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Draft Report

After Hurricane Maria

Pre-Disaster Conditions, Hurricane Damage, and Recovery Needs for Puerto Rico

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Homeland Security Operational Analysis Center

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Preface

On September 19 and 20, 2017, Hurricane Maria devastated the U.S. Commonwealth of Puerto Rico. Coming just two weeks after Hurricane Irma, the storm significantly damaged local infrastructure and interrupted the provision of essential services to the people of Puerto Rico. In the aftermath, the President signed a Major Disaster Declaration for Hurricane Maria on September 20, 2017 (DR-4339) [1] under the *Robert T. Stafford Disaster Relief and Emergency Assistance Act* (Stafford Act). In the wake of Hurricanes Irma and Maria, the Federal Emergency Management Agency (FEMA) has been working closely with the Government of Puerto Rico and its municipalities, other federal agencies, private-sector entities, and voluntary, faith-based, and community organizations to stabilize Puerto Rico; attention is now turning toward the Commonwealth's long- term recovery needs.

The Supplemental Appropriation Bill requires the Governor of Puerto Rico, in coordination with FEMA, the Department of Treasury, Department of Energy and other federal agencies having responsibility under the National Disaster Recovery Framework, to **submit a report to Congress that describes Puerto Rico's 12- and 24-month economic and disaster recovery plan within 180 days of enactment of the legislation**. The recovery plan will define priorities, goals, and expected outcomes of the recovery effort in Puerto Rico to include the following sectors: housing; economic issues; health and social services; natural and cultural resources; governance and civic institutions; electric power systems and grid restoration; environmental issues; and other infrastructure systems.

The Government of Puerto Rico's recovery plan will be outcome-driven and developed in coordination with the Federal Oversight and Management Board (FOMB) established under Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA), the federal interagency, and key partners from private and nongovernmental entities using an agile process to identify recovery solutions. The approach includes engagement with key partners to gather information and solicit feedback, an assessment of damage and recovery needs by sector, prioritization of goals and objectives for recovery, identification and evaluation of potential solutions (i.e., courses of action [COAs]), estimations of rough order of magnitude costs for COAs, and the identification of funding mechanisms for COAs.

This comprehensive and collaborative planning process will ensure that the recovery plan is able to guide the substantial investments necessary to support Puerto Rico's rebuilding effort and is consistent with Puerto Rico's fiscal capacity to provide long-term operation and maintenance to rebuilt or replaced assets; the implementation of Public Assistance Alternative Procedures for permanent work in Puerto Rico; and the necessary actions to mitigate vulnerabilities to future disasters and increase community resilience.

This damage and needs assessment describes the pre-storm conditions in each sector and the specific impacts and damage from Hurricanes Irma and Maria. Each of the sector-specific chapters included this report is supported by a more detailed assessment, to be published at a later date in a series of forthcoming sector reports. We note that the needs assessment analysis contained in this document is not meant to be construed as a request for further appropriations.

This research was sponsored by the Federal Emergency Management Agency and conducted within the Strategy, Policy, and Operations Program of the Homeland Security Operational Analysis Center (HSOAC) federally funded research and development center (FFRDC).

About the Homeland Security Operational Analysis Center

The Homeland Security Act of 2002 (Section 305 of Public Law 107-296, as codified at 6 U.S.C. § 185), authorizes the Secretary of Homeland Security, acting through the Under Secretary for Science and Technology, to establish one or more FFRDCs to provide independent analysis of homeland security issues. The RAND Corporation operates the HSOAC as an FFRDC for the Department of Homeland Security (DHS) under contract HSHQDC-16-D-00007.

The HSOAC FFRDC provides the government with independent and objective analyses and advice in core areas important to the Department in support of policy development, decision making, alternative approaches, and new ideas on issues of significance. The HSOAC FFRDC also works with and supports other federal, state, local, tribal, and public- and private-sector organizations that make up the homeland security enterprise. The HSOAC FFRDC's research is undertaken by mutual consent with DHS and is organized as a set of discrete tasks. This report presents Project Management Plan HSOAC will use to undertake the Task Order 70FBR218F00000032, “Puerto Rico Economic & Disaster Recovery Plan: Integration and Analytic Support.”

The results presented in this report do not necessarily reflect official DHS opinion or policy. For more information on HSOAC, see www.rand.org/hsoac.

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Summary

Developing a recovery plan for Puerto Rico

In September 2017, Puerto Rico was struck by two major hurricanes—Irma and Maria—that severely damaged the Commonwealth over two weeks. The effects were widespread and catastrophic, causing extensive housing and infrastructure damage and leading to a months-long interruption of essential services to the people of Puerto Rico. Puerto Rico's challenges, however, extend back well before the 2017 hurricane season. An economic crisis spanning more than a decade, coupled with structural demographic, social, and infrastructure stresses, exacerbated the impact of the hurricanes and led to a broader long-term disaster that will necessitate transformative changes and investments in the years to come.

In response to the unprecedented damage inflicted on Puerto Rico by Hurricanes Irma and Maria, Congress passed the "Further Additional Supplemental Appropriations for Disaster Relief Requirements Act, 2018," which was signed into law on February 9, 2018 (*H.R.1892 - Bipartisan Budget Act of 2018*, 2018). This law requires the Governor of Puerto Rico, in coordination with FEMA, the Department of Treasury, Department of Energy, and other federal agencies with responsibilities under the National Disaster Recovery Framework (NDRF) to submit a report to Congress that describes Puerto Rico's 12- and 24-month economic and disaster recovery plan within 180 days of enactment of the legislation. Specifically, the plan should define "the priorities, goals, and expected outcomes of the recovery effort for the Commonwealth based on damage assessments prepared pursuant to Federal law, if applicable" for the following sectors: housing; economic issues; health and social services; natural and cultural resources; governance and civic institutions; electric power systems and grid restoration; environmental issues; and other infrastructure systems.

Assessing damage and needs

To ensure the Recovery Plan is as robust as possible and to respond to the requirements established by Congress, this assessment describes the damage from the hurricanes and remaining needs across the Commonwealth; it covers pre-hurricane conditions, including trends, challenges, and other long-term stresses affecting Puerto Rico prior to the 2017 hurricanes; hurricane damage, including direct damage to infrastructure or capital from the 2017 hurricanes as well as impacts to the economy, workforce, and population; post-hurricane conditions as of Spring 2018; and remaining needs that are candidates for recovery and not resolved as of Spring 2018, including both short-terms needs (that could be addressed within 12-24 months of the 2017 hurricane season) and longer-term needs (that could be addressed within ten years). The

assessment also describes any key information gaps or missing data as of the writing of this draft.

Across all sectors, over 100 separate data sources—with hundreds more individual datasets examined within those sources—were used for this assessment. The sources span all data types (qualitative, quantitative, primary, secondary) and cover a variety of time periods (historic, baseline, immediately post-hurricane, post-hurricane recovery). The Federal Emergency Management Agency (FEMA), other federal partners, and the Government of Puerto Rico provided most of the data, in the form of both quantitative datasets and documents and qualitative data gathered through interviews and discussions with subject-matter experts. Other sources of data and analysis included literature reviews, interviews with subject-matter experts and key stakeholders, media reporting (to gather or cross-check data), and open-source data. The team also collaborated closely with Federal Recovery Support Functions for related sectors, as well as members of the Puerto Rican Government (e.g., Central Recovery and Reconstruction Office) through briefings, workshops, meetings, and interim document reviews.

Puerto Rico before the 2017 hurricanes

Background

Situated between the Atlantic Ocean to the north and the Caribbean Sea to the south, Puerto Rico consists of a main island (3,515 square miles in size), two populated islands off its east coast, Culebra (24 square miles) and Vieques (51 square miles), and several smaller uninhabited islands (e.g., Mona).

Puerto Rico became a U.S. territory in 1898 at the end of the Spanish-American War. In 1917, the Jones-Shafroth Act granted citizenship to anyone born in Puerto Rico, and in 1950, Puerto Rico received the right to organize a government. Two years later, the territory adopted the Constitution of Puerto Rico, at which time it also became a Commonwealth. The Government of Puerto Rico is made up of executive, legislative, and judicial branches. The executive branch is headed by the governor, currently Ricardo Antonio Rosselló Nevares (elected in November 2016).

Puerto Rico is divided into 78 municipalities, ranging in size from 1,868 inhabitants in Culebra to 442,447 in San Juan (Government of Puerto Rico, 2018c). Each municipality is headed by a mayor and a municipal assembly. Municipalities have the authority to procure, provide, and manage some services, elect municipal assemblies, and manage municipal incomes ("Autonomous Municipalities Act of 1991," 1991).

As of July 2017, just prior to Hurricanes Irma and Maria, approximately 3.3 million people resided in Puerto Rico (U.S. Census Bureau American Fact Finder, 2016a), with 2.1 million residents living in the metropolitan area of the capital, San Juan (Data USA, 2018). In 2016, about 14 percent of Puerto Rico's population were young adults (15–24 years), 38 percent were prime-

working-age adults (25–54 years), and roughly 23 percent were over 60 (U.S. Census Bureau, 2018a). Over 98 percent of Puerto Ricans are ethnically Hispanic/Latino, and roughly 69 percent are white, 9 percent are black or African-American, and 7 percent are two or more races (U.S. Census Bureau, 2018a). In 2016, the median per capita income in the Commonwealth was $11,688. Forty-five percent of residents had an annual income below the federal poverty level.

Figure S.1. Map of Puerto Rico

Source: Google Maps

Critical stressors facing Puerto Rico before the hurricanes

In recent decades, Puerto Rico has faced a number of critical stressors, most importantly an economy in long-term decline.

Economic decline and debt crisis. Puerto Rico's economy has been in decline for more than 20 years, due in large part to the 1996 repeal by Congress of a 1976 tax credit (Internal Revenue Code Section 936) for U.S. corporations that generated income in Puerto Rico (MacEwan, 2016). Between 1997 and the end of the phaseout in 2006, manufacturing employment lost approximately 44,000 jobs (about 28 percent) (Bureau of Labor Statistics, 2018i), and the economy has been in near-continuous recession for the past two decades, with low labor-force participation and high unemployment relative to the rest of the U.S.

In conjunction with the contraction of the economy, lower revenues, high rates of expenditure, and heavy borrowing resulted in high and unsustainable levels of debt (Fisher and Horowitz, 2016; Commonwealth of Puerto Rico, 2016). Puerto Rico's credit rating dropped below investment grade in early 2014, followed by a series of defaults on debt payments. The financial crisis ultimately resulted in the passage of H.R. 5272, the Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA) in 2016, which established the FOMB and provided the frameworks for restructuring the Commonwealth's debt (Commonwealth of Puerto Rico, 2016; H.R. 5278 Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA), 2016).

Population dislocation. Puerto Ricans have a long history of migration to the continental U.S. (CONUS). Estimates based on flight data into and out of Puerto Rico indicate that, during the five years prior to Hurricanes Irma and Maria (2012–2016), the Commonwealth was seeing 1.5–2.0 percent net annual outmigration (U.S. Census Bureau American Fact Finder, 2016a), a trend exacerbated by a declining birth rate.

Import costs. Since 1922, Puerto Rico has been subject to the Jones Act, which requires U.S.-owned and flagged ships, built in the U.S. and crewed by predominantly U.S. citizens, to be used in coastwide trade. In Puerto Rico, this law may increase the price of many goods imported from U.S. ports for Puerto Rico residents because of the higher transportation costs associated with using Jones Act-qualified vessels. Because the electric grid is largely dependent on imported fuel, electricity is twice as expensive in Puerto Rico as in CONUS (U.S. Energy Information Administration, 2018a).

Ownership and responsibility. Across Puerto Rico, there has been a lack of clarity regarding asset ownership and responsibility for operations and maintenance, especially for public assets. According to the 2018 fiscal plan: "To date, with very few exceptions, the Government lacks a clear understanding of the number, type, location, legal status, and condition of the real estate assets it owns" (Government of Puerto Rico, 2018b). Many companies and tenants share responsibility for infrastructure, including telecommunications sites and seaports.

Pre-hurricane emergency preparedness. Municipalities in Puerto Rico are authorized by law to establish emergency plans, but a recent FEMA assessment found that mitigation plans were expired for 19 of the 78 municipalities in Puerto Rico, and as a result at least one quarter of the population of Puerto Rico was residing in municipalities without an approved mitigation plan prior to the 2017 hurricanes. Some municipalities appear to lack a detailed inventory of assets.

Socioeconomic and geographic vulnerability. Puerto Rico's aging population, high prevalence of poverty, challenges with educational attainment, number of rural communities, and other conditions made certain subsets of the population (e.g., the elderly, women, children and youth, residents of informal housing) more vulnerable to the impacts of disasters. High unemployment (above 10 percent) and low incomes have been persistent, and government assistance was significant even prior to the hurricanes, with nearly 39 percent of the population in 2016 receiving benefits from the Federal Nutrition Assistance Program (American Fact Finder, 2016a) and45 percent having public health insurance (including Medicare and Medicaid) (American Fact Finder, 2016b).

Economy

Conditions before the hurricanes

Prior to Hurricanes Irma and Maria, Puerto Rico faced four major challenges to economic development: outmigration of labor, outmigration of capital, low labor force participation, and significant public debt. Each of these challenges has multiple root causes:

- **Cost of doing business.** Puerto Rico is approximately 17 percent less efficient in terms of ease of doing business than the United States as a whole (World Bank Group, 2018) and faces serious deficiencies in recording and enforcing property rights, corporate tax burden, transaction costs of tax and permitting processes, and high energy costs.
- **Tax structure.** Puerto Rico's tax structure poses several challenges, including the Global Intangible Low Tax Income (GILTI), a 10.5 percent rate on profits from pharmaceutical, medical device, and other manufacturing imports from Puerto Rico to CONUS. State and local tax rates are also relatively high, though the system suffers from low collection rates (Federal Reserve Bank of New York, 2014b; Krueger, Teja and Wolfe, 2015)
- **Labor policy.** Current labor policies have created disincentives for younger and less-skilled residents to seek work, and contributed to low labor force participation (just under 40 percent) (Bureau of Labor Statistics, 2018f). Low education levels also have implications for Puerto Rico's workforce capacity and individual earning capacity. Relatively high taxes on labor (as well as sales taxes), coupled with social welfare benefits that are a high proportion of median income, may incentivize participation in Puerto Rico's sizable informal economy (Federal Reserve Bank of New York, 2014b; Krueger, Teja and Wolfe, 2015).
- **Transportation and the Jones Act.** The main economic impact of the Jones Act is extra expenses by excluding competent competitors from providing lower-cost transportation services between ports in Puerto Rico and other U.S. ports. Additionally, Puerto Rico does not have any coal, natural gas, or oil reserves and therefore must import fossil fuels to produce energy. This places Puerto Rico at a disadvantage compared with states that produce electric power at less than half of Puerto Rico's price.

Damage from the hurricanes

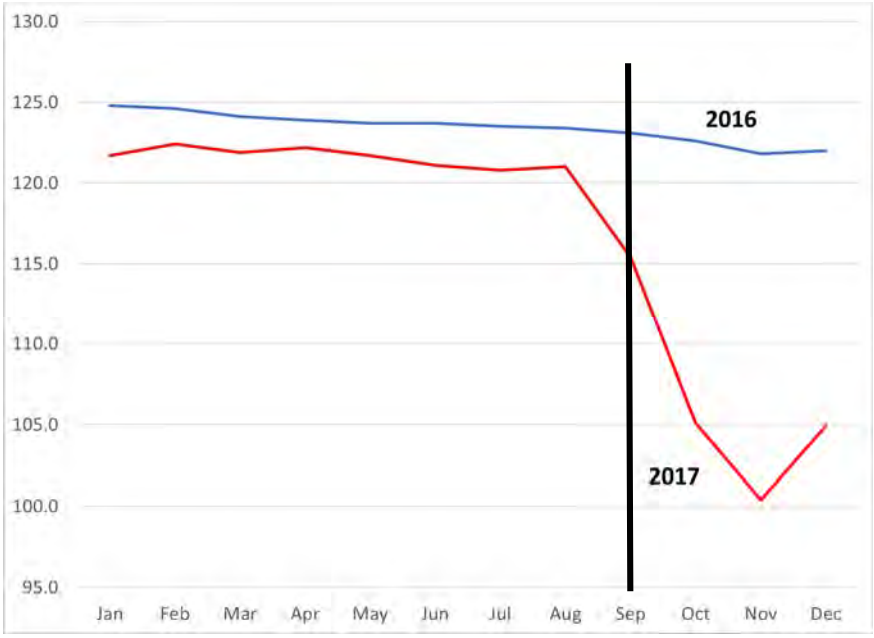
The economic losses due to Hurricanes Irma and Maria were large in the short run, with hundreds of thousands depending on external help for an extended period of time to meet basic needs. Hurricane Maria essentially destroyed Puerto Rico's already fragile electric grid, resulting in power outages that created additional economic hardships. Communications (internet, cellular, and landlines) were also severely disrupted, resulting in substantial business losses.

Coupled with the damage to various capital stocks, the short-term impact to economic activity was severe (Kuligowski, 2018). Although data are limited at the time of this writing due primarily in time lags, estimated impacts from post-storm data for the months following the hurricanes (September–December 2017) include[1] the following: a short-run decline in the Government Development Bank Economic Activity Index (GDB-EAI) (correlated with GNP) of approximately 12 percent (see Figure S.); agricultural production losses estimated at $227

[1] These damage estimates use only available data (generally through December 2017), and include economic activity from the recovery effort, which likely contributed to increases in economic activity following the storm.

million for crops being grown at the time of the hurricanes; losses of over $547 million to Puerto Rico's tourism industry; negative impacts to trade, especially exports; a decline in average payroll of approximately 4.35 percent for private employment and 1.27 percent for manufacturing; and decreases in the labor force.

Figure S.2. GDB Economic Activity Index (GDB-EAI), 2016–2017



NOTE: GDB-EAI is an indicator of general economic activity, generally highly correlated with the level of real GNP. Thick vertical line indicates the month of landfall for Hurricanes Irma and Maria (monthly time series). Source: Puerto Rico Fiscal Agency and Financial Advisory Authority, http://www.aafaf.pr.gov/.

Post-storm conditions

At the time of writing, many economic sectors (e.g., tourism, trade) have not returned to pre-storm economic production levels, though there are emerging signs of improvement (Department of Labor and Human Resources, 2017) such as upticks in traveler counts and value of exports. However, even when accounting for seasonal patterns and the influx of recovery funds and employment opportunities, employment and wages remain lower than they were pre-storm (Bureau of Labor Statistics, 2018g). High rates of poverty and unemployment, coupled with continued outmigration of working-age adults, are expected to present continued challenges. Furthermore, tax legislation passed in December 2017 (Public Law No. 115-97) imposed a 12.5 percent tax on income attributable to intellectual property for CONUS firms operating in Puerto Rico. Puerto Rico remains under FOMB oversight, and continued fiscal pressures will strain the Commonwealth's ability to operate and maintain repaired and rebuilt infrastructure.

