Droughts of the 21st Century in Puerto Rico

Eva Holupchinski[1,2], Nora Álvarez-Berríos[1], Maya Quiñones[1], William A. Gould[1]
[1]U.S. Department of Agriculture (USDA) Forest Service, International Institute of Tropical Forestry, Rio Piedras, P.R., [2]University of Puerto Rico, Rio Piedras, P.R.

Drought conditions are created when there is a lower than normal amount of rainfall over an extended period, leading to lower than normal amounts of water availability. High temperatures, high winds, and low relative humidity can intensify drought conditions by reducing available water. Drought may be associated with a delay in the start of a rainy season, the timing of rains in relation to cropping stages, changes in rainfall intensity, and a decrease in the number of rainfall events. Droughts can have significant effects on soils, aquifers, and water reserves. There are four main types of drought (Wilhite 1985):

1. meteorological drought, a period of relative deficiency in rainfall;
2. agricultural drought, when water deficiency affects crops;
3. hydrological drought, when surface water storage becomes reduced; and
4. socioeconomic drought, when dry conditions affect the availability of economic goods and water for consumption.

This research map shows the distribution of accumulated drought in time and space and describes the effect of drought conditions on reservoirs, agricultural lands, and people on the main island of Puerto Rico, Vieques, and Culebra.

INDICATORS AND INDICES

Unlike other natural hazards such as floods and hurricanes that manifest as clearly defined events, drought onset and conclusion are less clearly observed. Drought indicators and indices are used to describe the onset and conclusion of a drought during a prolonged dry period. Indicators of drought are climatic and physical factors such as rainfall, temperature, evapotranspiration rate, and rate of soil moisture depletion. Drought indices, on the other hand, apply these climate and environmental indicators to produce a value that describes drought severity. Some commonly used indices include: Decile Index, Standard Precipitation Index, Crop Moisture Index, and Palmer Drought Severity Index.

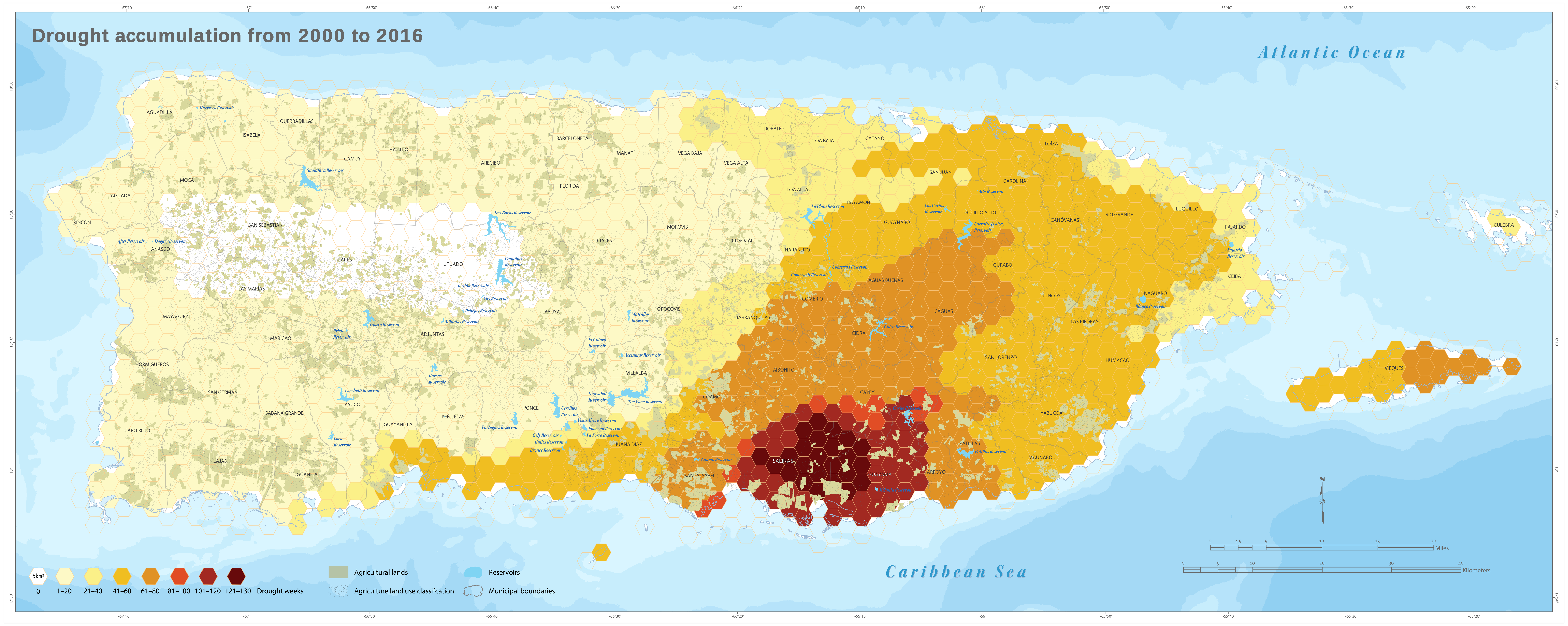
The United States Drought Monitor (USDM) classification scheme combines several indicators that describe the severity of water deficit, crop damage, and water use restrictions in four drought classification categories (moderate, severe, extreme, and exceptional drought) for the United States and Puerto Rico. Government agencies, such as the U.S. Department of Agriculture, use the USDM classification to declare a drought and put adaptive measures in place.

