland, Center for Watershed Protection report, 68 p., accessed May 15, 2020, at https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/project/397/Guanica_Lagoon_Farm_Inventory.pdf.

For more information about this publication, contact

Director, Caribbean-Florida Water Science Center
U.S. Geological Survey
4446 Pet Lane, Suite 108
Lutz, FL 33559

For additional information visit
https://www.usgs.gov/centers/car-fl-water

Publishing support provided by
Lafayette Publishing Service Center

Molina-Rivera and Irizarry-Ortiz—**Estimated Water Withdrawals and Use in Puerto Rico, 2015**—Open-File Report 2021–1060

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20211060