Remaining needs and recovery priorities

The Government of Puerto Rico, the FOMB, and the Federal Government must work together to ensure real economic recovery in the short term, sustainable economic growth in the medium to long term, and real and measurable fiscal responsibility throughout the post-storm period.

Short-term needs

In the shorter term, economic recovery depends largely on the recovery of the other sectors, as they are typically demand- and supply-side factors that ultimately determine economic outcomes (in conjunction with the decisions of millions of autonomous individuals and firms acting largely in their own interests).

Longer-term needs

- Increase the attractiveness of doing business in Puerto Rico by lowering the costs of doing business, including both financial and non-financial costs, and stemming the flow of outmigration.
- Increase the formal labor force participation rate by reducing or removing disincentives for formal work.
- Broaden the tax base and increase the fiscal and economic resiliency of the Commonwealth through a flattening of the tax structure and lower dependence on particular tax exemptions.
- Increase fiscal discipline to ensure a sustainable and right-sized public sector.

People and Communities

Conditions before the storms

Prior to Hurricanes Irma and Maria, Puerto Rico faced several challenges that rendered many of its residents susceptible to the impacts of a disaster event:

- **Urbanization and environmental degradation.** In Puerto Rico, urbanization has often been accompanied by unplanned and spontaneous settlement, with many residents living in insecure houses that cannot withstand the effects of floods and hurricanes. Puerto Rico also faces the challenge of environmental degradation. The Río Grande de Arecibo has been polluted at multiple points (Newkirk, 2017), Puerto Rico has 23 Superfund sites, and, for over half a century, the U.S. military used the island of Vieques as a bomb-test site, causing widespread contamination.
- **Populations disproportionately affected by disaster.** Several critical populations were identified as especially susceptible to disasters in Puerto Rican: elderly persons, who may lack the resources to leave Puerto Rico or improve their situation there; female caregivers, who may bear a greater burden during times of disaster; young children, more than half of whom are in families whose income is below the poverty level; residents of informal housing (i.e., built without permits), which is particularly susceptible to hurricane damage; and residents of rural areas, who have faced more economic, demographic, and disaster recovery challenges than have coastal urban areas.

- **Chronic poverty and unemployment.** Unemployment in 2017 was 10.8 percent in Puerto Rico compared with 4.4 percent nationally (Bureau of labor Statistics, 2018). High relative levels of unemployment have likely contributed to a high rate of poverty in Puerto Rico, with more than 43 percent of incomes are below the federal poverty level.
- **Population loss and population aging.** Puerto Rico's population has been aging at a rapid pace while outmigration to CONUS has increased; as a result, Puerto Rico's population, workforce, and, consequently, its tax base continue to shrink.
- **Municipality operations.** Municipalities also faced several pre-existing challenges, including operating deficits and impacts from population loss, which has affected some municipalities disproportionately. Municipality capacity can be stretched due to staff reductions and overlap in responsibilities with the Government of Puerto Rico.
- **Emergency preparedness.** Almost 90 percent of the municipalities surveyed by HSOAC reported having disaster preparedness plans in place before 2017 hurricane season, and 72 percent of municipalities reported conducting emergency preparedness exercises at least once a year. However, only 37 percent reported that the plans worked adequately after the hurricanes.

Damage from the storms

Hurricane-related deaths. The physical toll of Hurricane Maria on the island's population is only beginning to be documented. Although the official death count from the Puerto Rico Department of Public Safety has been 64, subsequent analyses of vital statistics data have shown that about 1,000 more deaths occurred in the two months after the hurricane than expected (Sosa Pascual, 2017; Santos and Howard, 2017; Robles et al., 2017). The Governor has commissioned a study to examine excess mortality from the storm more closely.

Residents' physical/mental health. Many individuals described the negative impact of the hurricane on their physical and mental health. Some residents reported not having access to adequate medical care or medicine. Some reported that their communities and families had experienced loss of life, and some shared that they had witnessed suicide in their family and neighborhoods. Many interviewees related the psychological distress they had experienced themselves or observed.

Impact on populations disproportionately affected by disaster. Elderly people were reported to be depressed or traumatized by the events, and many faced challenges in storing medications and powering medical devices. Female caregivers described challenges in completing daily tasks, such as cooking or doing laundry, without electricity. The hurricanes have also proven disruptive for children and youth, particularly those in shelters or whose schools faced prolonged closures. Housing Secretary Fernando Gill stated that the informal housing sector accounted for the majority of the approximately 300,000 dwellings that suffered significant damage from the recent hurricanes (Viglucci, 2018). Isolated rural areas were also severely impacted as electrical power was restored more slowly outside urban areas (Stoneham, Hasty and Sesin, 2018). Damage to the agriculture sector was felt most acutely in rural areas, and transportation challenges were evident in hard-to-reach municipalities.

Impact on municipalities. In general, Hurricanes Irma and Maria exacerbated underlying problems that existed before the hurricanes—including placing additional stress on local economies and municipal finances—while also creating new issues. The fiscal situation of municipal governments is likely to deteriorate substantially in 2018 due to expected sharp declines in fee, license, and tax collections. Participants in roundtables reported heavy damage to municipally-owned assets, including roads and highways, buildings and other structures.

Municipal governments reported that their capacity to provide services to citizens had been diminished, in part because significant numbers of public employees left municipal government in key sectors such as public health and public safety. The hurricanes also created new public safety needs: for example, the loss of power across Puerto Rico created new safety issues which required police to divert resources from more proactive policing to patrolling poorly lit areas. Debris removal was also challenging, with only 17 percent of municipalities reporting having access to a landfill.

Post-storm conditions

The elderly population, women, young children, residents of informal housing, and rural residents continue to have significant unmet needs with respect to essential services, housing, medical and mental health, physical security, employment, and education. In the aftermath of the hurricanes, the immediate needs of these groups and regions seem to have been addressed mostly through family and local community support, but some indications suggest that they are beginning to receive help—for example, in the form of monetary and temporary housing assistance—from Commonwealth, Federal Government, and non-profit organizations. The departure of many Puerto Rican residents to CONUS has increased the vulnerability of those left behind, particularly the elderly population.

Participants in every roundtable reported that immediately following the hurricanes, municipal authorities undertook various activities to provide emergency relief to their communities and to begin the recovery process. In several cases, participants reported that how quickly and effectively they were able to respond seemed to be related to the municipality's proximity to San Juan and other large urban areas. Another key factor in how quickly municipalities have been able to engage in recovery seems to be related to municipal-level emergency preparedness and mitigation efforts prior to the hurricanes. However, no plans were in place to address a total collapse of the energy grid or to mitigate the extent of the landslides and debris that cut off entire municipalities. Participants also felt that the implementation of existing plans was ineffective, and described problems coordinating relief efforts and receiving assistance from federal and state agencies.

Remaining needs and recovery priorities

Short term

- Emergency preparedness across Puerto Rico's communities
- Impact of the hurricane in reshaping Puerto Rico's population trends
- Hazards of Puerto Rico's highest-risk communities
- Community resilience to disasters
- Ways that infrastructure decisions may exacerbate or relieve vulnerability
- Communication with GPR's constituents about recovery
- Duplication of efforts
- Ambiguity in municipal asset ownership.

Longer term

- Financial challenges' impact on municipal functions
- Barriers to economic development
- Transparency in data and decisionmaking
- Delivery of basic services and municipal planning
- Knowledge-sharing across municipalities.

Health, Social Services, and Education

This section comprises several mission areas: public health, health care services, behavioral health, environmental health, food safety and regulated medical products, long-term responder health issues, social services, disaster case management/referral to social services, children and youth in disasters, and education. Taken together, these mission areas seek to ensure a sufficient "human recovery," along with recovery of the economy and of physical infrastructure. For clarity, we discuss these issues within three categories: health, social services, and education.

Conditions before the hurricanes

Communities in Puerto Rico have faced widespread and persistent health, social service, and education challenges in many areas, as well as challenges related to the needs of vulnerable groups, including children and the elderly:

- **Burden of chronic disease.** The leading causes of death in Puerto Rico are heart disease, cancer, and diabetes. Before the 2017 hurricanes, overall rates of chronic disease were similar to those in CONUS, but may worsen as the population ages (Natural Resources Defense Council, 2017; Puerto Rico Department of Health).
- **Prevalence of mental health problems.** Overall rates of psychiatric disorders in Puerto Rico prior to the 2017 hurricanes were similar to those of CONUS (23.7 percent and 26.2 percent, respectively, in 2015), and suicide rates were declining, although gender differences in suicide were stark, with far more men than women committing suicide.
- **Exposure to environmental health hazards**. Puerto Rico has had long-term challenges related to water, air, and waste pollution. The energy system has contributed to the waste

problem: byproducts from coal energy generation include coal ash, which contains lead and arsenic, and some communities have been exposed to harmful sulfur dioxide from oil-based power generation (Federal Register, 2018).

- **Health care workforce and access to services.** Puerto Rico has struggled to provide healthcare services to all residents through a fragmented system of public, private, and non-profit healthcare. There are many health provider shortage areas, and 73 of the 78 municipalities are coded as "medically underserved." The number of people using mental health services is growing, but usage is still much lower than in the U.S. as a whole (Rodreguez, Greeman and Pesante, 2012, Substance Abuse and Mental Health Services Administration (SAMHSA), 2015).
- **Health care finance challenges.** The Government of Puerto Rico has borrowed money through municipal bonds to pay for public services, including Medicaid. Mi Salud reimbursement rates have not been high. Shortfalls in funding have limited access to care for low-income Puerto Ricans (Perreira et al., 2017).
- **Population changes creating new vulnerabilities.** Puerto Rico's elderly population has been increasing as a percentage of the total, with 37.2 percent of the population projected to be age 60 or older by 2050 (Puerto Rico Office of the Ombudsman for Elderly, 2015). Chronic health conditions are a concern for the elderly, and outmigration can result in loss of the student population and a decrease in the health care workforce.
- **Risk factors among children.** A large proportion of children in Puerto Rico live in poverty. Puerto Rico has also failed to meet targets on other indicators of child well-being, such as having permanency and stability in their living situation (Administration for Children and Families of Puerto Rico, 2015).
- **Lack of access to income and food assistance.** As of 2016, 45.1 percent of Puerto Ricans had incomes below the FPL, and approximately 470,000 received benefits from NAP (38.9 percent) (American Fact Finder, 2016a).
- **High concentration of economically disadvantaged and special needs students.** Puerto Rican schools serve a high concentration of economically disadvantaged students and students with disabilities. In 2016–17, the total number of economically disadvantaged students (those with family incomes under 150 percent of the FPL) represented 81 percent of the student population, while the number of students with disabilities or special needs in represented 32 percent of the student population (Puerto Rico Department of Education, 2017a).
- **Lagging student performance.** These challenges have contributed to Puerto Rican students' relatively low performance compared to students in CONUS. In Puerto Rico, fewer than one percent of students scored at or above a proficient score on the 2017 National Assessment of Educational Progress (NAEP) math assessments for fourth and eighth graders.
- **Financial and structural challenges in education system.** Enrollment in public schools has been declining and dropped by nearly a third since 2010 (Robles, 2017). This decline has been accompanied by a reduction in federal funding for some educational grants.

Damage from the hurricanes

Loss of access to care due to infrastructure damage. Damage to buildings and to electrical, water, and communications infrastructure closed hospitals, clinics, public health laboratories, Special Supplemental Nutrition Program for Women, Infants, and Children (WIC)

clinics, schools, elder-care facilities, and other social service agencies. This was especially true on the east side of Puerto Rico. Some of Puerto Rico's federally qualified health centers stayed open when the hurricanes made landfall, and most opened immediately afterwards. As many as 74 schools were closed permanently due to structural damage to the buildings (Governor of Puerto Rico, 2017a). As of February, roughly 20 percent of Head Start facilities were closed (U.S. Department of Health & Human Services and Office of the Assistant Secretary for Preparedness and Response (ASPR), 2017). Similarly, the University of Puerto Rico (UPR) system suffered a wide range of damage across campuses

Hazardous exposure. In the immediate aftermath of Hurricane Maria, much of the Puerto Rico's power grid was offline, and sewage wastewater treatment plants, including those upstream of drinking water supplies, were out of service, leading to contamination of drinking water sources. Many public buildings and surrounding areas incurred water damage, leading to potentially hazardous environmental conditions, such as the development of mold, an increase in rodents and pests, and the potential mobilization of hazardous chemicals and waste.

Service provision. Even at facilities that remained open, services were compromised by intermittent access to power and water, lack of access to electronic records, and absence of staff unable to come to work because of compromised roads and effects on their own homes and families. Water damage to paper records affected services and operations at the Department of Family and in many elder care facilities. In some schools, instruction was interrupted by the need to use the buildings as shelters.

Mental health. Increases in anxiety, depression, and PTSD were widely reported following the hurricanes. The need for mental health services was especially great in Toa Baja, where storm damage was among the worst. Suicide also appears to be an issue: the rate of suicide had fallen in the most recent three-year assessment periods, but initial reports indicate that it spiked following Maria. As of January 22, 2018, the suicide hotline had received 3,050 calls since the storm, a 246 percent increase compared to the same time the previous year (Governor of Puerto Rico, 2017b).

Impacts on school operations and student outcomes. Across Puerto Rico, schools were closed for a total of 33 to 70 days (FEMA, 2018). The loss of instructional time caused by school closure is likely to have a negative impact on student achievement for the current and perhaps even the next school year (Goodman, 2014; Fuller, 2013). A December report based on data from school visits noted an increase in behavioral health needs among students, families, faculty and staff (FEMA, 2018). The educational impacts of these disruptions are difficult to estimate. Some effects have been mitigated through flexible decision-making.

Post-storm conditions

At the time of writing, most critical infrastructure related to health and social services (e.g., hospitals, water treatment facilities) is operational. However, some infrastructure (including six hospitals) is operating at limited capacity or on emergency generator power (Kaiser Family

Foundation, 2018). Access to health care is variable and was also an issue identified by municipal leaders in a survey conducted between April 24, 2018 and June 8, 2018. As of March 8, 2018, the Department of Education estimated that between 64 and 88 percent of teachers and 67 to 87 percent of principals have reported back to work. On March 1, 2018, the Additional Supplemental Appropriations for Disaster Relief Act of 2017 made an additional $1.27 billion available for Puerto Rico's NAP for nine months (Caribbean Business Staff, 2018), and the federal Food and Nutrition Service approved a request to extend a limited number of waivers to schools operating the National School Lunch Program and School Breakfast Program and to child care institutions that operate the Child and Adult Care Food Program thorough March 31, 2018 (U.S. Department of Agriculture, 2017).

Infectious diseases such as influenza have been controlled to within comparable rates in CONUS, although concerns about water quality persist. Remaining debris on roads, in schools, and in residential facilities continues to present transportation challenges (especially in rural areas) and hazards to public safety. Key issues that remain for public and environmental health include lack of access to potable water, water safety and access concerns, and unsafe living conditions with respect to mold, proximity to debris, and pests. There are also concerns about the impact of storm-related trauma on long-term mental and behavioral health in the Commonwealth (FEMA, 2018).

Remaining needs and recovery priorities

Short-term needs

- Repairs to remaining health care, public health, and school building infrastructure damage.
- Reliable access to safe drinking water to address safety concerns.
- Improved mental health care access to address suicide and other mental health issues.

Longer-term needs

- Improved financial viability of the health system to sustainably provide health care services to the future population of Puerto Rico.
- A stronger and better funded social services sector to provide adequate services and benefits to populations disproportionaltely affected by disasters (PDADs).
- Improved or full functionality for all schools, with options to address the lingering effects of learning loss and mental health effects on students' ability to learn.

Housing

Conditions before the hurricanes

Puerto Rico's housing sector was in decline before the hurricanes hit. Both housing prices and rents had been in decline since 2010 (Kasper, 2018), with high vacancy rates and many areas

plagued by abandoned and blighted buildings. The HSOAC team identified a number of other pre-storm issues:

- **Vulnerability to natural hazards.** Housing in Puerto Rico is exposed to risks from high winds, flooding, erosion, earthquakes, and landslides (Morelock and Barreto, 2000; Skibell, 2018); a substantial percentage of the housing stock is not sturdy enough to withstand these risks and is built in high-risk locations, such as near rivers. coastlines, or earthquake liquefaction zones (Morelock and Barreto, 2000; Skibell, 2018). However, the percentage of homes with either homeowners' insurance, or flood insurance, is low.
- **Informal housing and poor code enforcement.** Puerto Rico's building codes were aligned with international standards only in 2011 (Commonwealth of Puerto Rico Regulations and Permits Administration, 1999; Commonwealth of Puerto Rico Oficina de Gerencia de Permisos, 2016). Eenforcement has been inadequate, and as much as 55 percent of residential or commercial structures in Puerto Rico may be built without permits, often on land not owned by the resident or builder.
- **Title, tax records, and insurance.** Recent estimates suggest that, prior to the 2017 hurricanes, only about 70 percent of property titles were recorded in the land registry, and many of those are likely out of date (Governor of Puerto Rico, 2017a). The lack of property title records has created challenges for providing assistance following disasters and complicates processes for collecting property taxes. In addition, many residential structures lacked flood and homeowner's insurance, and Puerto Rico's confusing address system has made it difficult to map properties in geographic information systems and determine risk exposure (Kasper, 2018).

Damage from the hurricanes

Damage to housing from the hurricanes includes damage to real estate as well as personal property. The number of registrants for FEMA individual assistance following Hurricanes Irma and Maria totaled over 1.1 million, meaning that approximately 90 percent of the Commonwealth's 1.23 million households applied for assistance. When they registered for FEMA assistance, approximately two-thirds of owners (527,000 out of 768,000) indicated that the hurricanes had caused damage to their real property, and just under three-quarters indicated personal property loss.

The HSOAC team used data from two analyses—FEMA inspections of 596,000 properties and from a modeling-based approach—to estimate the cost of property damage; they estimated the cost of damage—to owner-occupied properties only—to be approximately $17.2 billion. Given the large number of renter- or multi-family-occupied properties, as well as the existence of many vacation or seasonal properties, the costs of damage to Puerto Rico's housing stock overall (including multi-family, renter-occupied, and vacation homes) could be as much as $33.9 billion.