DROUGHT HISTORY IN PUERTO RICO

During the latter half of 20th century, five long-term periods of drought exposure were registered in Puerto Rico (1966 to 1968, 1971 to 1974, 1976 to 1978, 1993 to 1995, and 1997 to 1998), the most severe being the 1966 to 1968 drought when the period's average annual rainfall of 32% below normal caused water rationing (Larsen 2000). The rainfall during the major drought of 1993 to 1995 was 18% below average annual rainfall, which resulted in $165 million in agricultural losses and also required mandatory water rationing (Larsen 2000).

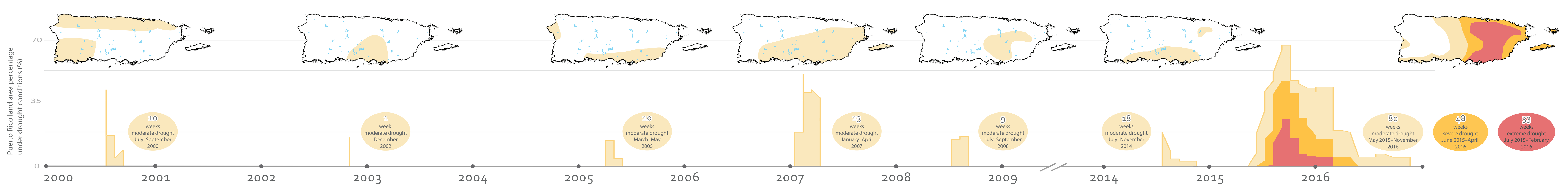
During the early 21st century, there have been five short-term droughts in Puerto Rico (2000, 2002, 2005, 2007, and 2008) (Álvarez-Berríos et al. 2018). The timeline on this map shows the maximum spatial extent, duration, and intensity of each event.

The eight warmest years on records occurred between 2005 and 2017 (NOAA 2018). From 2014 to 2016, a major period of drought in Puerto Rico activated an emergency declaration that was swiftly followed by strict restrictions in water use. During this period, water rationing was implemented for at least 1.2 million people (Puerto Rico Department of Natural and Environmental Resources 2016). While the average annual rainfall on the island is 1687 mm (66 in) (Daly et al. 2003), the annual rainfall for 2015 was 1312 mm (52 in) (NOAA 2017). The USDM classified the drought intensity as "extreme" in 2015 and conditions persisted for 8 months, covering over 25% of Puerto Rico's land area. Severe drought conditions lasted for 12 months and covered 45% of Puerto Rico, while moderate drought conditions endured for about 20 consecutive months and covered 68% of the land area. Drought conditions concentrated around the southeast region of the main island, and in Vieques and Culebra. Others are studying the variables that may influence recent drought conditions to concentrate in the eastern region (Van Beusekom et al. 2017, Mote et al 2017, Murphy et al. 2017, Miller et al. 2018).