Post-storm conditions

As of May 2018, FEMA had approved $517 million in home repair and replacement assistance programs and an additional $402 million in personal property assistance through its Individual

Assistance Program. FEMA, which administers the Sheltering and Temporary Emergency Power (STEP) program, has disbursed $221 million in recovery grants. More than $358 million has been paid out to date on homeowners' policies written by private insurance companies, and insurance policies held on government-owned public housing are expected to pay $71 million with additional recoveries on policies held by the Puerto Rico Housing Finance Authority. The Small Business Administration (SBA) has provided $1.2 billion in low-interest loans to nearly 41,000 households. Despite these investments, substantial additional resources will be needed to repair the remaining damaged residential structures, with estimates of unmet need ranging from $28.4 to $31.9 billion.

Remaining needs and recovery priorities

Short-term needs

- Repairs to residential structures damaged or destroyed during the 2017 hurricane season
- Better enforced land-use plans and improved compliance with building permit requirements
- A strategy to provide adequate affordable housing

Longer-term needs

- A process for establishing property titles
- A comprehensive property registry
- A modernized property address system
- An integrated housing data system
- A strategy to increase take-up rates of risk-based insurance and maintain them over time
- New resources and strategies to improve housing resilience to disaster risk

Natural Resources

Conditions before the hurricanes

For purposes of this assessment, we define natural resources to include coastal resources, forestry and key species, and other natural resources, including solid waste and landfills. Key challenges facing these subsectors include the following:

- **Damage and stress to coastal resources.** Human activity, combined with natural processes and environmental changes, has damaged or severely eroded coastal areas of Puerto Rico over several decades. Prior to the 2017 hurricanes, coastal resources—including mangroves and wetlands, seagrasses, coral reefs, and beaches and dunes—were stressed by pollution, over-fishing, ocean acidification, sea-level rise, erosion, excess warming, development practices, recreational damage, and other human-induced effects, collectively making them more vulnerable to hurricane damage (Dee, Horii and Thornhill, 2014; Miller and Lugo, 2009).
- **Forestry and key species.** Persistent problems affecting Puerto Rico's forests, wildlife, and other natural resources have included urban and suburban development pressures,

lack of sustainable land use planning, invasive species threats, forest and other habitat fragmentation, climate change (especially sea level rise), wildfires, pests and diseases, and impacts from economic challenges (Puerto Rico Department of Natural and Environmental Resources, 2015a)

- **Other natural resource impacts.** Before Hurricane Maria, Puerto Rico had 29 operational landfills, most operating beyond capacity and nearly half not in compliance with environmental regulations (U.S. Environmental Protection Agency, 2016a). Landfills are also subject to leaching and flooding, with the potential for harm to aquifers, wetlands and waterways, drinking water supplies, natural reserves, federal endangered species, and homes or schools (Plossl, 2018c).

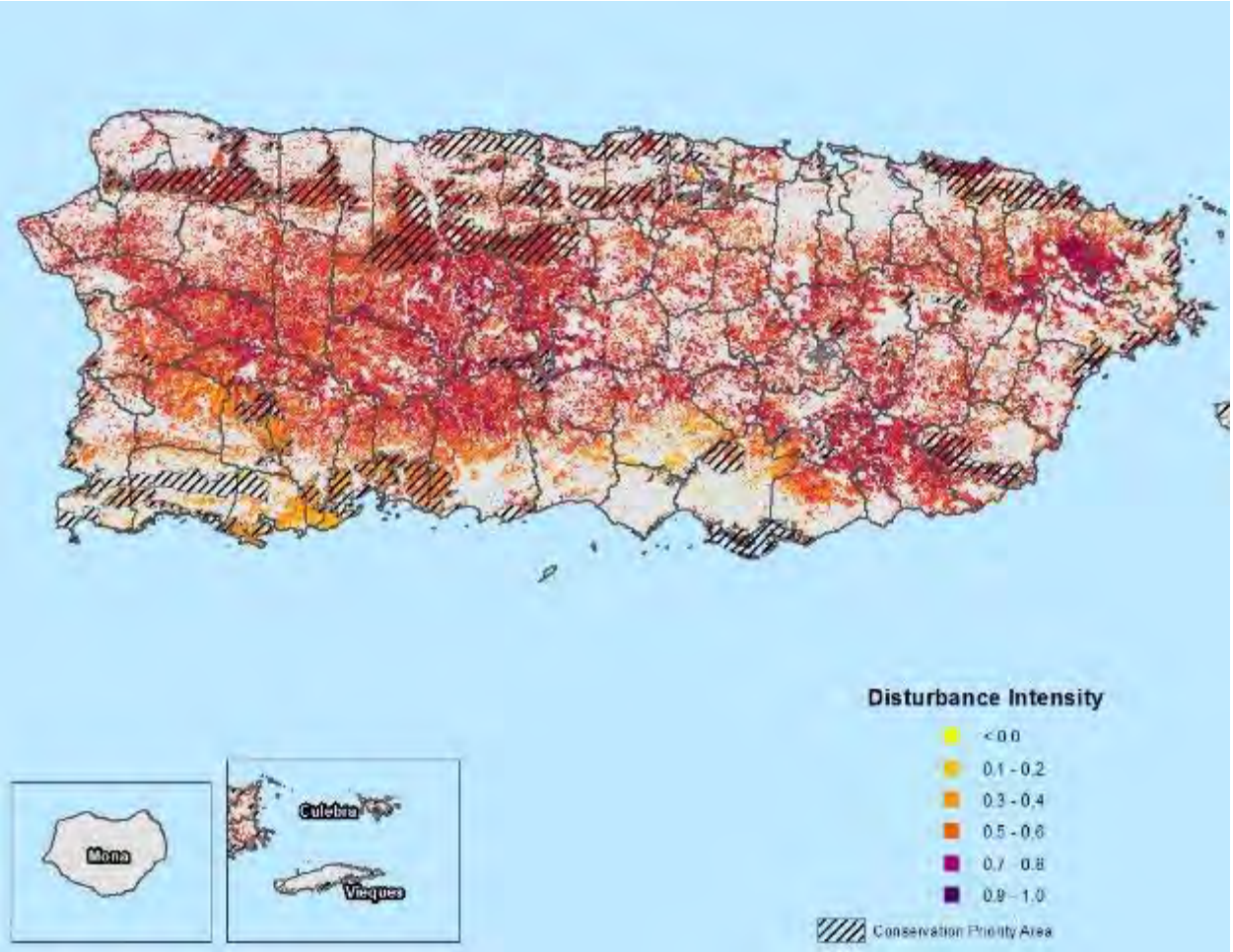
Damage from the hurricanes

Coastal resources. Impacts to coastal resources from the hurricanes included wetland and mangrove damage from winds; changes in biodiversity, invasive species, and a change in the proportion of various types of vegetation (Soler-Figuero and Ambienta Inc, 2018); severely eroded beaches and dunes; stranded boats; damage to coral reefs; and possible wave and scouring damage to seagrasses, reducing the wave attenuation and flood protection provided by these systems.

Forestry and key species. Hurricane Maria's path cut across many of Puerto Rico's forested and natural protection areas. Consequently, damage to forests was widespread (Figure S.3), affecting forest functions that support plant and animal habitats, diminishing recreational opportunities, and increasing landslide, sedimentation, and stormwater runoff potential. Hurricane Maria killed or severely damaged 23 to 31 million trees across Puerto Rico (Feng et al., 2018). Parks also suffered structural damage with significant debris and other damage affecting trails and facilities. Hurricane Maria also caused damage to species habitats directly, while beach erosion both directly and indirectly impacted sea turtle nests and nesting grounds (Leibach, 2017).

Other natural resource impacts. Hurricanes Irma and Maria led to landslides in the interior part of Puerto Rico, resulting in blocked roads, increased sedimentation of reservoirs and behind dams, disruptions to species habitats, and significant amounts of debris. Vegetative debris caused flooding hazards or barriers to aquatic species and limited access to some state forests, natural reserves, ecological corridors, and wildlife refuges (Adams, 2018). The hurricanes caused varying degrees of damage on the structural integrity of sanitary landfill systems and open dumps ("Sanitary Landfill Systems (SRS) and Open Dumps in Operation in Puerto Rico,"). Puerto Rico's Solid Waste Authority estimated that the hurricanes created 6.2 million cubic yards of waste and debris, enough to fill about 43 football stadiums with waste eight stories high (Kennedy and Migaki, 2017a).

Figure S.3. Forest Area Disturbance from Hurricane Maria



Notes: Darker shades of red represent more intense disturbance (Fang et al., 2018); Puerto Rico State Wildlife Action Plan: Ten-Year Review. 2015. Department of Natural and Environmental Resources. Available at: http://arcg.is/180Lri.

Post-storm conditions

Damage assessments of natural resources are ongoing in the post-storm period. At the time of writing, coral reef and critical species stabilization (e.g., sea turtles) is underway, though incomplete. Imagery, Light Detection and Ranging (LiDAR), and other measurement data of forests, landslides, beaches and dunes are being gathered and analyzed. Debris removal and processing and repurposing of salvageable wood debris was 75 percent complete as of February 2018 (Kornacki, 2018b).

Remaining needs and recovery priorities

Short-term needs

- Restored functionality of coastal resources near human-impacted areas and critical habitats near coasts.

- Completed natural resources damage assessments, as well as assessments of cross-cutting and secondary impacts.
- Identification of areas of focus for reforestation, and mitigation actions to aid threatened and endangered species recovery
- Data collection to fill key information gaps that could have important environmental quality and human health impacts, such as information on open dumps and landfills or soils data.

Longer-term needs

- New or updated forest and species conservation assessments.
- New strategies for landscape-scale conservation and habitat restoration to help restore and preserve entire ecosystems and as many species at risk as possible.
- Habitat restoration for interior areas of the main island affected by landslides, as well as restored site accessibility.
- New approaches to address landfill overcapacity challenges.
- Enhanced resilience of wetlands, mangroves, dunes, and beaches to serve as a natural buffer against future storm impacts.
- Invasive species management, especially habitats where invasive species impacts may have been exacerbated by storm damage.
- Improved water quality and new investments to address high rates of sedimentation in freshwater reservoirs (also see Water sector below).

Cultural Resources

Conditions before the hurricanes

This section focuses on four types of historic, cultural, and recreational sites in Puerto Rico:

- **Archeological and historic sites.** Pre-storm assessments and emergency plans exist for some of Puerto Rico's significant cultural and historic sites. However, a 2014 UNESCO assessment of La Fortaleza and San Juan Historic Site (UNESCO, 2014) found several aspects of the site in need of improvement, including the detrimental impact of tourism, invasive species (particularly feral cats), and wind/water erosion (UNESCO, 2014).
- **Museums, libraries, and archives.** Financial resilience has been hindered by cultural and historical resources' ownership structure and not-for-profit status. Some cultural sites, including museums and libraries, have historically relied on subsidies or private donations to operate.[2]
- **Performing arts, sports facilities, and parks and recreational facilities.** Due to uncertain ownership and budgetary shortfalls, many Commonwealth and municipal parks have not been maintained in recent decades, and key questions remain regarding who has authority to make decisions about the future of these sites or legal standing to apply for federal aid.
- **Artists and artisans.** As in many communities, artists and artisans in Puerto Rico face challenges related to informal production spaces and piecemeal income streams. Such

[2] Personal communication with Pablo Guardiola, March 15, 2018.

conditions can make it difficult to qualify for funding from public and not-for-profit sources.

Damage from the hurricanes

Damage to structures and collections. Wind and water from Hurricanes Irma and Maria weakened physical structures of many historic and cultural sites, such as Fortin San Jeronimo (an 18th century fortress) and the National Library and General Archives. Water damage also increased the risk of mold (Bajandas, 2018; Shepard, 2017), including in smaller museums, libraries, and arts organizations. Debris from the hurricanes caused damage to physical structures in recreation sites and park facilities. Disruption of public services sometimes created opportunities for additional damage, such as when disruptions in law enforcement services enabled theft of valuable park building components.

Impact on arts and artists. Although there has been no formal assessment of artists, estimates suggest that total FEMA registrations from artists average 4.9 per municipality, ranging from 0 to 58 based on the uneven distribution of artists around the Commonwealth. Most artists and arts organizations earned no income from their art practice for 3 to 6 months after the storm. Many sources project continuing losses well into 2018, if not after.[3]

Post-storm conditions

In many cases, cultural institutions have re-opened to the public, but sometimes with temporary fixes for structural damage or with diesel generators to provide power. Parks and recreation sites have reopened as debris and other obstacles have been cleared, although parks vary widely in attention received, both before and after the hurricanes. Cultural institutions are also being provided emergency preparedness education, response kits, and protocols in preparation for future disasters. After a disaster, funding for the cultural sector becomes available through a patchwork of government relief programs, foundations, other arts organizations, and charitable groups. However, navigating the eligibility requirements for the various funding sources is not easy, and there is no centralized mechanism to match those who need funding with those who can provide it. Further, artists who do not own their studios or workspaces may not qualify for funds to rebuild the physical structures.

Remaining needs and recovery priorities

Short-term needs

- Completed cultural resources damage assessments.
- Data collection to fill remaining information gaps on cultural resources, including information on artists and artisans.

[3]Discussion with Amy Schwartzman based on her data and research conducted in April–May 2018.

- Improved emergency preparedness for cultural heritage sites, cultural institutions, and artists.

Longer-term needs

- New information and datasets describing historical and cultural heritage sites.
- Repairs and future resilience of parks and recreation sites.
- Additional funding sources to support recovery in the cultural sector.

Energy Systems

Conditions before the hurricanes

The generating capacity of the Puerto Rico Electricity grid has been stable at approximately 6 GW over the past five years (PREPA, 2018b) of which approximately 57 percent was produced from petroleum (fuel oil), 31 percent from natural gas, 18 percent from coal, and 3 percent from renewable energy (wind, solar, biomass, and hydroelectricity) sources (U.S. Energy Information Administration, 2018a).

Prior to Hurricanes Irma and Maria, Puerto Rico's energy systems, consisting of electricity and liquid fuels, faced difficulties with infrastructure maintenance, funding, and governance:

- **Aging infrastructure.** Puerto Rico's system of electricity generation and distribution was aging and stressed prior to the hurricanes, with five of PREPA's eight major power plants constructed before 1980 (PREPA) and consumers experiencing blackout rates four to five times higher than those for other American utilities (Synapse Energy, 2016). The connecting transmission system traversed mountainous geography, reducing accessibility. Infrastructure maintenance has been challenging due to more-rapid degradation in a hot, humid, saline, densely vegetated environment, especially for remote assets ("Be PREPA-ed: The story of Puerto Rico's power grid is the story of Puerto Rico," 2017).
- **Funding challenges.** Economic and population trends in Puerto Rico led to major challenges in funding the maintenance, expansion, and improvement of Puerto Rico's energy sector. These challenges contributed to Puerto Rico's high level of debt—$73 billion, or approximately 68 percent of gross domestic product (GDP)—and PREPA's debt, which includes over $9 billion in outstanding bonds and an additional $3.6 billion in underfunded pension obligations (PREPA, 2017; Walsh, 2017; Bradford, 2017). The electricity sector's dependence on fuels imported from CONUS also led to higher electricity prices (U.S. Energy Information Administration, 2018a).
- **Governance challenges.** In 2014, following a series of complaints about management and electricity service, Puerto Rico created the Puerto Rico Energy Commission (PREC) as an independent oversight board and regulatory authority charged with implementing energy policy. In mid-2017, due to the inability to repay their billions of dollars of outstanding debt, PREPA began a judicial debt restructuring process pursuant to Title III of PROMESA.

Damage from the hurricanes

The damage to the electricity sector from the 2017 hurricanes was catastrophic, causing the entire transmission system to fail. After Hurricane Maria, all port services were interrupted, and, without electricity and with many roads impassable to delivery trucks, fuel for cars and for generators providing backup power was scarce in the days immediately following the storm.

Electricity. One hundred percent of the Commonwealth lost power during Hurricane Maria. The larger, fossil fuel-based power plants that generate most of Puerto Rico's electricity did not suffer major damage during the storm (Puerto Rico Electric Power Authority, 2017). However, renewable power installations suffered a wide range of damage, and damage to the electricity grid—including downed power lines, transmission lines, and poles—was severe. According to USACE, as of March 19, 2018, the entire restoration effort across transmission, sub-transmission, and distribution required 170,000 insulators, 4,900 miles (26 million feet) of conductors, 780 towers, 50,000 USACE poles, and 10,000 transformers.

Fuels. Direct damage from the hurricanes was incurred by the infrastructure needed for fuel import, fuel stockpiles, and distribution channels within Puerto Rico. In addition, damage to other sectors, especially transportation and electricity, likely impacted the availability of fuel in the wake of the storm (U.S. Department of Energy and Office of Cybersecurity Energy Security and Emergency Response; U.S. Department of Energy, 2018a). Shipping terminals suffered damage to buildings, fencing, fenders, and signage. In October 2017, 21 percent of Puerto Rico's retail gas stations were reported closed, whether due to damage from the storm, lack of fuel or power, or other reasons.

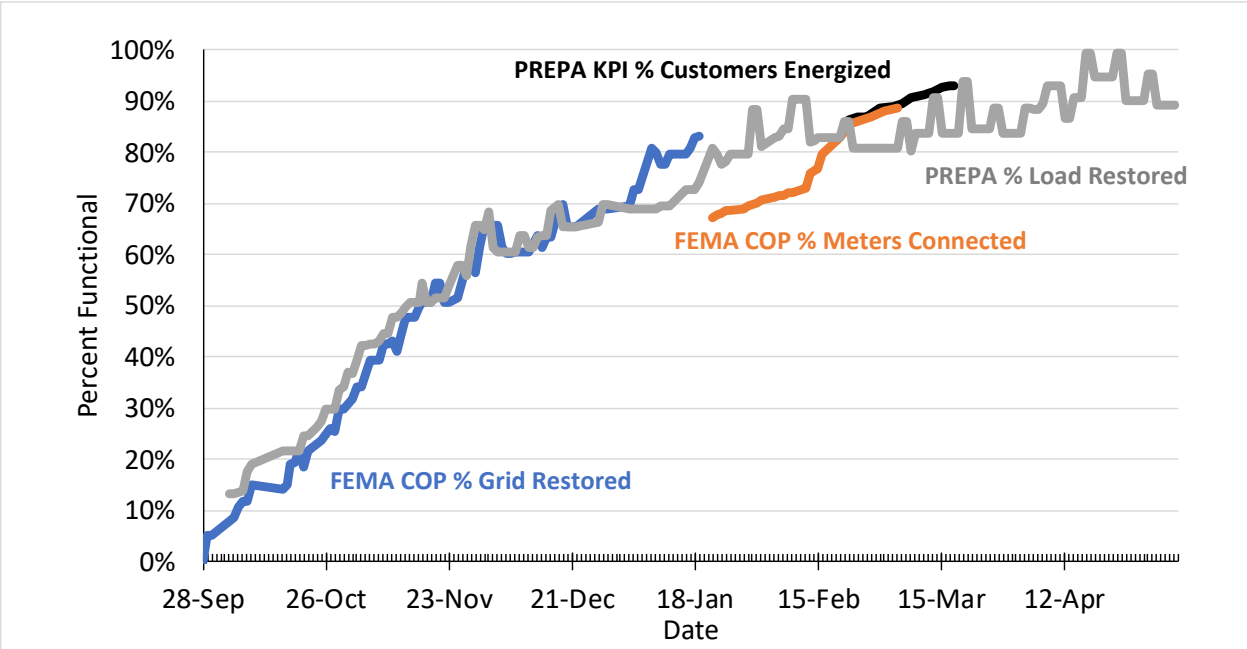
Post-storm conditions

As of a March 18, 2018 snapshot, USACE data showed that power had been restored to 92.9 percent of customers. Seventy-three percent of transmission lines were energized (U.S. Army Corps of Engineers, 2018a), allowing power to be supplied the vast majority of substations; however, this power was not as reliable as it would have been if all transmission lines were in service. As of March 2018, unofficial reports suggest that about seven percent of Puerto Rico remained without power, primarily in mountainous areas that are difficult to access. Repairs have been slowed by a host of factors, including differences in voltage and other technical specifications from CONUS systems, making parts harder to obtain.