TIMELINE

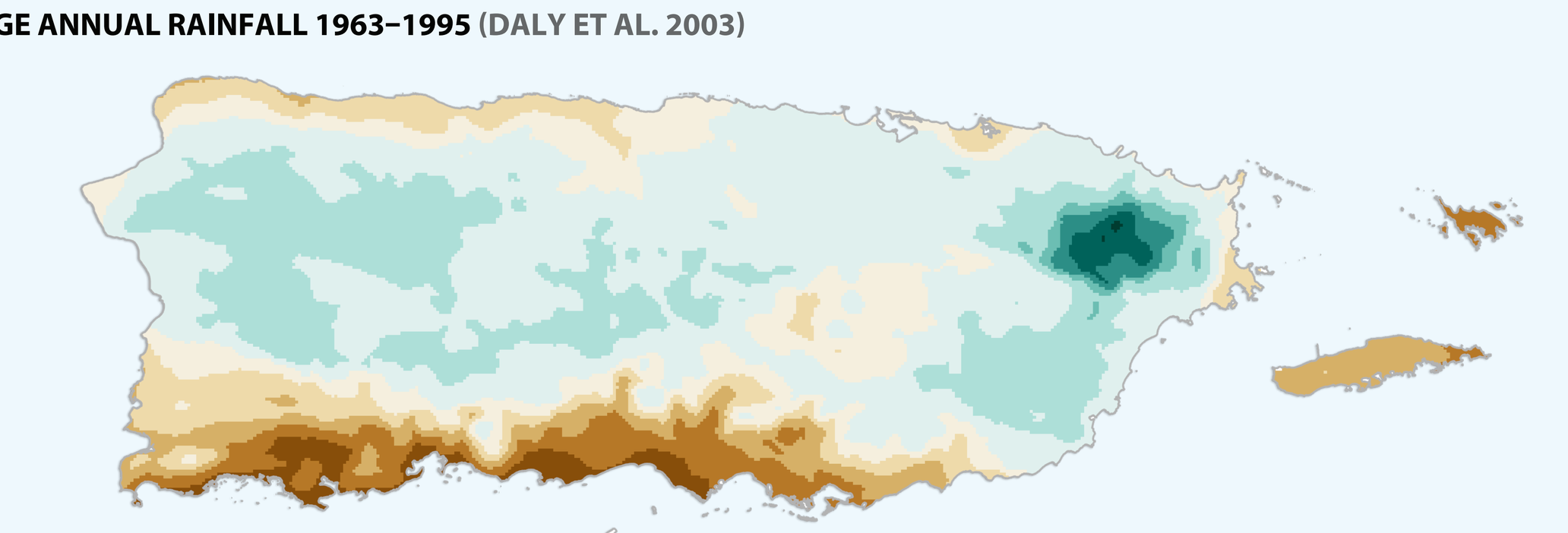
DROUGHT SEVERITY, EXTENT, AND DURATION FROM 2000–2016



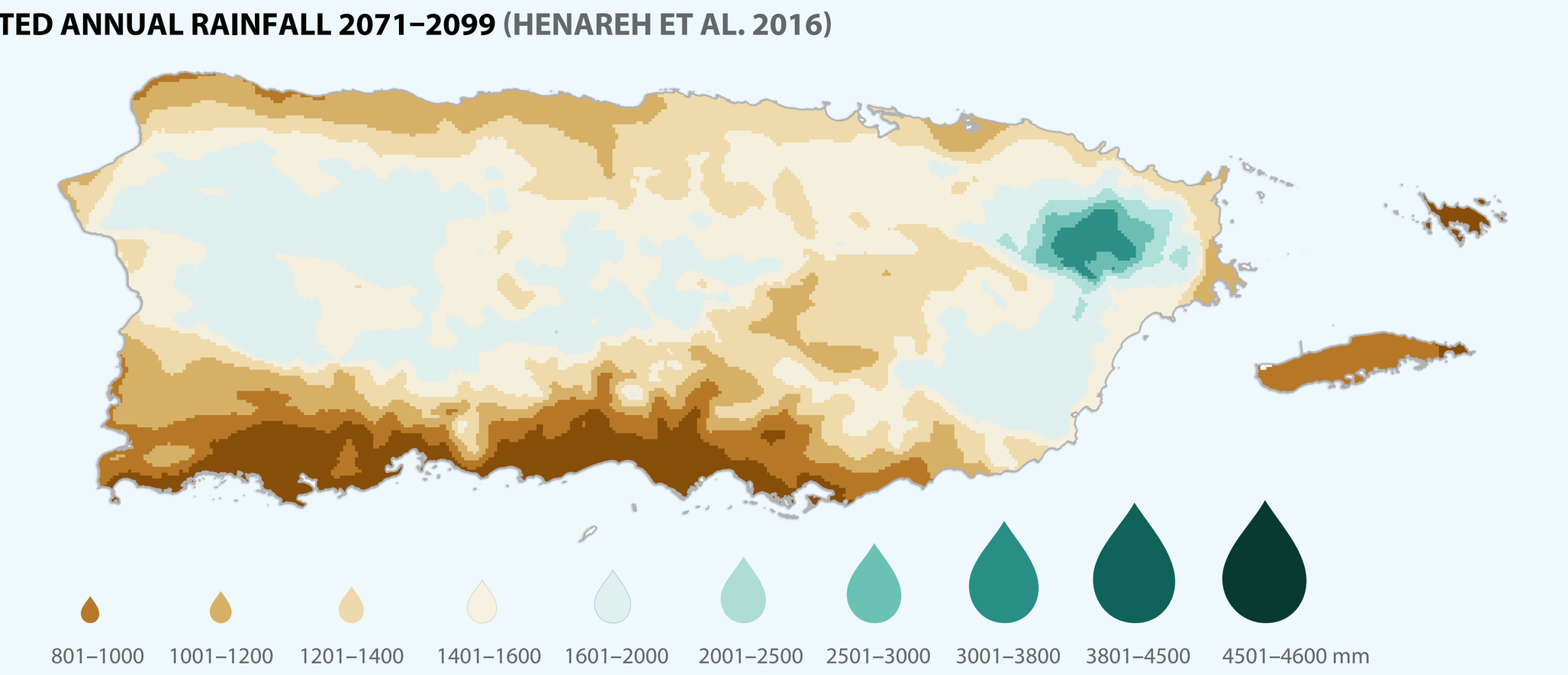
RAINFALL IN PUERTO RICO

Puerto Rico falls within the tropical climatic zone, with average temperatures from 13°C–32°C and abundant rainfall throughout the year. Puerto Rico receives an average annual rainfall of 1687 mm (66 in) (Daly et al. 2003). Rainfall varies significantly across the island, ranging from 850 mm (33 in) in the south coast of the main island to 4500 mm (177 in) in the eastern Luquillo Mountains (Daly et al. 2003). While in Puerto Rico it rains throughout the year, relatively dry seasons are typically observed from January to April and in the summer months of June and July (Larsen 2000). Higher rainfall is observed during the month of May and between August and November (Larsen 2000). Global and regional climate projections indicate rainfall may be expected to decrease while temperatures may be expected to increase for the Caribbean Region and Puerto Rico during this century (Henareh et al. 2016). A combination of more intense rainfall events coupled with projections of more consecutive days without rain increases the likelihood of an increase in the intensity and frequency of drought events, particularly in the eastern region of Puerto Rico where a greater decline in rainfall is predicted (Henareh et al. 2016). The calculation of island-wide rainfall from weather station data varies widely depending on the methods used. The average annual precipitation map below shows the historical average for annual rainfall in Puerto Rico from 1963 to 1995 according to Daly et al. 2003. In projecting future climate, there is always a level of uncertainty. The projected annual rainfall for the end of the 21st century mapped below is an uncertain projection (Henareh et al. 2016). The latest climate projections for Puerto Rico estimate a decrease in rainfall between 130-1397 mm (1.18-55 in); declining most severely in the northeastern, eastern and central mountain range areas, while average temperatures could increase 4.6-9°C by the end of the century (Henareh et al. 2016). According to the Fourth National Climate Assessment, climate change will likely lead to water shortages in the U.S. Caribbean (U.S. Global Change Research Program 2018).