Figure S.4 shows the history of the power restoration effort starting September 28, 2017—about one week after the storm—until May 8, 2018. While much progress has been made, it is expected that final steps will continue to be slow. Attaining full reliability and 100 percent service is expected to require substantial additional time and effort.

In terms of fuels, by late March 2018, fuel stocks were assessed to be adequate, and the number of closed retail gas stations had declined to 140 (U.S. Department of Energy, 2018a)

Figure S.4. Daily Overall Grid Status from Sept 28, 2017 to May 7, 2018



NOTE: Various measures indicate slightly different aspects of grid restoration. The discontinuity around January 20, 2018 reflects a change in FEMA's indicator of grid status from PREPA's "% of the power grid restored" (percentage of normal peak load) from September 28 to January 19, to "% of power meters connected" from January 22 to March 5. PREPA's Daily Updates resume on February 5, tracking "% of customers energized," which tracks well with the later FEMA COP indicator. SOURCE: (Puerto Rico Electric Power Authority, 2018)

Remaining needs and recovery priorities

Short-term needs

- Electricity service for the approximately five percent of Puerto Rican customers who are still without power
- New inventory of energy assets to understand what types of energy assets exist and where they are currently located so that emergency responders can enact repairs
- Stockpiles of sufficient repair material and numbers of trained personnel or contractors authorized to conduct work in potentially unsafe conditions.

Longer-term needs

- Enhanced future response capacity, including improved communications within utility, to customers (e.g., systems operation and billing), and among Commonwealth and federal agencies
- Sustainable funding for energy systems, ensuring sufficient funds for restoration and repair as well as future operations and maintenance
- A clear, unified vision and improved management of the Energy sector.

Water

Conditions before the hurricanes

Puerto Rico's water sector encompasses drinking water and wastewater services, stormwater management, and flood control. Puerto Rico faced various water and wastewater system challenges before the hurricanes, including inadequate infrastructure, and lack of compliance with regulatory standards, such as violations of Safe Drinking Water Act (SDWA) and Clean Water Act (CWA) water quality standards:

- **PRASA water and wastewater systems.** The Puerto Rico Aqueduct and Sewer Authority (PRASA) is the primary supplier of drinking water and wastewater services in Puerto Rico. In 2015, 99.5 percent of residents received water at some point from PRASA and other community drinking water systems that violated the SDWA (e.g., health standards violations, failure to test or report on water safety) (Natural Resources Defense Council, 2017). High leakage rates (50 to 55 percent) have contributed to a significant volume of non-revenue water that is further heightened by poor metering and illegal connections (Puerto Rico Aqueduct and Sewer Authority (PRASA), 2018). PRASA has also experienced challenges related to drought, lack of supply diversification, and financial sustainability.
- **Non-PRASA water and wastewater systems.** Most non-PRASA water utilities are small community systems, typically located in rural areas and relying on both surface water and groundwater for their supply. Prior to the 2017 hurricanes, many water sources were inadequately protected from contamination, and treatment, distribution, and revenue collection have been performed by the communities themselves.
- **Stormwater and flood control.** Stormwater management functions are typically the responsibility of municipalities or, in some urban areas, PRASA. Lack of maintenance and oversight of these systems has led to clogging and blockages, and illegal wastewater connections have complicated operations and degraded the quality of receiving waters. As of 2010, several levees in Puerto Rico were out of compliance with USACE design standards and judged to be ineffective some flooding events.

Damage from the hurricanes

PRASA water and wastewater. Immediately following the hurricanes, almost all PRASA customers lacked drinking water. Twenty-two of the system's 51 wastewater treatment plants were non-operational and three facilities were fully inundated. In addition, 222 of PRASA's 714 sanitary pumping stations were out of service. Significant damage to trunk sewers caused major sewage overflows, particularly at intersections with surface water. Over 13.7 billion gallons of untreated wastewater was discharged into the San Juan metropolitan area due to energy failures at PRASA wastewater treatment plants and pumping stations (National Oceanic and Atmospheric Administration, 2018b).

Non-PRASA water and wastewater. The primary impact of the hurricanes on non-PRASA facilities was the loss of grid power, which rendered many of the community well and surface

pumps inoperable. Other concerns included damage to water distribution pipes and storage tanks, clogging, and site inaccessibility due to debris.

Stormwater and flood mitigation impacts. Following Hurricanes Irma and Maria, portions of stormwater infrastructure were either damaged or not fully functional. Estimates of stormwater sewer system damage amount to more than $215 million. The hurricanes also damaged some of Puerto Rico's dams and levees. The *Build Back Better* report stated that, in total, 13 levee systems were damaged by the hurricanes, although surveys conducted by USACE in early October reported damage to only five levee systems. USACE found issues and/or damage at many of the 18 dams[4] it surveyed in September/October 2017, although only one, the Guajataca, was assessed as having major safety issues of concern.

Post-storm conditions

As of February 2018, all water and wastewater treatment plants in each of PRASA's principal service regions were operational, although 10 non-PRASA facilities were classified as a state priority and eight were classified as a U.S. EPA priority. To date, solar-powered water pumping systems have been installed to restore drinking water provision in 46 non-PRASA communities ("EPA Teams Up with Non-Governmental Organizations to Help Restore Drinking Water to Communities in Puerto Rico," 2017; Water Mission, 2018) In addition, as of January, 2018, Guajataca Dam's integrity was somewhat stabilized and the second phase of repairs was underway to provide temporary fixes to the spillways. Pumps have been installed to maintain the reservoir's supply of water while recovery efforts continue.

Remaining needs and recovery priorities

Short-term needs

- Repairs to Guajataca Dam, especially the water supply conduit and spillway, to address immediate safety concerns.
- Reliable electricity supply to reduce water safety risks at drinking water and wastewater facilities.
- Repairs to water treatment facilities to restore the confidence that Puerto Rico residents and industries have in the safety of water systems.
- Repairs to wastewater pumping stations and treatment plants to avoid discharge of untreated effluent to Puerto Rico's waterways.

Longer-term needs

- Enhanced fiscal sustainability of the water sector, addressing PRASA's ongoing challenges with servicing federal and private debt, fees evasion, declining population, and lack of access to capital markets.

[4] Personal communication ESF-2 and other FEMA officials March 2, 2018.

- New investment addressing infrastructure degradation across drinking water, wastewater, and dams and levee systems to reduce water quality violations and improve regulatory compliance.
- Strategies to address long-term sedimentation issues, exacerbated by Hurricane Maria in order to enhance capacity, operations, and water quality in Puerto Rico's reservoirs.
- Improved capacity to manage drought risk for Puerto Rico's water systems.

Telecommunications/Information Technology

Conditions before the hurricanes

Over 80 percent of Puerto Rico customers exclusively used cellular phone or other wireless connection prior to the hurricanes (Hurricane Maria Task Force, 2017). Pre-existing issues in Puerto Rico's communications/information technology (IT) sector involved infrastructure maintenance, difficult geography, and complex ownership or responsibility for key assets:

- **Infrastructure maintenance issues.** Puerto Rico's telecommunications infrastructure was in a fragile state prior to the hurricanes.[5] Telecommunication towers were overloaded with equipment, and many telecommunication sites were not properly maintained.[6]
- **Difficult geography.** The remote mountainous location of some key sites made them difficult to access for regular maintenance or vegetation clearing. In many cases, response equipment could not be prepositioned before the storm due to the risk it would be lost, damaged, or destroyed (Federal Communications Commission, 2017)).[7]
- **Complex ownership.** Many telecommunication sites are located at sites with multiple owners and multiple users, and numerous users, including police, emergency medical service (EMS), PREMA, and private carriers, who may lease both a space in the tower to install their antennas and a part of the building to house their electronic equipment. For many sites it can be difficult to determine which owner is responsible maintenance or repairs.[8] Governance challenges for emergency telecommunications were identified as critical pre-storm issue (DHS Office of Emergency Communications and Interoperable Communications Technical Assistance Program, 2018b).

Damage from the hurricanes

Emergency communications

Hurricane Maria severely impacted Puerto Rico's ability to respond to 9-1-1 emergency calls. Moreover, citizens fortunate enough to have their emergency calls received by 9-1-1 dispatchers may not have received a response from emergency services due to the lack of emergency telecommunications linkages across municipalities and agencies. Public safety

[5] Personal communication, ESF-2 and other FEMA officials, March 2, 2018

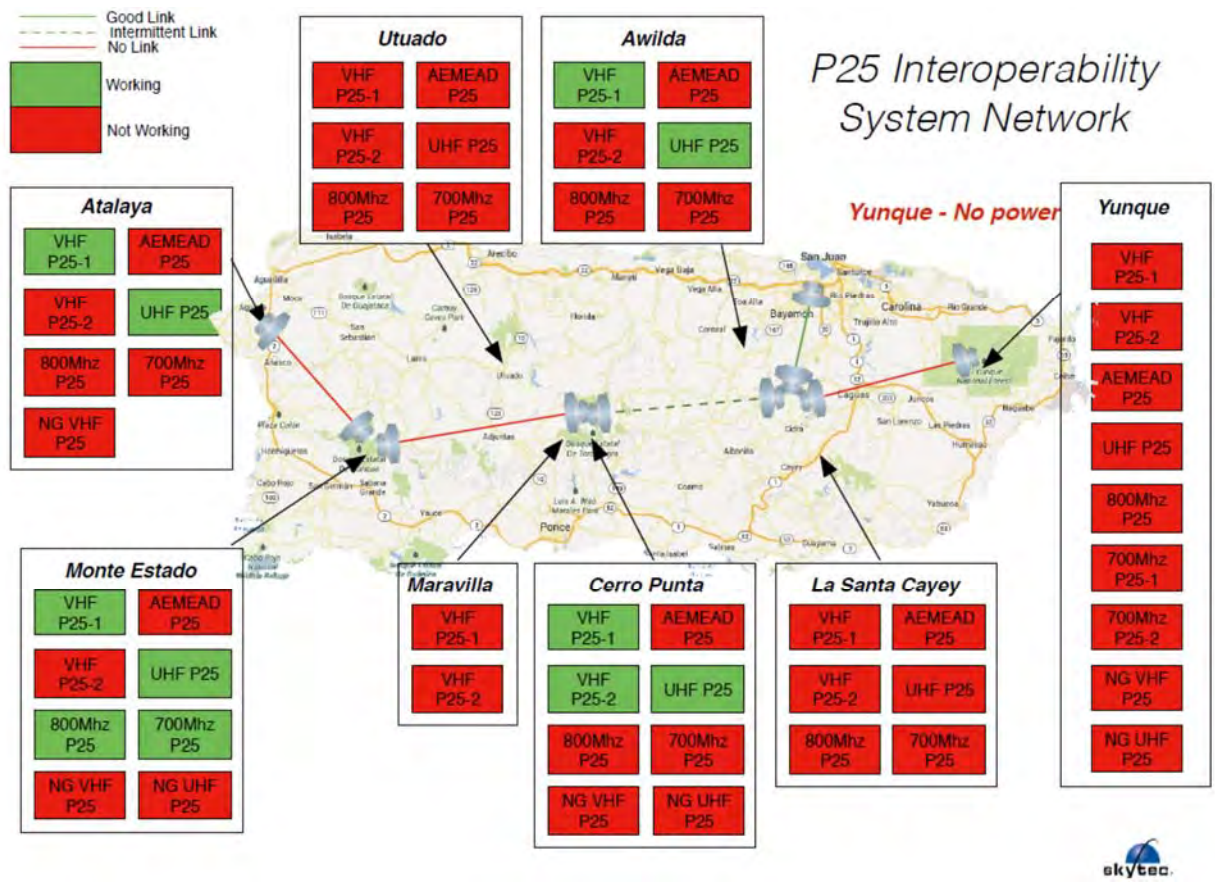
[6] Interview with ESF-2 and other FEMA officials, March 2, 2018

[7] Personal communication, AT&T response to FCC press release.

[8] Personal communication, ESF-2 and other FEMA officials, March 2, 2018

telecommunications systems, including land mobile radio systems and their microwave backbones, sustained significant damage. For example, damage to the State Interoperability System (Figure S.5), a key public safety communications system in Puerto Rico, left many agencies and municipalities without critical communications capabilities during the hurricane response. The Government of Puerto Rico also had limited means by which to communicate essential information to its citizens (Hurricane Maria Communications Task Force, 2017)

Figure S.5. Puerto Rico State Interoperability System Status Post Hurricane Maria



Source: 30 October 2017 Hurricane Maria Communications Task Force Report (Hurricane Maria Communications Task Force, 2017).

Commercial telecommunications, such as telephone and internet services for businesses and residents, were severely impacted by Hurricanes Irma and Maria. Most residents lacked the ability to use telecommunications services until repairs were made and the electricity grid restored. Over 90 percent of the private telecommunications infrastructure suffered damage—primarily antennas and fiber—affecting government, industry, transportation, and other sectors (Torres Lopez, 2018). In addition, the primary submarine cable landing stations for many of the major U.S. telecom carriers were damaged during Hurricane Maria, leaving only one of six landing stations to support off-island telecommunications.

Post-storm conditions

After Hurricane Maria, immediate steps were taken to restore public safety telecommunications. Commercial carriers sought options to restore wireless service to customers, such as using cells on light trucks, cells on wheels, and portable generators. Four wireless carriers opened up roaming to ensure service to the maximum population with the coverage available.[9] As of the drafting of this report, FEMA has approved funding for the restoration of the Puerto Rico Police Department land mobile radio (LMR) and microwave networks. With respect to commercial communications systems, specific information on repairs conducted to date remains limited, given that this information is proprietary. As of March 2018, only 4.3 percent of cell sites in Puerto Rico were out of service, though there is variability by municipality (Federal Communications Commission, 2018a). FCC's reports do not provide information on whether these sites have been fully restored to pre-storm status.

Remaining needs and recovery priorities

Short-term needs

- Repairs to damaged infrastructure to support the communications network, such as electricity, aerial fiber, and cell tower sites.
- Backup power or other options to reduce dependence on the electrical grid during emergencies.

Longer-term needs

- Improvement or replacements for vulnerable and outdated communications infrastructure.
- Effective governance that takes a unified approach to multiple emergency communications systems.
- Access to broadband technology for residents of Puerto Rico.

Transportation

Conditions before the hurricanes

Puerto Rico's transportation system includes roads and bridges, public transportation, seaports, and airports, all of which faced challenges prior to the 2017 hurricanes:

- **Roads and bridges.** Some of the major issues that have affected Puerto Rico's road systems and bridges include road congestion and safety issues, structural soundness, and traffic problems. Major roads in Puerto Rico were, overall, in fair condition before Hurricanes Irma and Maria, although road roughness was widespread. A 2012 assessment found that around 50 percent of Puerto Rico's 2,222 bridges were structurally deficient or functionally obsolete (Puerto Rico Department of Transportation and Public Works, 2013)

[9] Comments of CTIA, In the Matter of Response Efforts Undertaken During 2017 Hurricane Season, January 22, 2018.

Puerto Rico has also struggled with significant traffic congestion, especially in San Juan, and traffic safety (National Highway Traffic Safety Administration and National Center for Statistics and Analysis, 2017).

- **Public transportation.** Public transportation is generally considered inadequate and ridership of both fixed-route public transportation systems and *públicos* (jitneys) has been declining for a decade (Puerto Rico Department of Transportation and Public Works, 2013). Among the country's 15 heavy rail systems, Tren Urbano has the highest operating costs and costs per passenger, second lowest farebox recovery (the proportion of operating costs paid directly by riders through fares), and second lowest ridership. Maritime public transportation is provided by ferries (Puerto Rico Department of Transportation and Public Works, 2013).
- **Seaports.** Puerto Rico has ports in 15 cities, but the Port of San Juan accounts for more than three-quarters of all goods shipments to and from the Commonwealth (USACE Navigation Data Center). One of the greatest challenges to maritime transportation in Puerto Rico has been coordinating with multi-jurisdictional entities and diverse owners and operators. Puerto Rico's ports also face competition from other Caribbean transshipment ports that have similar facilities but lower costs (Kulisch, 2014).
- **Airports.** All 10 of the public airports in Puerto Rico, as identified by the FAA, are owned by the Puerto Rico Ports Authority (PRPA). However, Luis Muñoz Marín International Airport in San Juan (SJU) has been operated by Aerostar Airport Holdings since 2013 on a 40-year lease (Boynton, 2012).
- **Funding environment.** Puerto Rico's fiscal crisis has led to insufficient funding for surface transportation. Tax and fee income from PRHTA's dedicated revenue sources have not kept pace with inflation, and the agency faces a $4.49 billion financial gap for the next 10 years.

Damage from the hurricanes

Roads and bridges. Following the hurricanes, debris blocked most roads, and at the worst point, fewer than 400 miles of Puerto Rico's 16,700 miles of roadways were passable (Governor of Puerto Rico, 2017a). Landslides and flooding also damaged roads and bridges, and most traffic signals were not operating (Governor of Puerto Rico, 2017a), while gasoline was scarce (Levin, Newkirk and Ockerman, 2017).

Public transportation. Service on San Juan's Tren Urbano was suspended until December 19, 2017, largely due to the lack of power at key substations. Three stations suffered structural damage (Rolon Cintron, 2017). No bus service was provided in the San Juan area immediately following the storm (Gray, 2017), while ferry service to Vieques and Culebra was unavailable for several days, and all ferry terminals and vessels were damaged (U.S. Department of Transportation, 2017).

Seaports. Seaports sustained substantial damage from the 2017 hurricanes. There was significant damage to piers and ports, as well as to sea-based vessels, including 377 sunken or beached vessels (U.S. Coast Guard, 2018). Damage to seaports affected tourism, with the number of passengers processed by the Port of San Juan falling by 65 percent from September 2017 to March 2018, and the number of vessel calls falling by 56 percent in the same period.

Airports. Air travel was severely interrupted for several days following Hurricane Maria and there were initial reports of many passengers being stranded (Calfas, 2017). Heavy winds damaged airport facilities (Calfas, 2017), and the airport at San Juan closed for the two days immediately after Hurricane Maria (PR Newswire, 2017) and only accepted 10 flights a day roughly a week after the storm (Davila Calero, 2017).

Post-storm conditions

As of early March 2018, there were still nine bridges and 15 roadway segments closed according to the Puerto Rico Department of Transportation and Public Works (DTOP). According to FEMA reports, repairs on these and other roads are ongoing, although difficult terrain, especially in rural areas, has increased the challenge. By March 2018, San Juan bus services were operating at normal levels, and the Tren Urbano heavy rail system was operating normally except for two stations that remain closed due to damage. As of this report date, many seaports remained in need of permanent repairs. All airports are currently operational, although traffic has been markedly down at many.

Remaining needs and recovery priorities

Short-term needs

- Repairs to critically damaged roads and bridges.
- Remaining restrictions on maritime facility and vessel operations.
- Repairs to terminal damage at Luis Muñoz Marín International Airport.
- Repairs to FAA radar tower in El Yunque and restoration of its electricity supply.

Longer-term needs

- A more resilient road network.
- Accessible, high-quality information about transportation assets and ownership.
- Strategies to address low ridership and high costs for public transit systems.
- Strategies to help reduce dependence on driving for mobility needs.
- Reduced dependence on the Port of San Juan.
- Improved maritime public transit system service.

Public buildings

Conditions before the hurricanes

- **Public building ownership.** The complex ownership rights over public buildings have been long-standing issue of concern in Puerto Rico. For example, school buildings are owned by at least three different agencies: the Office for the Improvement of Public Schools of Puerto Rico, the PBA, and the Department of Transportation and Public Works. In addition, fragmentation has made it difficult to track and ascertain basic information about public buildings.

- **Underutilized buildings.** Another issue has been the substantial amount of underoccupied, excess building inventory, likely a result of economic recession and declining population. As a result, various initiatives to consolidate and "right-size" buildings have been proposed, including the School Modernization Program (Government of Puerto Rico, 2017a).
- **Insufficient maintenance.** Public buildings in Puerto Rico have suffered from insufficient maintenance, likely a result of insufficient funding and staffing. For example, lack of proper maintenance in schools has "led to the use of improvised maintenance services, the continued implementation of emergency repairs and the loss of a significant amount of school days" (Government of Puerto Rico, 2017a).

Damage from the hurricanes

Given the limitations of determining ownership and maintenance responsibility in Puerto Rico's public building sector, it has been difficult to gather information on the extent of damage specifically caused by Hurricanes Irma and Maria. Based on Public Assistance application data as of May 3, 2018, a total of $568 million has been requested in over 8,500 requests from 43 applicants. The majority of the applications are for debris removal, emergency protective measures (primarily security), and permanent damage to public buildings and contents (Public Assistance categories A, B and E, respectively).

Buildings owners, such as PRIDCO and PBA, are responsible for providing the damage assessments for their buildings. PRIDCO and PBA represent the largest stakeholders in the public buildings sector, and their combined inventory of buildings (around 1500) represents a large percentage of the sector. Damage assessments were conducted by lessees rather than PRIDCO, and assessment approaches and scopes were not standardized. Roofing, painting, fencing, and debris removal were the most common types of damage.

Damage to police stations. USACE assessments indicate that the vast majority of police stations are operational—only three were closed and less than a quarter had some (unspecified) restrictions on their functionality. The data do not include cost estimates, images, or other details. The most common damage issues are problems with water systems, general building damage, outdoor structural damage, and roof damage.

Damage to schools. USACE similarly provided damage assessments for 1,131 public schools in Puerto Rico, which likely addressed nearly all public schools open prior to the storm. While these assessments do not indicate the functional status, the Puerto Rico Department of Education reported that 1094 schools were open as of December 20, 2017 (Puerto Rico Department of Education, undated-b). The most common issues are again problems with water systems, general building damage, outdoor structural damage, and roof damage.

Damage to fire stations. Ninety-nine fire stations submitted PA applications to FEMA.[10] The sum of damage for all stations was about $3.3 million. In contrast to the case for PRIDCO

[10] Calculations based on FEMA Public Assistance data, as of May 3, 2018.

buildings, where roof damage accounted for 70 percent of the total damage, roof damage was about 23 percent of the total for fire stations.

Damage to corrections facilities. Damage to individual facilities range from under $10,000 to over $3 million, with total reported damage of $15.2 million. The most common types of damage include water system issues, general building damage, air conditioning, roof damage, and damage to equipment.

Post-storm conditions

HSOAC has almost no insight into post-hurricane response activities. PA application data describe emergency protective measures (primarily security) and debris removal activities, but do not indicate the extent to which the work has been completed. USACE damage data for police stations and schools indicate that public buildings sustained a substantial amount of structural damage requiring repair. It is possible that some of this work is already underway. To date, the majority of response work for which information is available involves emergency protection, debris removal, and damage assessment inspections.

Remaining needs and recovery priorities

Short-term needs

- Repairs to remaining damage from the 2017 hurricanes to fully restore critical services to the Commonwealth.
- Data collection to consolidate information on Puerto Rican government-owned buildings and systematically document the Commonwealth's public building stock.
- Improvements to building backup power sources to avoid extensive loss of electricity to public buildings future emergencies.

Longer-term needs

- Enhanced structural resilience to natural disasters to reduce structural damage in the face of future disasters.
- Adjustments to critical government activities in flood hazard zones to reduce water damage in the future.
- Utilization of vacant or destroyed buildings to address the stock of public buildings that are unsafe to remain in use.

Emerging recovery and resilience needs

Below, emerging cross-sectoral recovery needs drawn from this assessment are presented, building on the sector-specific needs summarized above.

Short-term cross-sectoral needs

- Charting Puerto Rico's path forward successfully requires a comprehensive assessment of damage to its infrastructure and environment as well as continuing social service needs.

- Reestablishing power, communications, and water utilities across Puerto Rico to the entire island remains a priority.
- Post-disaster assistance is only beginning to flow to Puerto Rico, and needs to continue. The diverse set of funding mechanisms available in Puerto Rico include federal grants and aid, federal loans, insurance payouts, Commonwealth grants and aid, Commonwealth loans, foundation aid, private-sector loans, and public-sector corporation revenue.
- Comprehensive information is needed about infrastructure asset inventory, ownership, and functionality. Next steps for the housing, energy, transportation, and public buildings sectors should involve creating a comprehensive inventory and clarifying parties' responsible for maintenance and repairs in asset management systems.
- Deficiencies in emergency preparedness protocols must be addressed. Near-term priorities include coordination of parties responsible for emergency response, as well as stockpiling of materials, resources, and personnel.

Longer-term cross-sectoral needs

- Economic challenges that precipitated population loss, worsened storm damage, and currently inhibit recovery must be addressed in order to support efforts to attract businesses, incentivize formal employment, and stimulate the return of the displaced population, along with efforts to restructure public debt and reduce the cost of services and materials in Puerto Rico.
- Timely, accurate, and comprehensive data on the Commonwealth's economic and fiscal status are required.
- Infrastructure vulnerability and degradation must be addressed to ensure that systems meet CONUS standards and are attractive to businesses and to potential immigrants (or returning migrants).
- Understanding vulnerabilities and creating robust and flexible systems will take significant investment moving forward. Puerto Rico might need to consider more dramatic policy actions, such as property acquisitions in high-risk floodplains, in order to reduce disaster vulnerability and losses.
- Clarity is needed regarding which entities are in charge of operating and regulating sector assets, as well as how codes and standards will evolve and enforcement improved during hurricane recovery.
- Informal employment needs to be addressed. The existence of a large informal economy has a number of negative effects, chiefly the erosion of Puerto Rico's individual and corporate tax base.
- Social service and infrastructure systems, including social service systems, financial planning, administrative functions, and physical infrastructure, must be scaled for the current and future population.
- Additional information is needed to help inform long-term resilience decisions. As Puerto Rico turns from immediate recovery to "building back better," improving the assessment and understanding of hazard vulnerability under future uncertainty will be a critical next step.

Next steps in the recovery planning process

The current DNA document provides an overview of damage and needs across Puerto Rico, by sector and by key cross-sectoral issues, as of Spring 2018. This document summarizes an extensive review of conditions in Puerto Rico prior to Hurricanes Irma and Maria, damage caused by the hurricanes, and conditions in the Commonwealth following the hurricanes, and notes emerging priority recovery and resilience needs, along with remaining information gaps that the team is working to fill.

HSOAC has been working with FEMA and the Governor's office, in coordination with the FOMB, to finalize the vision, goals, and strategies that will be the drivers of the actual recovery plan. Key information from the DNA is included in the recovery plan to provide a rationale and baseline for the courses of action that are selected to achieve the Governor's goals and implement his strategies. This deliverable also include preliminary courses of actions (COAs) that can be used to help Puerto Rico recover and transform its economy, institutions, infrastructure and communities in the coming years.

1. Introduction

The 2017 hurricane season severely damaged Puerto Rico, with two major hurricanes affecting the island within the span of two weeks. Hurricane Irma devastated the eastern Caribbean as a powerful Category 5 storm and passed close to the Island on September 8, causing wind damage and leading to power outages. Hurricane Maria arrived soon after, making landfall on Puerto Rico on September 19-20, 2017 as a strong Category 4 storm with maximum winds of 155 miles per hour (Pasch, Penny and Berg, 2018). Maria also dropped 15 to 20 or more inches of rain in many areas of Puerto Rico, leading to widespread flooding and landslides. The effects were devastating, causing extensive housing and infrastructure damage, an Island-wide blackout, and months-long interruption of essential services such as electricity and water to the people of Puerto Rico. As of the writing of this report, more than six months after landfall, Puerto Rico is still struggling to restore basic services such as electricity and safe drinking water to some locations.

Puerto Rico's challenges, however, extend back well beyond the 2017 hurricane season. An economic crisis spanning more than a decade, coupled with endemic demographic, social, and infrastructure challenges, exacerbated the impact of the hurricanes and led to a broader long-term disaster that will necessitate transformative changes and investments in the years to come. In fact, since the implementation of the National Disaster Recovery Framework (NDRF), there has never before been a situation in which the impacted economy has been in a long-term and severe recession for more than a decade, or in which the state-level government has been essentially insolvent, as was the case with Puerto Rico.

This report summarizes the challenges faced by Puerto Rico before, during, and shortly after Hurricanes Irma and Maria. It provides a summary of the background, recent trends, and challenges leading into the 2017 hurricane season; storm damage and other impacts; and post-storm conditions as of Spring 2018 across a range of sectors. The report also discusses cross-sectoral challenges and storm impacts and provides an initial summary of Puerto Rico's priority needs during hurricane recovery. This document is supported by a series of sector-specific appendices, and serves as a technical support for the economic and disaster recovery plan.

Puerto Rico in context

This section provides a brief overview of Puerto Rico, including backing on its geography, population, and government. Later chapters in this report describe the Island's population and governance in greater detail.

Geography

Situated between the Atlantic Ocean to the north and the Caribbean Sea to the south, the archipelago of Puerto Rico (Spanish for "Rich Port") consists of a main island (3,515 square miles in size), two populated islands off its east coast, Culebra (24 square miles) and Vieques (51 square miles), and several smaller uninhabited islands (e.g., Mona). The islands are located approximately 1,100 miles east-southeast of Miami, Florida.

Much of the interior of the main island is characterized by steep slopes and narrow valleys (Figure 1.1) (Kaye, 1959). The flow of trade winds over the mountainous terrain yields significant variations in rainfall, ranging from 10 to nearly 200 inches annually, generating runoff that extends in all directions. The northern Atlantic coastline experiences naturally high wave energy, while the southern Caribbean coastline has lower energy wave action (Miller and Lugo, 2009).

Figure 1.1. Puerto Rico's Geography

Source: Google Maps

Modern history

With the signing of the Treaty of Paris in 1898, ending the Spanish-American War, Puerto Rico shifted from being a Spanish colony to being an "unincorporated territory" of the United States. This early period as a U.S. territory—roughly 1898 through the 1930s—was marked by an agrarian economy. In 1917, the Jones-Shafroth Act granted citizenship to anyone born in Puerto Rico, and in 1950, Puerto Rico won with the right to organize a government with the passage of the PR Federal Relations Act. Two years later, the territory adopted the Constitution of Puerto Rico, at which time it also became a Commonwealth. More information on Puerto Rico's government is provided below.

For the past 70 years, Puerto Rico has experienced cycles of economic growth (e.g., 1970s–1990s, early 2000s) and retraction (e.g., 2006–present) (Toro, 2014). The impact of these cycles,

in particular the retractions, have had a significant impact on institutions and communities across the Commonwealth.

Population and income

As of July 2017, just prior to Hurricanes Irma and Maria, approximately 3.3 million people resided in Puerto Rico (U.S. Census Bureau American Fact Finder, 2016a). The most populous metropolitan area in Puerto Rico is the capital, San Juan, which is located in the northeast of the main island and home to about 2.1 million residents in its metro area (Data USA, 2018). In 2016, about 14 percent of Puerto Rico's population were young adults (15–24 years), 38 percent were prime-working-age adults (25–54 years), and roughly 23 percent were older than 60 years old (U.S. Census Bureau, 2018a). The fraction of elderly residents is a higher proportion than anywhere else in the Caribbean or Latin America except for the U.S. Virgin Islands (Wyss, 2017). By comparison, roughly 19 percent of the United States as a whole is over 60.

Puerto Rico's population peaked in 2004 at 3.8 million. Between 2004 and 2016, the population dropped to 3.4 million, or over 10 percent, and has declined further since the 2017 hurricanes (Krogstad, Starr and Sandstrom, 2017). The population decline is caused both by decreasing birth rates and net outmigration (Puerto Rico Planning Board, 2016), the latter being a more significant factor.

Over 98 percent of Puerto Ricans self-identify as ethnically Hispanic/Latino, and roughly 69 percent are white, 9 percent are black or African-American, and 7 percent are two or more races (U.S. Census Bureau, 2018a). Spanish and English are both official languages in Puerto Rico. However, according to 2016 U.S. Census data, 78 percent reported speaking English "less than very well"; by comparison, over 94 percent of Puerto Ricans reported speaking Spanish at home (U.S. Census Bureau, 2018a).

In 2016, the median per capita income in the Commonwealth was $11,688. Forty-five percent of residents had an annual income below the federal poverty level, with high rates of poverty among those under 18 (57 percent) and those over 65 (approximately 40 percent). Poverty rates in Puerto Rico are higher than in any U.S. state, and twice as high as the poorest state, Mississippi (U.S. Census Bureau, 2018a).

Government

The Government of Puerto Rico is made up of executive, legislative, and judicial branches. The executive branch is headed by the governor, currently Ricardo Antonio Rosselló Nevares (elected in November 2016). The legislative branch (the Legislative Assembly) is a bicameral legislature with a lower house (House of Representatives) and upper house (Senate). The Chief Justice of the Supreme Court of Puerto Rico heads the judicial branch and the legal system in Puerto Rico is a mix of the civil law and common law systems. The governor and legislators are elected by popular vote every four years. The governor, with the advice and consent of the Senate, appoints the members of the judiciary.

Puerto Rico sends a non-voting Resident Commissioner to the U.S. House of Representatives, but has no representation in the U.S. Senate and is not otherwise represented in Congress. The Resident Commissioner can introduce bills and participate in discussions and debates, serve on committees, and speak as a member of Congress, but cannot vote on bills. Residents of Puerto Rico also cannot vote in U.S. presidential elections. They do, however, vote in presidential primaries for both parties.

As U.S. citizens who share a common currency and defense with the mainland, Puerto Ricans pay payroll taxes and are eligible for Federal Government social programs, including Social Security and Medicare, though program benefits are allocated differently than in the continental U.S. Residents do not pay U.S. personal income taxes unless they work for the Federal Government (Federal Reserve Bank of New York, 2014a).

Municipal autonomy

Puerto Rico is divided into 78 municipalities, ranging in size from 1,868 inhabitants in Culebra to 442,447 in San Juan (Government of Puerto Rico, 2018c). Each municipality is headed by a mayor and a municipal assembly, both of which are elected every four years; the last mayoral election was held in November 2016. While municipal governments have autonomy over certain local affairs, the Commonwealth government generally retains responsibility for key public functions, including electric power and water service, for the large majority of residents (Government Development Bank for Puerto Rico, 2018).