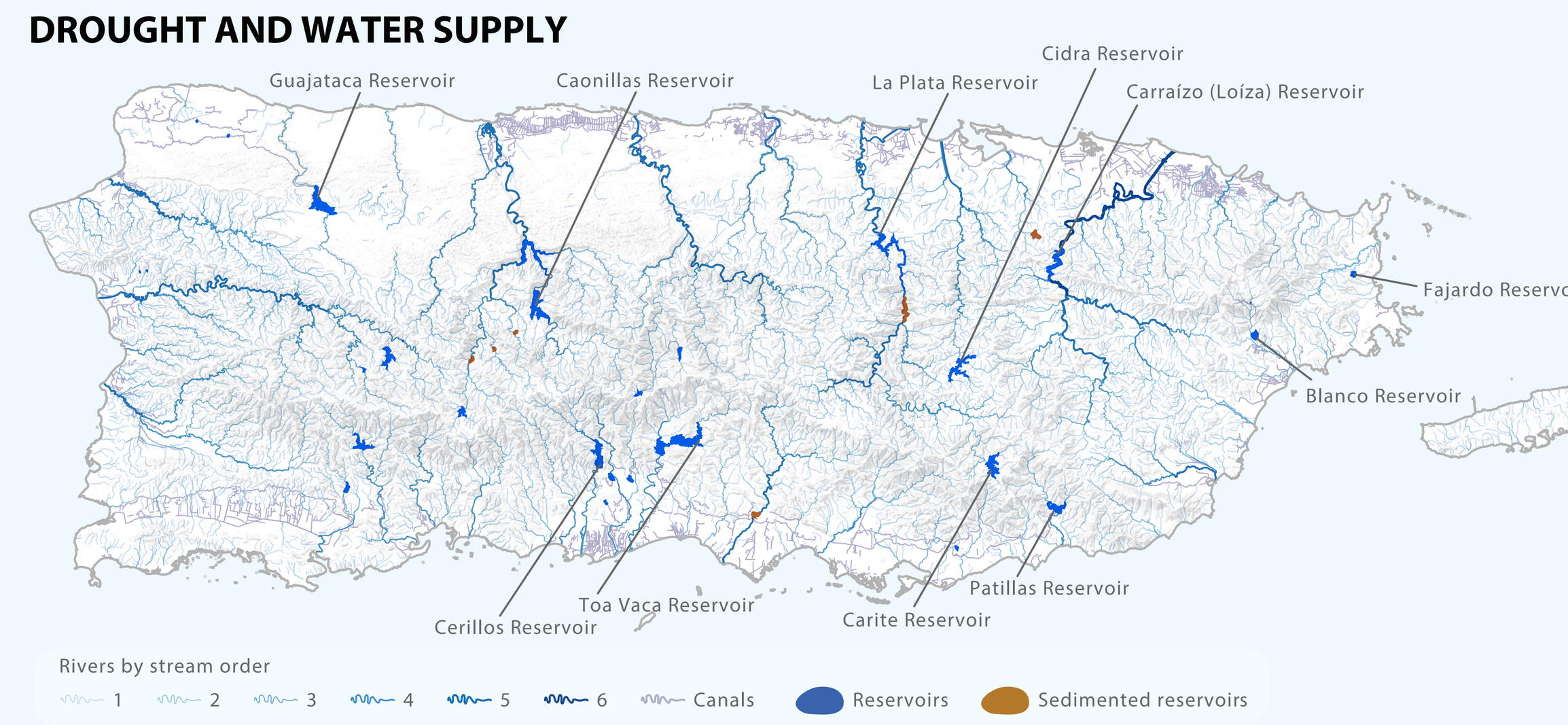
AVERAGE ANNUAL RAINFALL 1963–1995 (DALY ET AL. 2003)



PROJECTED ANNUAL RAINFALL 2071–2099 (HENAREH ET AL. 2016)