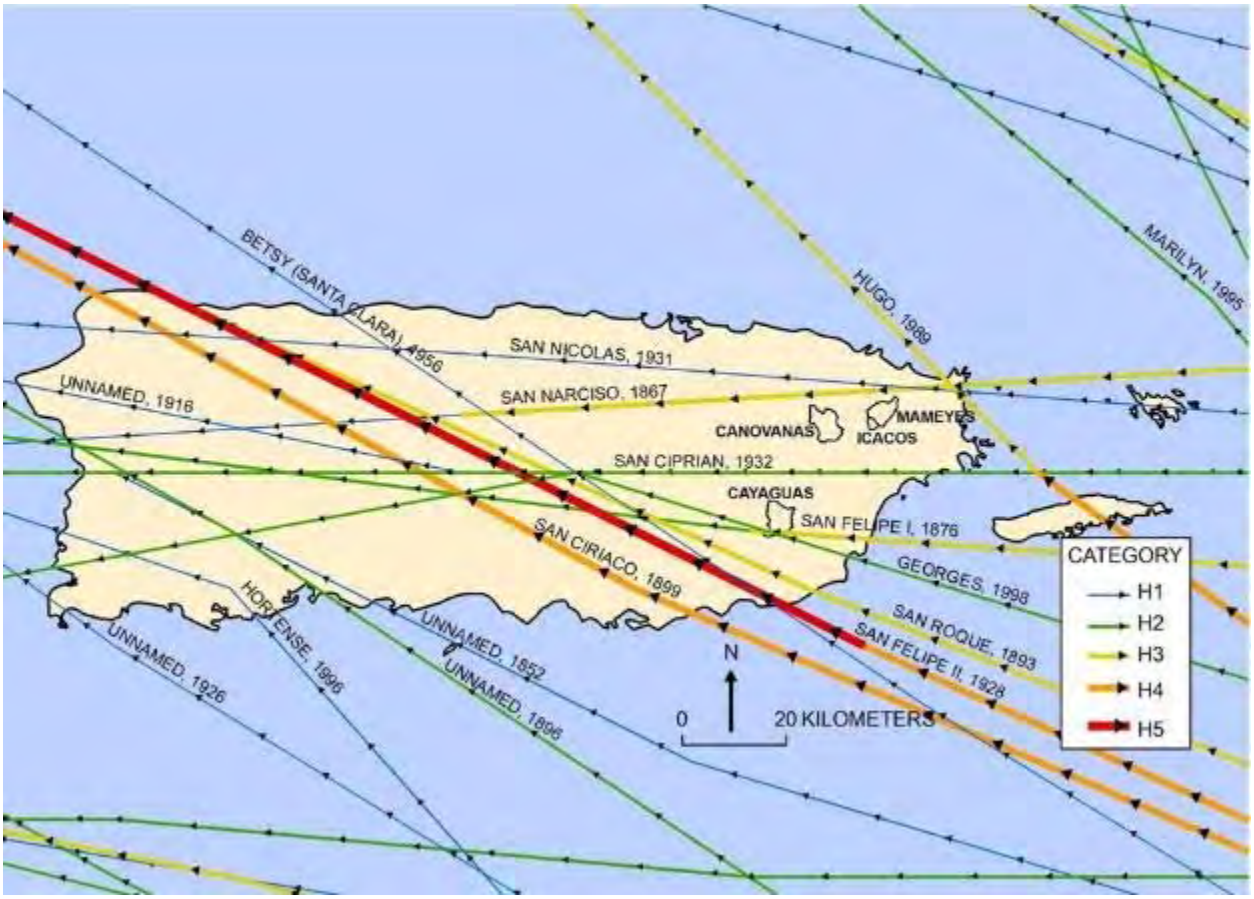
A 1991 law granted selected autonomy to the municipalities to procure, provide, and manage some services, elect municipal assemblies, and manage municipal incomes ("Autonomous Municipalities Act of 1991," 1991). In addition to funds they receive from issuing permits, real estate transactions, and local sales taxes, municipal governments receive a substantial part of their operating budget via subsidies from the Commonwealth government. The Financial Oversight and Management Board for Puerto Rico(FOMB), for example, noted in its latest fiscal plan that municipalities receive $220 million per year in appropriations, but are nevertheless operating at annual deficits of $260M (Financial Oversight and Management Board for Puerto Rico, 2018). These deficits have contributed to the Commonwealth's overall debt crisis.

In an effort to address these issues, Governor Rosselló has supported a number of initiatives including consolidating municipal service delivery, a centralized procurement body, a reduction of municipal appropriations, and enhanced tax compliance. The FOMB's most recent fiscal plan generally supports efforts to regionalize or consolidate municipal service delivery, and directs the Commonwealth to reduce subsidies to municipal governments by 80 percent over the next five years and to eliminate them by 2024 (Financial Oversight and Management Board for Puerto Rico, 2018). A number of municipalities have been exploring shared service arrangements in recent years, concentrated in areas such as transportation, permitting, and solid waste management. To date, however, these efforts have largely been ad hoc.

Hurricanes and Puerto Rico

Hurricane is one of the few words that survives from the Taino (early inhabitants of Puerto Rico), and these storms are one of the primary disturbances that occur in Puerto Rico with the potential to cause significant long-term change. Puerto Rico is exposed to tropical cyclones throughout the Atlantic hurricane season, like its neighbors in the North Atlantic and across the Caribbean. Tropical cyclones contribute on average approximately one quarter of the Commonwealth's rainfall (Rodgers, Adler and Pierce, 2001), and Puerto Rico falls in the vicinity of a hurricane of Category 3 or higher every three and a half years (U.S. Geological Survey). From 1851 through 2017, the only Category 5 hurricane to make landfall on the Island was the September 1928 Lake Okeechobee (San Felipe II) storm (Figure 1.2) (U.S. Geological Survey).

Figure 1.2. Hurricanes making landfall or passing new Puerto Rico since 1851



SOURCE: (U.S. Geological Survey, undated)

The 2017 Atlantic hurricane season was an active one. On September 8, 2017, Puerto Rico narrowly avoided a direct hit by the Category 5 Hurricane Irma, though heavy winds and a loss of electrical power affected a substantial proportion of the population (Cangialosi, Latto and

Berg, 2018). As expected, Category 4 Hurricane Jose took a path that veered away from Puerto Rico. However, a short time later, on September 20, the devastating Hurricane Maria made landfall in Puerto Rico as a Category 4 hurricane, with sustained 155 mph winds, torrential rains, and widespread flooding that caused tremendous destruction (National Oceanic and Atmospheric Administration, 2017b).

Purpose of this report

The purpose of this Damage and Needs Assessment is to support the development of Puerto Rico's 180-day economic and disaster recovery plan. To ensure the Recovery Plan is as robust as possible and to respond to the requirements established by Congress, the long-term strategy it presents should capture the damage from the storms and remaining needs across the Commonwealth, both within specific sectors and for challenges that cut across sectors. Specifically, this damage and needs assessment covers the following information:

- **Pre-hurricane conditions**: Recent trends, challenges, or other long-term stresses affecting Puerto Rico prior to Hurricanes Irma and Maria
- **Hurricane damage**: Damage caused by Hurricanes Irma and Maria; includes direct damage to infrastructure or capital as well as impacts to Puerto Rico's economy, workforce, and population during and in the aftermath of hurricane season (through March 2018)
- **Post-hurricane conditions**: Status of various sectors following emergency response and early recovery investments, as of March 2018
- **Remaining needs and recovery priorities**: Remaining needs to address during hurricane recovery not resolved as of March 2018, drawing from both pre-storm conditions and storm damage. Could be addressed through new investments or policy changes occurring one, two, or up to 10 years following the 2017 hurricane season.
- **Information gaps**: Key knowledge gaps as of the writing of this report.

The outcome of this damage and needs assessment is critical to ensure a strong baseline for defining and comparing the courses of action being considered for recovery planning.

Report organization

This report is organized into seventeen chapters:

- Chapter 2 presents an overview of Puerto Rico prior to the 2017 hurricane season, highlighting the key cross-sectoral issues and needs, especially those that exacerbated the storms' negative effects.
- Chapter 3 provides and overview of the climatology and key hazards caused by Hurricanes Irma and Maria, as well as an overview of the emergency preparedness structure of the Commonwealth and pre-storm steps taken prior to the 2017 hurricanes.
- Chapter 4 describes the methods used to assess damage following disasters and explains the approach that HSOAC sector teams used to gather, summarize, and analyze data on pre-storm needs in Puerto Rico, as well as damage inflicted by the hurricanes of 2017.

- Chapter 5 provides a summary of the key policies and economic trends that shaped many of the pre-storm challenges for Puerto Rico and offers an analysis of the estimated damage that Hurricanes Irma and Maria caused to the Commonwealth's economy.
- Chapter 6 provides an overview of the people and communities of Puerto Rico, with a focus on the Commonwealth's population and regions and its municipal structure and governance.
- Chapter 7 covers the pre-storm challenges and hurricane damage sustained by the health and human services sectors of Puerto Rico, including health, social services, and education.
- Chapters 8 through 14 of this document take a sector-by-sector approach to Puerto Rico's natural and built infrastructure. In each chapter, the HSOAC team describes the pre-storm needs of Puerto Rico, damage inflicted by the 2017 hurricanes, and remaining needs and priorities for Puerto Rico to build back better. The sectors covered in these chapters include Housing (Chapter 8), Natural Resources (Chapter 9), Cultural Resources, (Chapter 10), Energy (Chapter 11), Water (Chapter 12), Telecommunications (Chapter 13), Transportation (Chapter 14), and Public Buildings (Chapter 15).
- Chapter 16 summarizes cross-sector impacts from the hurricanes and highlights emerging needs and priorities across sectors for short- and longer-term economic and disaster recovery.
- The report concludes with Chapter 17, which describes limitations of the damage assessment in its current form, key data gaps to fill, and next steps for research to inform and support ongoing recovery.

2. Puerto Rico before the storms

In recent decades, Puerto Rico has faced a number of critical stressors, most importantly an economy in long-term decline. Many of these pre-existing challenges exacerbated the impacts and damage from Hurricanes Irma and Maria. An overview of key stresses challenging Puerto Rico leading up to the hurricanes is provided below, highlighting those that cut across sectors. This document then provides a summary for nine sectors of focus, including details of pre-storm conditions or challenges, descriptions of the damage wrought by the storms, and conditions following the storms.

Economic decline and debt crisis

Puerto Rico's economic development in the twentieth century can be at least partially attributed to a history of tax policy and incentives. These incentives have existed in various forms since just after World War II, when Puerto Rico began to transform from an agrarian society to an industrialized economy.

In 1996, Congress repealed and began to phase out a 1976 tax credit (Internal Revenue Code Section 936) that essentially granted U.S. corporations a tax exemption on income generated in Puerto Rico (although there were similar provisions in place years before Section 936) (MacEwan, 2016). Some corporations responded by restructuring their Puerto Rico operations to "Controlled Foreign Corporations," which exempted them from Federal taxation on profits until the income was returned to the U.S.[11] Following completion of the phase-out in 2006, economic growth has generally been negative, with low labor-force participation and high unemployment relative to CONUS. While the unemployment rate hovered between 10 percent and 12 percent between 2000 and 2008, it rose to about 16 percent during the Great Recession, 2009 to 2011. Between 2011 and 2017, the unemployment rate fell from about 16 percent back to 10 percent. While CONUS and Puerto Rico unemployment rates follow similar trends, CONUS unemployment rate is on average less than half the rate for Puerto Rico (Bureau of Labor Statistics, 2018a; Bureau of Labor Statistics, 2018b). While the phase-out of the tax incentives was certainly a contributing factor, recessionary pressure in the United States in 2001 and during the Great Recession (late 2007 – 2009), high fuel prices, and high costs of doing business, among others, also contributed.

In conjunction with the contraction of the economy, lower revenues, high rates of expenditure, and heavy borrowing by the Commonwealth of Puerto Rico, municipal governments, and public-sector corporations resulted in high and unsustainable levels of debt (Fisher and Horowitz, 2016;

[11] Puerto Rico is treated as a foreign jurisdiction for tax purposes, but products made there are considered "Made in the U.S.A."

Commonwealth of Puerto Rico, 2016). Puerto Rico's credit rating dropped below investment grade in early 2014, followed by a series of defaults on debt payments. The financial crisis ultimately resulted in the passage of H.R. 5272, the Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA) in 2016, which established the FOMB and provided the frameworks for restructuring the Commonwealth's debt. The FOMB's purpose is "to provide a method for [Puerto Rico] to achieve fiscal responsibility and access to the capital markets" by certifying financial plans, approving and monitoring budgets and activities related to the budgets and fiscal plans, providing advice on issues of financial stability and management, and certifying restructuring and approving actions related to debt issuance (Commonwealth of Puerto Rico, 2016; H.R. 5278 Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA), 2016). More information on the Island's economic decline can be found in Chapter 5 (Economy).

Population loss and population aging

In every decade that the U.S. Census Bureau has conducted a census in Puerto Rico until 2000, the territory experienced population growth, including the period of the "Great Exodus" of migrants from Puerto Rico to the continental U.S. (1945-1960) which until the turn of the 21st century had been the largest previous migration wave (Valeazquez-Estrada, 2015). Prior to the economic contraction set in motion in 2006, Puerto Rico's population peaked in 2004 at an estimated 3.8 million. Between 2004 and 2016, the population dropped to about 3.4 million. Two factors are about equally responsible for this population decline: an increase in the net population outflow to the continental U.S. and childbearing that has continued to drop below replacement level. Puerto Rico now ranks as having among the lowest of fertility rates compared to the CONUS and other countries world-wide, with only four other countries reporting lower fertility.

The economic contraction has had a dynamic and mutually reinforcing relationship to the population losses. The continuing loss of people in Puerto Rico, particularly school-aged children and working adults, has added to its economic concerns (Krogstad, 2016). Coupled with the general aging of Puerto Rico's population, Puerto Rico's population, workforce, and, consequently, its tax base are expected to continue to shrink.

Analysis has also been conducted on the expected long-term economic impacts of these population trends. The March 2018 Certified Fiscal Plan for Puerto Rico provides economic and demographic forecasts from a pre-storm baseline[12] and projects into the future, taking into consideration hurricane damage and proposed fiscal and economic reforms. Over the next five years, the plan predicts that GNP will rise (likely combined result of $55.4 billion in Federal Government recovery assistance and insurance payments coupled with accelerated population

[12] Pre-storm baseline is from the Certified Fiscal Plan dated March 13, 2018. As of this writing, the New Fiscal Plan has not been approved by the Financial Management and Oversight Board.

decline following the storm) but with slightly less inflation (-4.6 percentage points) and lower population (9 percent) (Government of Puerto Rico, 2017b).[13]

High import costs

Since 1922, Puerto Rico has been subject to all Jones Act requirements with respect to shipping cargo (see Box 1). The Jones Act may increase the price of many goods imported from U.S. ports for Puerto Rico residents because of the higher transportation costs associated with using Jones Act-qualified vessels, though the extent is subject to debate. In addition, since Puerto Rico has no natural sources of petroleum, coal, or natural gas, and the electric grid has been largely dependent on imported sources of fuel, electricity is twice as expensive in Puerto Rico compared to the continental United States (U.S. Energy Information Administration, 2018a). These high energy costs have had ripple effects across virtually every sector in Puerto Rico, contributing to comparatively high costs of living and of doing business in the Commonwealth, including relatively more costly food and construction materials. See Chapter 5 for more information.

Box 1: The Jones Act

Enacted by Congress in 1920 to strengthen national security by maintaining a robust shipbuilding industry and merchant navy, the Merchant Marine Act (commonly referred to as the "Jones Act") controls *coastwise trade** within the United States.

The Jones Act requires that U.S.-owned and flagged ships, built in the U.S. and crewed by predominantly U.S. citizens, be used in coastwide trade and determines under which rules they must operate.

Three U.S. territories, including the neighboring U.S. Virgin Islands, are exempt from Jones Act requirements. In Puerto Rico, however, this law potentially increases import prices because it restricts foreign flag carriers from competing with U.S. shipping companies that provide transport services between ports in Puerto Rico and other U.S. ports.[1]

* *Coastwise trade* refers to a voyage beginning at any point within the U.S. and certain territories, including Puerto Rico, and delivering a type of commercial cargo to any other point within the U.S.

Deferred infrastructure maintenance

Puerto Rico's infrastructure was weakened and degraded due to many years of deferred maintenance. Infrastructure maintenance has been challenging due to more-rapid degradation in a hot, humid, saline, and densely vegetated, environment—especially for remote energy and communications infrastructure assets. Additionally, many infrastructure owners were burdened with unsustainable debt loads and thus were unable to invest in maintenance. These challenges were compounded by lost revenue and higher repair costs, which further drew public utilities and agencies into debt. For example, high leakage rates (50 to 55 percent) in PRASA's drinking

[13] Although precise methodological details are not given, the plan states that population is estimated jointly with GNP, with main drivers of population growth being past GNP growth (a positive relationship), past population growth (positive), growth of net federal transfers (positive), effects of the storm (negative), and relief spending (positive). Explicit drivers of GNP growth are not documented, though the plan implies that population changes are not a driver of GNP growth. This runs counter to the assumptions of many Solow-style growth models, which considers labor/population an input into economic output.

water distribution systems have contributed to a significant amount of water loss. Many of the systems in Puerto Rico lagged behind CONUS and are not built according to the latest standards, particularly in telecommunications, which has reduced the attractiveness of Puerto Rico to businesses and has subsequent economic implications. For more information, see Chapters 5, and 11 – 15 (Energy, Water, Telecommunications/Information Technology, Transportation, Public Buildings).

Asset ownership and management responsibility

One of the causes of deferred maintenance to infrastructure such as the telecommunications system, transportation networks, and public buildings was a lack of transparency over ownership and responsibility. According to the 2018 New Fiscal Plan for Puerto Rico (Government of Puerto Rico, 2018b), "To date, with very few exceptions, the Government lacks a clear understanding of the number, type, location, legal status, and condition of the real estate assets it owns." It is common in Puerto Rico for buildings to be owned by one set of entities (e.g., the Public Buildings Authority [PBA], Puerto Rico Industrial Development Company [PRIDCO]) and for day-to-day operations to be managed another organization, such as a government agency or private sector tenant. For example, the hospital in Vieques features a building owned by the municipality, but all the medical equipment within the building is owned by the Commonwealth—and the hospital includes a privately-owned wing. Public and private ownership varies significantly by municipality. Additionally, many companies and tenants may utilize the same infrastructure, including telecommunications sites and seaports. A lack of accountability over asset management meant repairs were often deferred, which was compounded by a widespread lack of capacity to make repairs, as many entities were facing financial hardship pre-storm. For more information, see Chapters 12 – 14.

Pre-storm emergency preparedness and disaster mitigation

At the time of writing, the HSOAC team lacks information on the extent to which emergency preparedness plans had been implemented by government and non-governmental agencies across Puerto Rico before the storms. Municipal governments play a crucial role in emergency operations because they are typically the first responders. Puerto Rico's State Agency for Emergency Management and Disaster Administration (AEMEAD) developed and adopted an operational plan for emergencies in September 2016 that spells out the roles and responsibilities of municipal governments and state agencies during an emergency (Departamento de Justicia, 2016). The plan calls for state and local agencies, as well as NGOs and private organizations, to coordinate with AEMEAD leadership in preparation for such an event and to harness their capacities towards a more effective response.

However, there is evidence that many municipalities, public agencies, businesses, and cultural institutions did not have or execute emergency preparedness protocols in advance of

hurricanes Irma and Maria. For example, though 90 percent (60 out of 70) municipalities surveyed by HSOAC reported having disaster preparedness plans, only 37 percent reported that the plans worked adequately after the storms. Additionally, according to a FEMA Community Conditions Assessment from May 2018, 19 of the 78 municipalities had hazard mitigation plans—which aim to reduce the ultimate damage caused by a disaster—that were expired. Moreover, according to a February 2018 DHS report, the Puerto Rico Interoperability Committee for Emergency Communications was established in 2011 but did not meet for two years (U.S. Department of Homeland Security, 2018).

In general, it appears as though plans within the most vulnerable zones were not developed before the storm leading to inadequate storm preparation and a lack of pre-positioned materials. Some municipalities also lacked a detailed inventory of municipal assets, hindering their ability to both protect those assets ahead of a disaster and facilitate their repair and recovery afterward. The Puerto Rico Aqueduct and Sewer Authority (PRASA) and the Puerto Rico Electric Power Authority (PREPA) did take some precautions, including preemptively lowering water in reservoirs and stockpiling materials—steps that proved insufficient given the prolonged response period following Maria.

Some have questioned why Puerto Rico, which is clearly in an area commonly hit by hurricanes, was not better prepared with stocks of sufficient replacement materiel and emergency fuel to support rebuilding its infrastructure. The landfall of a Category 4 or 5 hurricane is a devastating event; for example, most of Puerto Rico's energy transmission assets (towers and wires) were utterly destroyed. It was not possible (from either a physical space or a funding perspective) to have sufficient materiel on hand to entirely rebuild assets. There was also the risk that stockpiled materiel would be lost, damaged, or destroyed since it was predicted that all of Puerto Rico was in the path of Hurricane Maria.[14]

More information on municipal preparedness is available in Chapter 6, and for specific pre-storm preparedness activities undertaken by infrastructure sector, see Chapters 11 through 14.

Socioeconomic and geographic vulnerability

Across Puerto Rico, economic conditions before Hurricanes Irma and Maria created a particularly difficult environment for governance and disaster preparedness and response. Puerto Rico's rapidly aging population, high prevalence of poverty, challenges with post-secondary educational attainment and student achievement scores, number of rural and largely isolated communities, and other conditions made certain subsets of the population more vulnerable to the impacts of disasters (Box 2).

[14] Comments of AT&T, Public Safety and Homeland Security Bureau Seeks Comment on Response Efforts Undertaken During 2017 Hurricane Season, Feb. 21, 2018.

High unemployment (above 10 percent) and low incomes have been persistent, and government assistance has been significant even prior to the storms. For example, in 2016 approximately 470,000 received benefits from the Federal Nutrition Assistance Program (38.9 percent) (American Fact Finder, 2016a). Additionally, the same year approximately 45 percent of the Puerto Rican population participated public health insurance (including Medicare and Medicaid/other means-tested coverage) compared to approximately 20 percent of the U.S. population overall (American Fact Finder, 2016b). The majority of this population is required to enroll in Mi Salud (the Commonwealth's managed care organization[15]); only Medicare beneficiaries who are only eligible for Medicare are not required to enroll. Partially due to high rates of eligibility, financial challenges have been prevalent across government assistance programs (Wolkomier, 2017; Perreira et al., 2017).

Geographic vulnerability has resulted from urbanization and environmental degradation. Urbanization in areas that are at high risk of infrastructure failure (e.g., flood-prone, landslide-prone) and unplanned urban sprawl have increased the vulnerability of Caribbean islands to natural disasters in certain respects. Rapid changes to urban land cover and the consequent loss of soil capacity to absorb rainfall, combined with poor maintenance of urban drainage, contribute to increased runoff and associated urban floods, which were frequent before the hurricanes (Lopez-Marrero and Tschakert, 2011). Man-made challenge of environmental degradation include pollution of the Río Grande de Arecibo, which flows into the highlands from the northwestern municipality of Arecibo (Newkirk, 2017), risk of 23 Superfund sites contaminating soil and groundwater, uncovered coal ash deposits which contain heavy metals like arsenic, mercury, and chromium (Atkin, 2017), and other challenges as described in greater detail later in this report.

[15] Managed care enrollment requirements for Medicaid beneficiaries differ by state, with no other states requiring it for all Medicaid beneficiaries and ten states only requiring it for Medicaid enrollees who also receive Temporary Assistance for Needy Families (TANF) benefits (Howell, Palmer and Adams, 2012).

Box 2: High-risk populations
Although Hurricanes Irma and Maria impacted every sector of Puerto Rican society, certain population groups and geographic regions were more susceptible to their effects than others.

Elderly: Even before the storms struck, the population of Puerto Rico was aging at a rapid pace, as a weak economy and limited employment opportunities encouraged many young people to seek work in the continental U.S. Approximately half of Puerto Rico's elderly population is on Medicaid and about half is living under the federal poverty level. In addition, this population may not have the physical, emotional, social, or economic resources needed to either leave Puerto Rico or improve their situations within the Commonwealth, making them less likely to recover from the effects of the disaster in the near term.

Female Caregivers: Puerto Rican women are another group that faces higher vulnerability in disasters, as they are often principal family caregivers and important sources of income. For example, the loss of power in a disaster often means that people (mostly women) must make daily trips to shops if they want to eat fresh food. Also, women who run food-based businesses in their homes are unable to continue earning their own income. Ordinary chores like cooking and doing laundry are much more onerous without regular power. Furthermore, women are often the primary caregivers for extended family members who have been left temporarily homeless.

Children and youth: More than half the nearly 175,000 Puerto Rican children under 4 years old live below the federal poverty level. Many children depend on public support for food assistance and security, housing, health and medical care, and early education. Puerto Rico's students had low achievement scores relative to students of many states, and the Puerto Rican education system had been facing a number of financial strains due to factors including recent declines in student enrollment.

Informal housing residents: According to the Puerto Rico government, as much as half the housing in the Commonwealth (roughly one million dwellings) was built without permits. Although these houses range in quality and size, most were not constructed in accordance with building codes. Also, informal housing tends to be established in precarious areas, such as those at risk for flooding and landslides.

Rural residents: Rural, mountainous areas of Puerto Rico have faced more challenges than coastal urban areas in recovering from the effects of natural disasters. Residents may be hard to reach due to impassable roads. These areas may also offer limited employment opportunities, and have a more elderly population compared to cities.

Conclusion

Puerto Rico was challenged with extensive and deep-rooted stressors prior to the 2017 hurricane season. As discussed in much greater depth in the chapters to follow, these pre-hurricane issues exacerbated the effects of the hurricanes and have had significant implications for the Island's ability to respond, rebuild, and recover post-disaster. The Government of Puerto Rico has also committed to address these long-standing challenges during hurricane recovery, helping Puerto Rico to "build back better" and become more resilient to future extreme events.

3. Overview of Hurricane Irma and Hurricane Maria

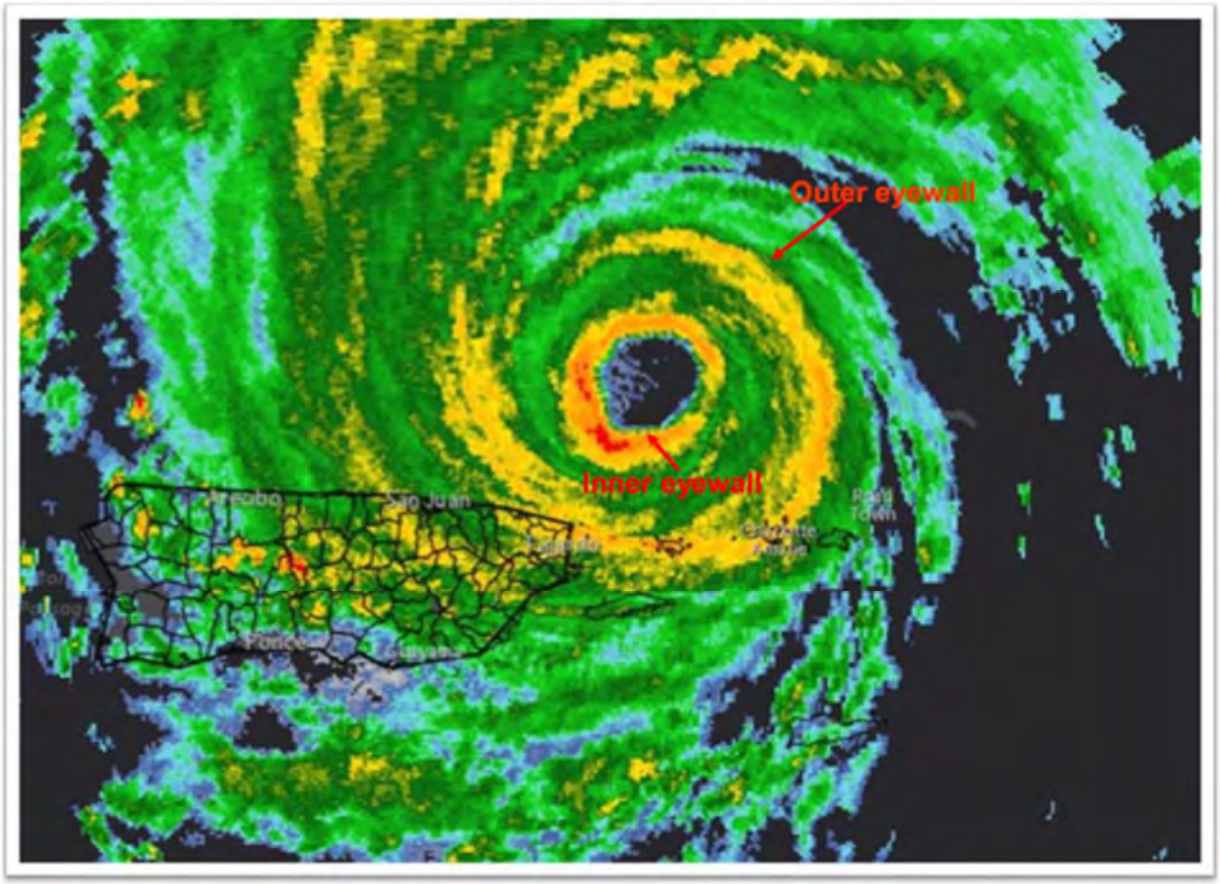
Hurricane Irma

Storm climatology

Hurricane Irma began to form its convective shape in the eastern Atlantic Ocean on August 26, 2017. On August 30, as it neared within 400 miles of the Cabo Verde Islands, moving westward at 13 miles per hour, Irma was classified as a Tropical Storm with maximum sustained winds of 50 miles per hour. Over the next day, Irma rapidly intensified due to the very warm sea temperatures and moist air, officially becoming a Category 3 hurricane on August 31. Irma did not intensify much more as it continued to move west-northward. On September 2, due to high pressure over the central Atlantic, Irma began to migrate west-southwest. As models began to predict Irma's trajectory heading toward Puerto Rico and the U.S. Virgin Islands, a hurricane watch followed by a hurricane warning was issued on September 4, 2017. Warm sea surface temperatures and low wind shear contributed to Irma's continued strengthening, causing it to intensify into a Category 5 hurricane with wind speeds up to 185 miles per hour on September 5 (National Oceanic and Atmospheric Administration, 2017a).

Irma begin impacting the northern Leeward Islands in the early morning hours of September 6, notably the islands of Barbuda and Saint Martin. The hurricane's southern eyewall moved over the British and U.S. Virgin Islands in the late morning, early afternoon hours. At this point, the main island of Puerto Rico began experiencing sustained tropical storm force winds. The eyewall passed 30 miles north of San Juan (Cangialosi, Latto and Berg, 2018) as Irma continued to move west-northwestward (Figure 3.1).

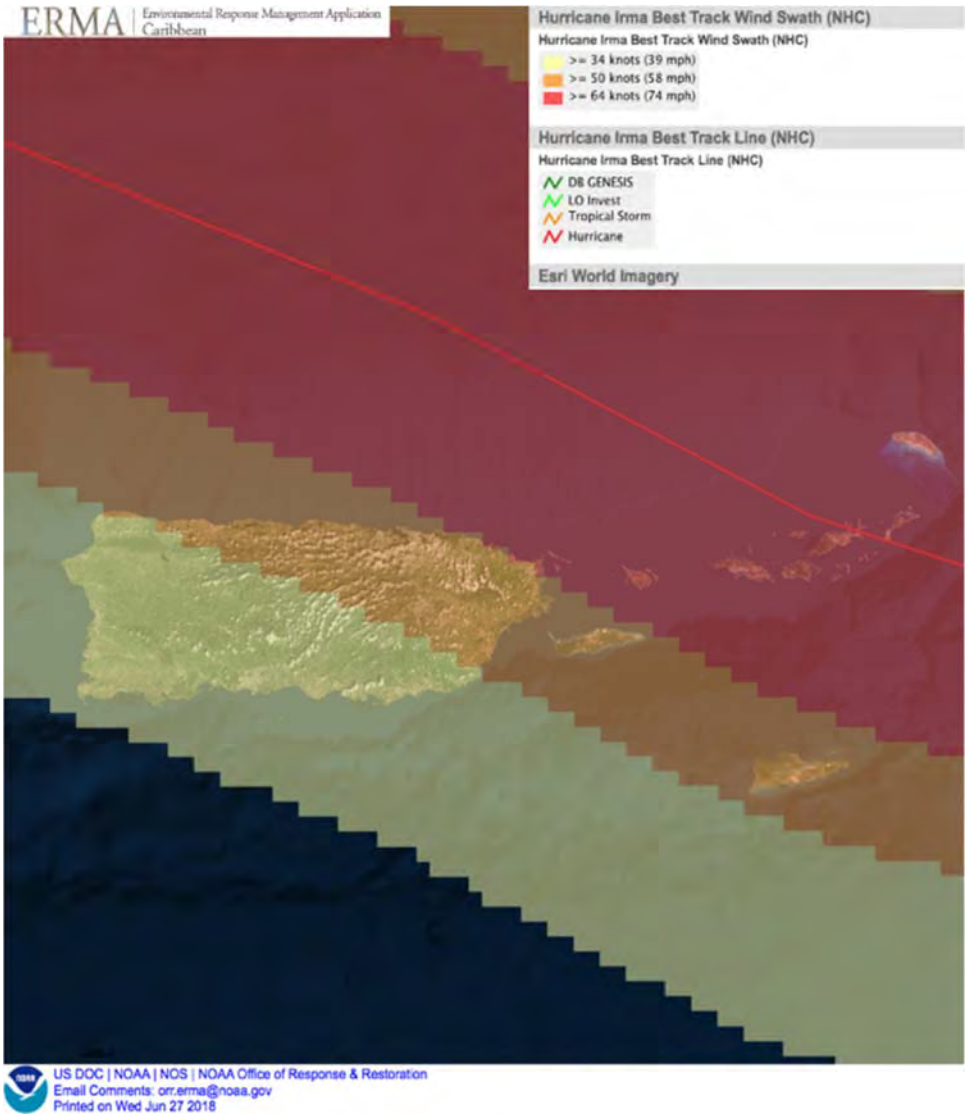
Figure 3.1. San Juan Doppler radar at 2115 UTC 6 September showing Hurricane Irma passing north of Puerto Rico



SOURCE: (Cangialosi, Latto and Berg, 2018).

Most of Puerto Rico only observed tropical storm forced wind (maximum speed of 50 miles per hour; range of 22 to 50 miles per hour at observation sites). However, the island of Culebra experienced hurricane force winds during this time period, with wind gusts reaching at least 90 miles per hour. Wind swaths of Hurricane Irma are shown in Figure 3.2. Conditions began to improve in Puerto Rico on September 7, as Irma continued to pull away toward the northwest (National Oceanic and Atmospheric Administration, 2017a).

Figure 3.2. Storm track and wind swaths of Hurricane Irma, September 2017



SOURCE: (National Oceanic and Atmospheric Administration, 2015a)

Impacts to Puerto Rico

Although Irma's southern eyewall passed just north of Puerto Rico, the Commonwealth experienced heavy rainfall totaling 10 to 15 inches, concentrated in high elevation areas, between September 5 and 7 (Cangialosi, Latto and Berg, 2018). Rain, combined with tropical-storm-force winds, resulted in minor damage to structures and trees on mainland Puerto Rico and widespread power outages. The island of Culebra suffered the most devastating impacts of Irma (Figure 3.3), with many homes destroyed or suffering major damage, trees uprooted, and near-total power and water loss (Cangialosi, Latto and Berg, 2018).

Figure 3.3. Photo of flood damage from Irma in Culebra

Source: (Ahiram Diaz-Ramos, 2017)

Hurricane Maria

Storm climatology

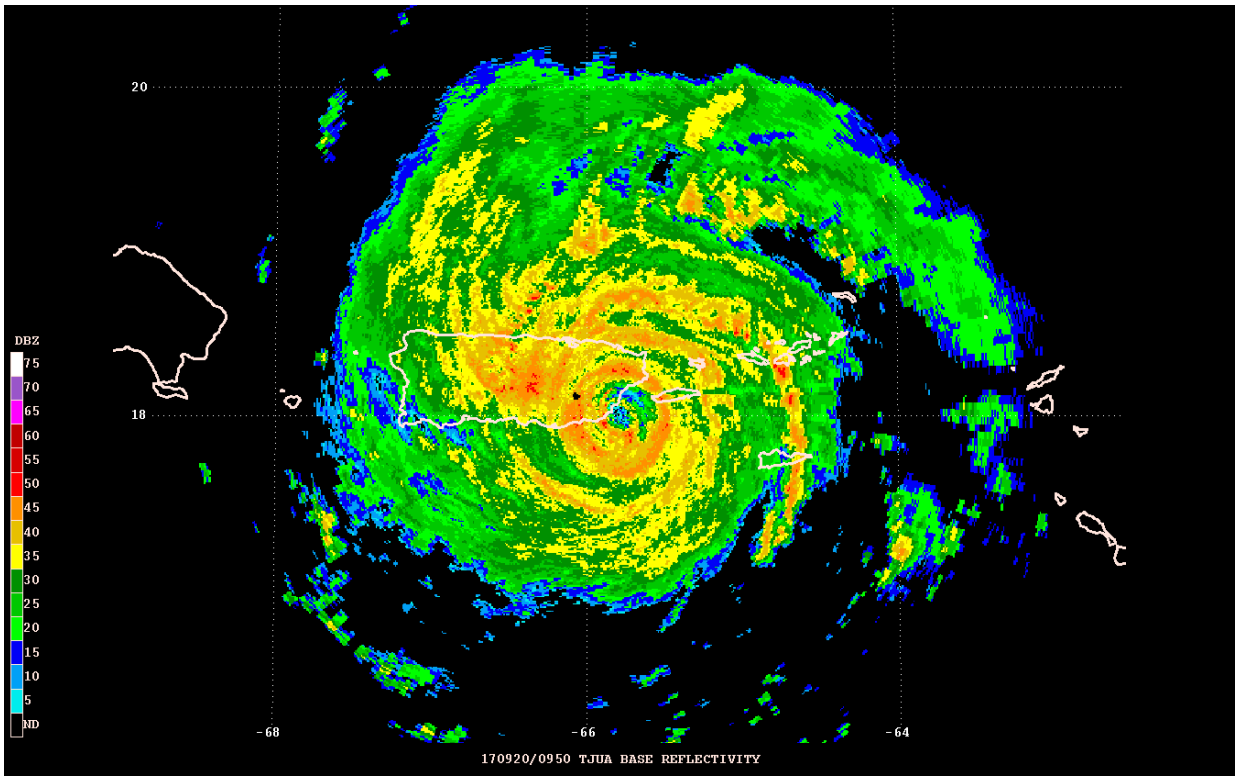
Hurricane Maria began forming in the tropical Atlantic Ocean less than a week after Hurricane Irma passed Puerto Rico. Starting on September 10, 2017 an African easterly wave began moving across the tropical Atlantic Ocean. By 2:00 PM AST on September 16, it had the characteristic of a tropical depression, and was at that point located 700 miles east-southeast of the Lesser Antilles. Three hours later, at 5:00 PM AST, Maria was officially upgraded to a Tropical Storm with maximum sustained winds of 50 mph. The storm continued to intensify over the next day to become a hurricane with 75 mph maximum sustained winds at 5:00 PM AST on September 17 (National Oceanic and Atmospheric Administration, 2017a; National Oceanic and Atmospheric Administration, 2018c; NOAA's Office of Response and Restoration).