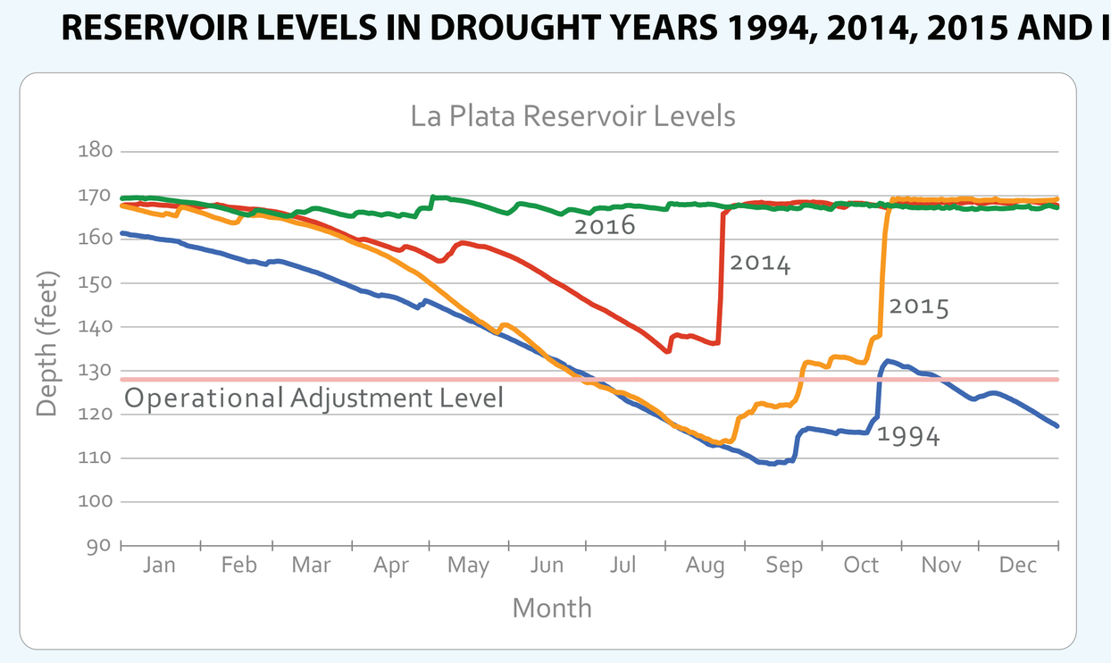


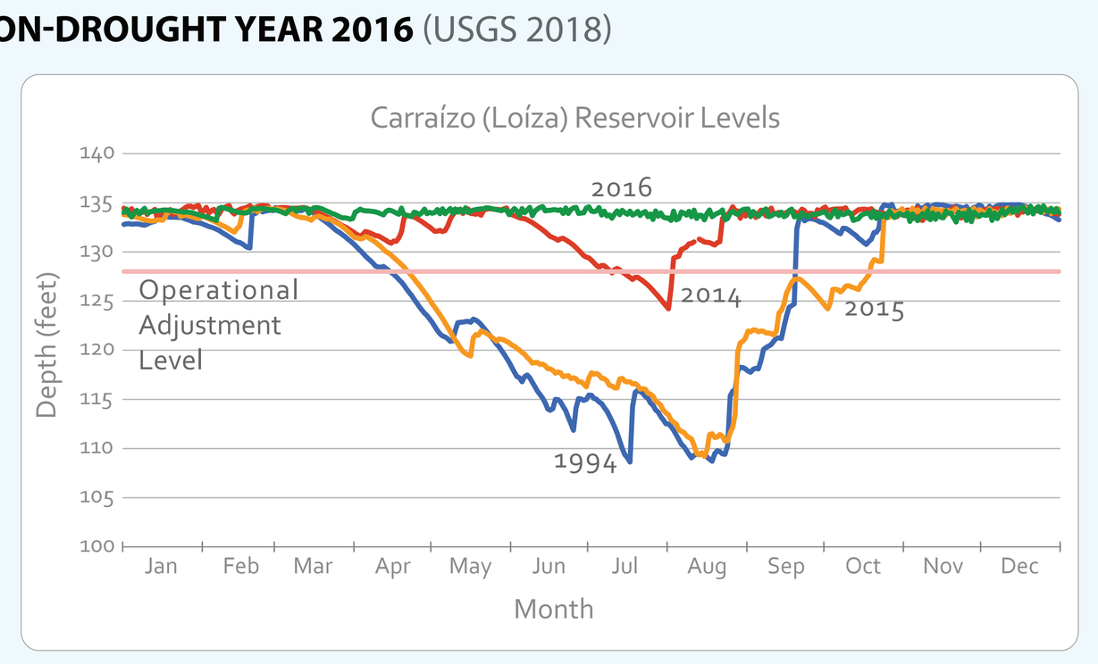
DROUGHT AND WATER SUPPLY



Puerto Rico has a complex network of rivers and streams, orders 1 to 6, that discharge rapidly to the ocean. Stream order refers to the relative size of a stream within a watershed. A first order rank represents a headwater stream while the highest order rank represents the largest river in the watershed. Due to the absence of natural lakes in Puerto Rico, residents primarily rely on human-made reservoirs for freshwater storage. There are 36 reservoirs in Puerto Rico that serve multiple purposes such as hydroelectric production, recreation, irrigation, flood control, and public consumption (Puerto Rico Department of Natural and Environmental Resources 2004). Puerto Rico has 11 main reservoirs for public water consumption. During the most recent severe droughts of 2015 and 1994, reservoir levels became so low that mandatory water rationing was implemented for much of the population. The water levels are graphed below for two of the most important reservoirs that supply the San Juan metropolitan area (La Plata and Carraízo Reservoirs) for the drought years 1994, 2014, and 2015 as well as the non-drought year 2016. Drought effects reflected similarly for 2015 and 1994, dipping well below their respective operational adjustment levels therefore requiring rationing for consumers. The capacity of the island's reservoirs has been steadily decreasing as river sediment deposits over time. However, during the 2014 to 2016 drought, the low reservoir levels allowed for a sediment removal operation in key reservoirs (Puerto Rico Department of Natural and Environmental Resources 2016). Another challenge in local freshwater management is the complex grid of aging pipes and infrastructure, which contribute to significant losses in managed water. As of 2015, 54% of managed water was reported as lost by the local water authority (Puerto Rico Aqueducts and Sewers Authority 2015). While the lost water leaks from the infrastructure and becomes unavailable to consumers, much of it likely seeps down to recharge the aquifer.

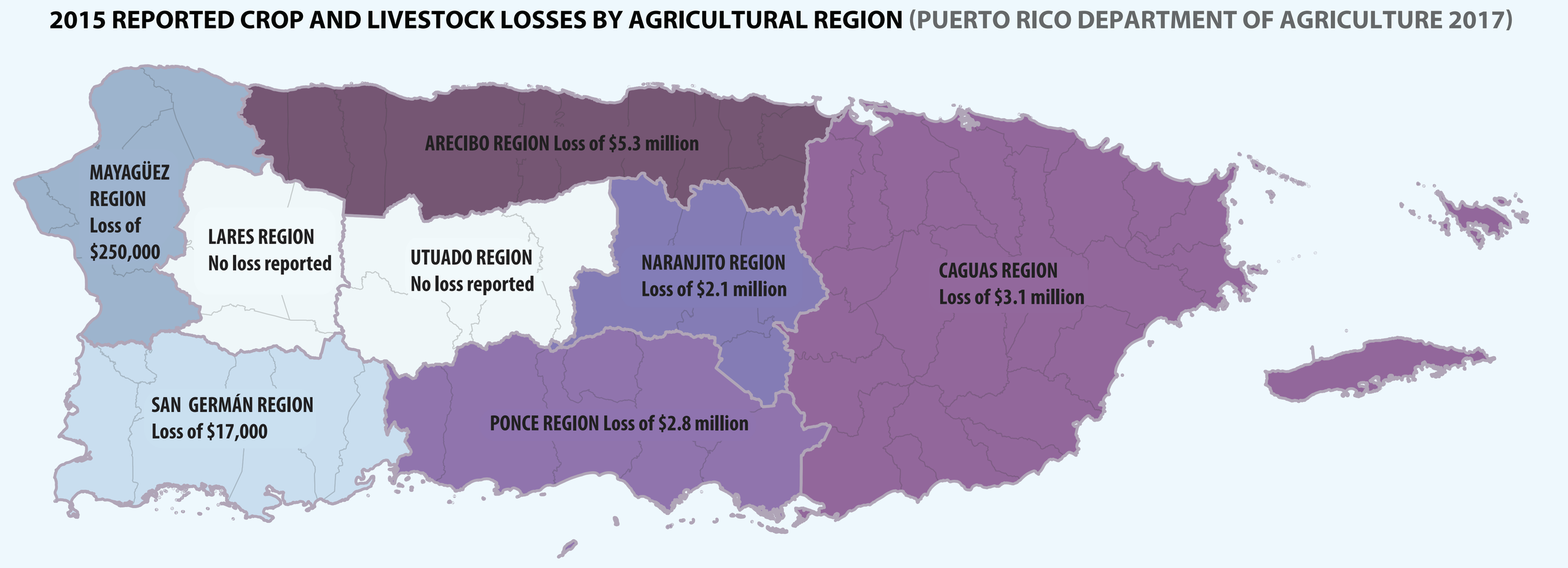
RESERVOIR LEVELS IN DROUGHT YEARS 1994, 2014, 2015 AND IN NON-DROUGHT YEAR 2016 (USGS 2018)





DROUGHT AND AGRICULTURE

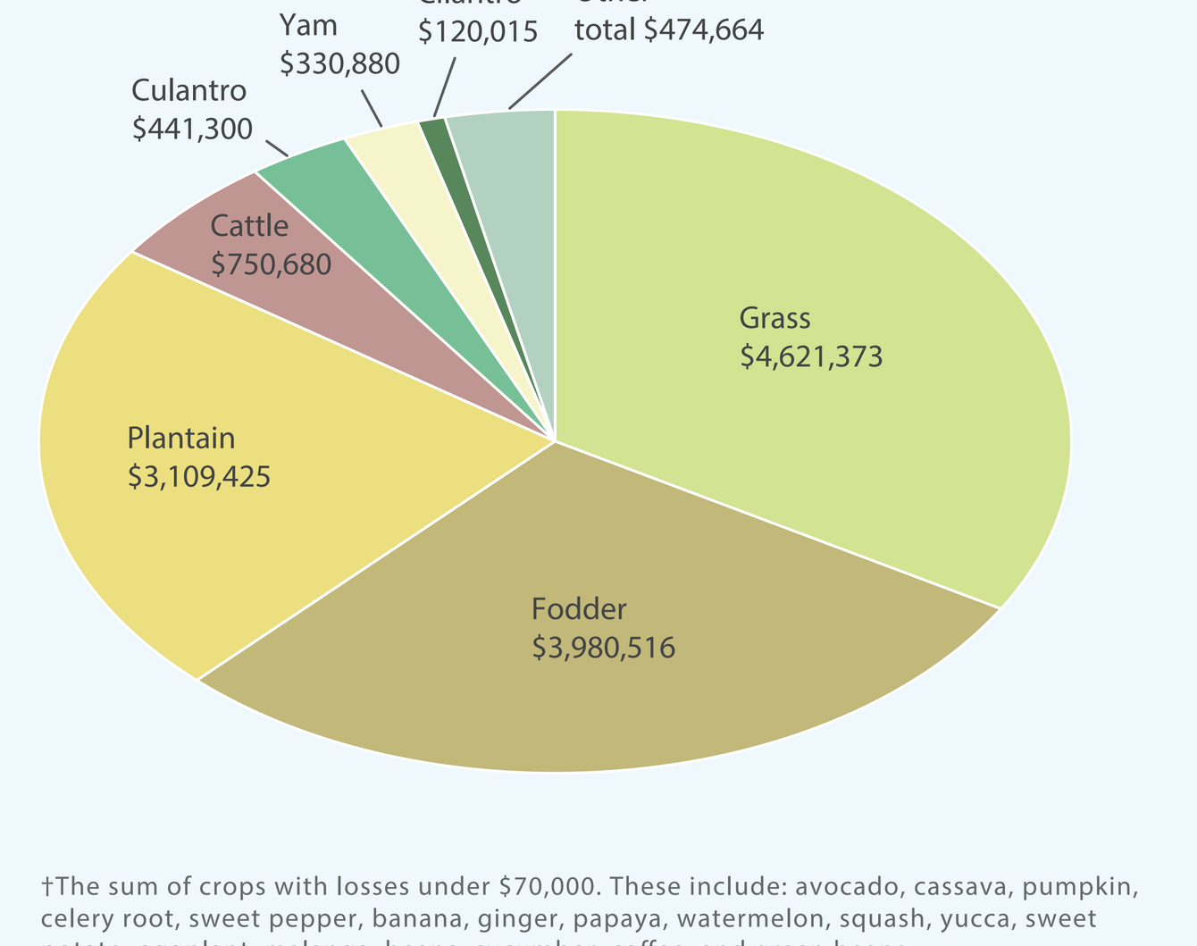
2015 REPORTED CROP AND LIVESTOCK LOSSES BY AGRICULTURAL REGION (PUERTO RICO DEPARTMENT OF AGRICULTURE 2017)



The agricultural sector is often the first to feel the effects of drought. Dry conditions cause soil to lose moisture and plants to become stressed. Non-irrigated crops are most vulnerable because they rely solely on rain for water. In Puerto Rico only 9% of farmed land is irrigated, leaving 91% of farmland dependent on rainfall (Puerto Rico Department of Agriculture 2017). Reduced rain and soil moisture during the 2015 drought contributed to significant losses for the agricultural sector (as seen in the pie chart and map to the right); nearly 14 million dollars lost throughout 25 product categories (Puerto Rico Department of Agriculture 2017). In the drought accumulation map, stippled (dotted) regions show lands zoned for agriculture by the Puerto Rico Planning Board in the Land Use Plan, while green-gray areas show recently active farmland.

Agricultural drought vulnerability can be reduced with the application of mitigation and adaptation practices. Drought-related mitigation practices are recommended by the Natural Resources Conservation Service for the management of crops, land, and water. Examples of recommended practices for rainfed crops include the use of cover crops as well as the management and incorporation of crop residue. Cover crops and crop residue help decrease surface erosion, promote rainwater retention in the soil, and mitigate soil temperatures. In the case of grazing lands, recommended practices help maintain the health of pastures during a period of drought by maintaining an appropriate soil-animal carrying capacity. One such practice is rotational grazing which maximizes the quality and quantity of forage growth. In times of rainfall deficiency, water supplies are essential for livestock production. Water availability can be optimized by installing efficient watering equipment, by establishing ponds, wells, springs, and water conveyance systems, and by harvesting rainwater for storage in tanks or cisterns.

2015 REPORTED AGRICULTURAL LOSSES BY CROP IN U.S. DOLLARS (PUERTO RICO DEPARTMENT OF AGRICULTURE 2017)



†The sum of crops with losses under $70,000. These include: avocado, cassava, pumpkin, celery root, sweet pepper, banana, ginger, papaya, watermelon, squash, yucca, sweet potato, eggplant, malanga, beans, cucumber, coffee, and green beans.

DATA AND METHODS

To create the main feature map, we used USDM drought datasets. The USDM provides weekly maps and drought condition data for the United States and Puerto Rico through their website (http://droughtmonitor.unl.edu/Data/GISData.aspx). The data, based on climate, soil, and hydrologic conditions, incorporates drought indices and indicators and integrates input from drought experts (Svoboda 2000). For Puerto Rico, USDM drought data were first published in 2000. USDM uses four drought classifications (moderate drought, severe drought, extreme drought, and exceptional drought) and an 'abnormally dry' classification. Areas categorized as 'abnormally dry' were excluded from the analysis since they are considered zones in transition to or from drought.

To display an extended period of accumulated drought exposure, we combined the weekly data provided by USDM using Geographic Information Systems (GIS). The data included 887 individual weeks of accumulated drought conditions. Drought condition data were then merged into a single layer of overlapping polygons. To display the accumulated drought data in an observable manner, the information was consolidated into a grid of 5 km² (1.93 square miles) hexagons (as per Álvarez-Berríos et al. 2018). The resulting drought accumulation map displays the number of non-consecutive weeks that each 5 km² hexagon was exposed to drought conditions from 2000 to 2016. Agricultural zoning, recently active agriculture lands, reservoirs, and municipal boundaries are also featured in the main map.

ACKNOWLEDGEMENTS
This research map was supported by the NRCS cooperative agreement 67-F352-17-262. Special thanks to Dr. Ariel Lugo, Dr. Grizelle González, Dr. Nicholas Brokaw and reviewers for their valuable time and critical reviews of this map. This research was conducted in collaboration with the University of Puerto Rico.

SUGGESTED CITATION
Holupchinski, E., Álvarez-Berríos, N., Quiñones, M., and Gould, W.A. 2019. Droughts of the 21st Century in Puerto Rico. Scale 1:260,000. IITF-RMAP-04. Rio Piedras, PR: U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry.

REFERENCES

Álvarez-Berríos N.L.; Soto-Bayó S.; Holupchinski E.; Fain S.J.; Gould W.A. 2018. Correlating drought conservation practices and drought vulnerability in a tropical agricultural system. Renewable Agriculture and Food Systems. Retrieved from: https://-doi.org/10.1017/S174217051800011X.

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

Henareh Khalyani A.; Gould W.A.; Harmsen E.; Terando A.; Quinones M.; and Collazo J.A. 2016. Climate change implications for tropical islands: Interpolating and interpreting statistically downscaled GCM projections for management and planning. Journal of Applied Meteorology and Climatology 55, 265–282.

Larsen M.C. 2000. Analysis of 20th century rainfall and streamflow to characterize drought and water resources in Puerto Rico. Physical Geography 21, 494–521.

Lugo, A.; García Martinó, A.; Quiñones Márquez, F. 2011. Cartilla del Agua para Puerto Rico. Acta Cientifica 25 (1-3): 4.

Miller, P.W.; Mote, T.L.; Ramseyer, C.A.; Van Beusekom, A.E.; Scholl, M; González, G. 2018. A 42 year inference of cloud base height trends in the Luquillo Mountains of northeastern Puerto Rico. Climate Research. 76(1): 87-94. https://doi.org/10.3354/cr01529.

Mote, T.L.; Ramseyer, C.A.; Miller, P.W. 2017. The Saharan Air Layer as an Early Rainfall Season Suppressant in the Eastern Caribbean: The 2015 Puerto Rico Drought. Journal of geophysical Research: Atmosphere, 122. https://doi.org/10.1002/2017JD026911

Murphy S.F., Stallard R.F., Scholl M.A., González G, Torres-Sánchez A.J. 2017. Reassessing rainfall in the Luquillo Mountains, Puerto Rico: Local and global ecohydrological implications. PLoS ONE 12(7): e0180987. https://doi.org/10.1371/journal.pone.0180987

National Oceanic and Atmospheric Administration and National Centers for Environmental Information. 2018. Global Climate Report - August 2018. Accessed September 2018 at: https://www.ncdc.noaa.gov/sotc/global/201808

National Oceanic and Atmospheric Administration and National Weather Service. 2017. 2015 Average Rainfall Accumulation per Climate Zones. Retrieved from: https://www.weather.gov/media/sju/climo/stats/2015.pdf

Puerto Rico Aqueducts and Sewers Authority. 2015. Informes Estadisticos Balance de agua 2015. Retrieved from: http://www.acueductospr.com/INFORMESESTADISTICOS/download/2016/Balance%20de%20Agua%20AF2015.pdf

Puerto Rico Department of Agriculture, Statistics Division. 2017. Summary of the Agricultural losses during the 2015 drought. San Juan, Puerto Rico.

Puerto Rico Department of Natural and Environmental Resources. 2016. Informe sobre la sequía 2014-16 en Puerto Rico. División Monitoreo del Plan de Aguas, San Juan, Puerto Rico.

Puerto Rico Department of Natural and Environmental Resources. Water Planning Office. 2004. Características y Condición de los Embalses Principales en Puerto Rico. By Ortíz-Zayas, J.; Quiñones, F.; Palacios, S.; Vélez, A.; Más, H.

Svoboda, M. 2000. An introduction to the Drought Monitor. Drought Network News (1994-2001) 12:15–20.

U.S. Geological Survey in cooperation with the U.S. Department of Agriculture, Natural Resource Conservation Service. 2002. Hydrologic unit boundaries for Puerto Rico [GIS Data]. Shapefile format. San Juan, PR. https://datagateway.nrcs.usda.gov/ (29 April 2014).

U.S. Geological Survey. 2018. National Hydrography Dataset. Reservoirs, rivers and streams for Puerto Rico [GIS Data]

U.S. Geological Survey, National Water Information Systems in cooperation with the Puerto Rico Aqueducts and Sewers Authority. 2017. Provisional Reservoir Level Data. https://waterdata.usgs.gov/pr/nwis/current/?type=lake&group_key=basin_cd (14 February 2018).

U.S. Global Change Research Program, 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. doi: 10.7930/NCA4.2018.

Van Beusekom, A.E.; Gonzalez, G; Scholl, M.A. 2017. Analyzing cloud base at local and regional scales to understand tropical montane cloud forest vulnerability to climate change. Atmospheric Chemistry and Physics. 17(11): 7245-7259. https://doi.org/10.5194/acp-17-7245-2017.

Wilhite D.A. 2000. Drought as a natural hazard: Concepts and definitions. Drought Mitigation Center Faculty Publications. Lincoln, Nebraska: University of Nebraska- Lincoln, Paper 69.

Wilhite, D.A.; Glantz, M.H. 1985. Understanding the Drought Phenomenon: The Role of Definitions. Water International 10(3):111–120.

Publication date: 2019