The environmental conditions were favorable to the further intensification of the storm, including warm sea surface temperature, moist air, and light vertical wind shear. Over the next 30 hours, Maria intensified to a Category 5 hurricane and on September 18 at around 9:15 PM AST, the storm first made landfall in Dominica in the Windward Islands. Maria maintained its

strength as a Category 5, approaching the U.S. Virgin Islands and Puerto Rico. Saint Croix, Saint John, and Saint Thomas began experience rain bands early on September 19, and rain and tropical storm conditions reached the islands of Puerto Rico, Vieques, and Culebra by early evening that day.

The hurricane continued to intensify as Maria's center approached Puerto Rico and the U.S. Virgin Islands as a Category 5 storm with maximum sustained winds of 175 mph. The eyewall moved over St. Croix between 12:00 and 1:00AM AST on September 20, and decreased in intensity with maximum windspeeds of 155 mph as it moved closer to Puerto Rico. Hurricane force winds were first reported in Vieques at around 5:00 AM AST on September 20, and about an hour later at 6:15 AM AST Maria first made landfall on mainland Puerto Rico in Yabucoa.

Figure 3.4. Radar image of Hurricane Maria at 0950 UTC 20 September just before landfall

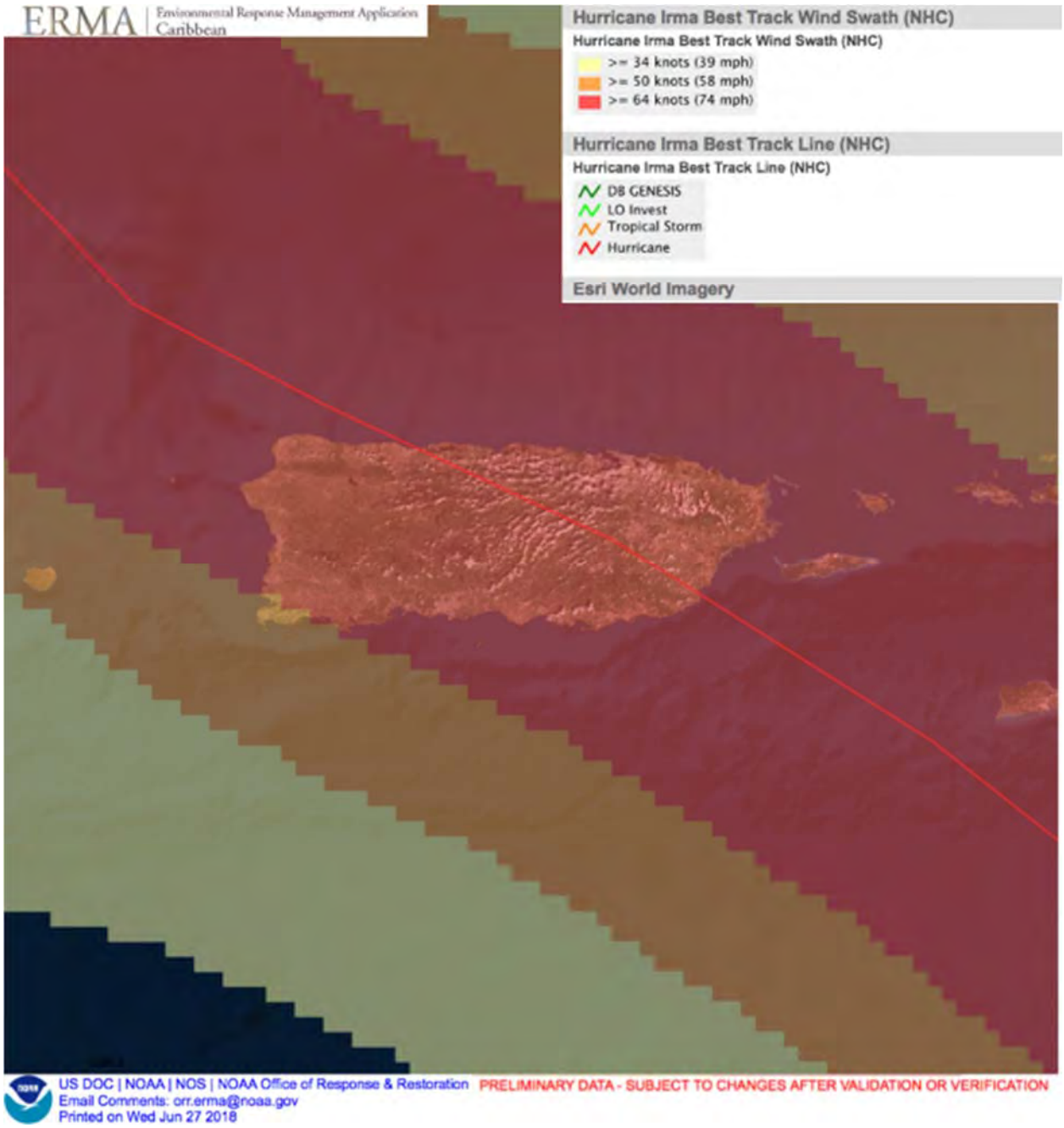


NOTE: Last image from this radar station before it was destroyed. SOURCE: (Pasch, Penny and Berg, 2018)

At the time it made landfall, Maria was a Category 4 hurricane with maximum windspeeds of 155 mph (Figure 3.4). The center of the storm continued to move west-northwest from southeastern Puerto Rico, over the center of the main island, passing only 25 miles from San Juan, to its northwest edge, bringing with it widespread and sustained hurricane force winds, shown in Figure 3.5, and heavy rainfall. Extreme wind gusts were experienced across the entirety

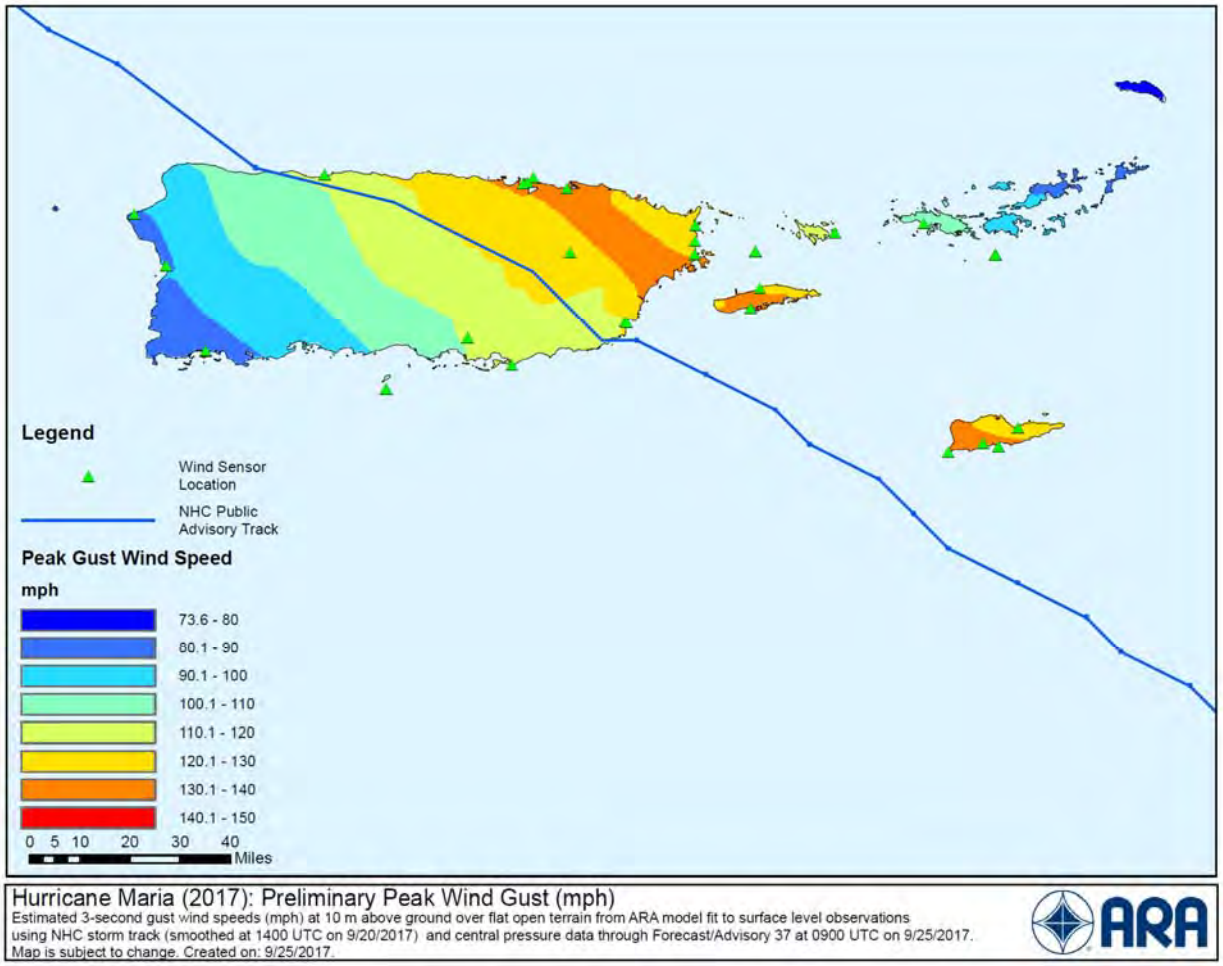
of mainland Puerto Rico, Vieques, and Saint Croix (Figure 3.6), and mainland Puerto Rico experienced extreme flooding across most of the main island(Pasch, Penny and Berg, 2018). Early in the afternoon of September 20, the storm moved off-shore to the waters northwest of the main island, though tropical storm force winds continued into the evening and late night hours (National Oceanic and Atmospheric Administration, 2017b). Maria was the most intense hurricane to make landfall in mainland Puerto Rico since Hurricane Felipe II in 1928, also a Category 5 storm (Voiland, 2017; National Oceanic and Atmospheric Administration, 2017b; National Oceanic and Atmospheric Administration, 2018c).

Figure 3.5. Storm track and wind swaths of Hurricane Maria, September 2017



SOURCE: (National Oceanic and Atmospheric Administration, 2015b)

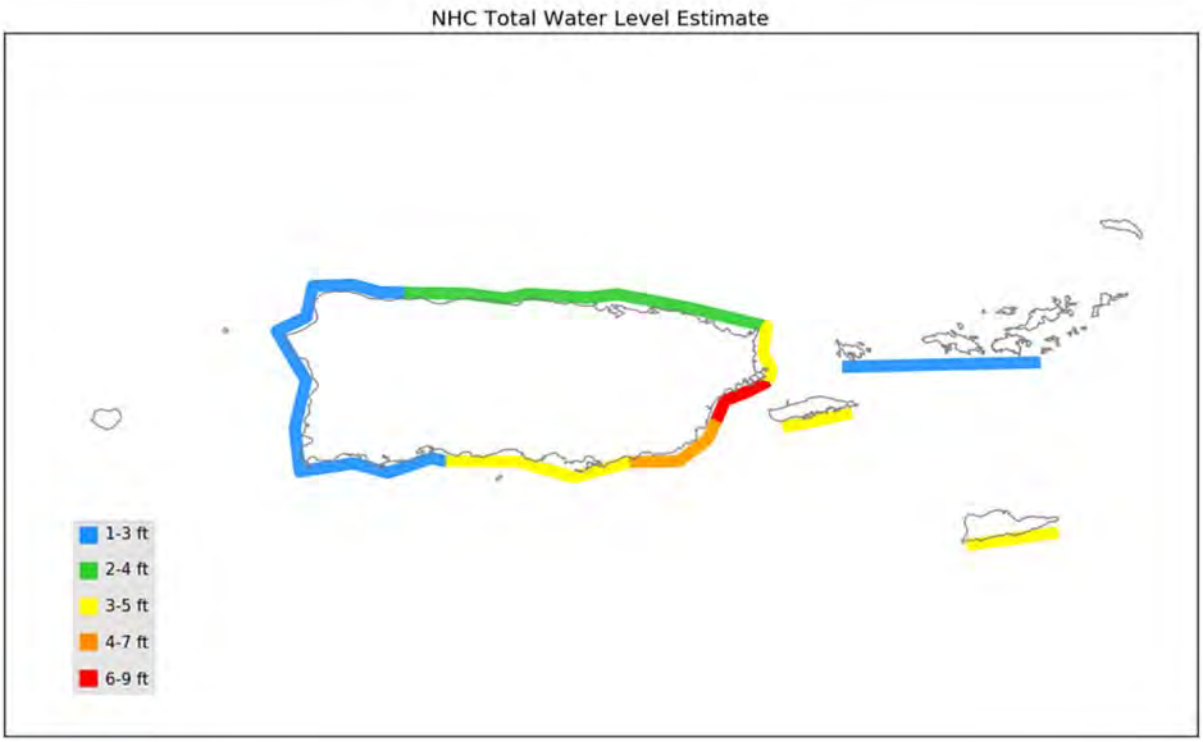
Figure 3.6. Peak Wind Gusts from Hurricane Maria



SOURCE: (ARA, 2017)

Maria's maximum storm surge was measured at approximately 5.3 feet above mean higher high water (MHHW; or mean high tide), measured at a tide gauge at Puerto Rico's southeastern tip. Estimates based on peak water levels suggest that maximum inundation was as high as 9 feet above ground level in certain locations (Figure 3.7). Maximum waves associated with Maria of 44 feet were observed in 170 nautical miles north-northeast of San Juan. The maximum waves measured proximal to land in Puerto Rico were approximately 24 feet high, observed at a buoy off the coast near Rincon, on Puerto Rico's northwestern tip (National Oceanic and Atmospheric Administration, 2017b).

Figure 3.7 Estimated Storm Surge Inundation (feet) Above Ground Level During Hurricane Maria



SOURCE: (Pasch, Penny and Berg, 2018)

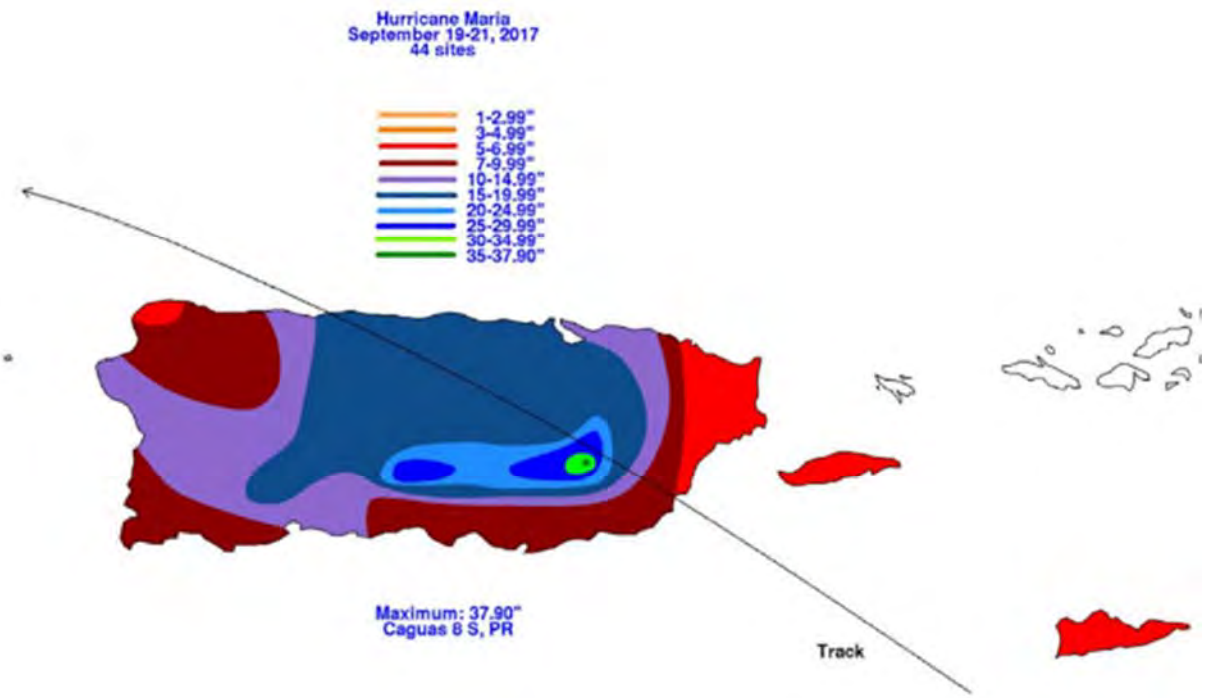
Impacts to Puerto Rico

Between September 19 through September 21, 2017, Puerto Rico experienced very heavy rainfall, with many parts of the Island receiving 15 inches of rain or more in the 48-hour period. The highest recorded rainfall (37.9 inches) was observed in a heavily forested area in southeast Puerto Rico (Figure 3.8). The significant rainfall is largely attributed to the slow-moving nature of the storm, with rain coming down at a rate of five to seven inches per hour (Samenow, 2017). It is also important to note that Maria's heavy winds impaired data collection at many weather stations, so precise windspeeds and rainfall are difficult to determine (National Oceanic and Atmospheric Administration, 2017b).

The high rainfall totals and runoff associated with Hurricane Maria resulted in extensive flooding. Due to the uneven and mountainous terrain in heavily impacted areas, stream and river flooding was widespread in the wake of Maria. Stream gage data from Puerto Rico indicate that discharge rates for some streams were several-fold higher than observations in prior or subsequent months, with a maximum observed discharge of over 20,000 cubic feet per second in September, compared to a maximum discharge of less than 5,000 cubic feet per second in the previous month.

Puerto Rico's mountains and valleys may have also led to very high peak windspeeds experienced during Maria. The extreme wind damaged most of the weather stations in Puerto Rico during Maria, but those that were able to record wind speeds logged measurements of 137 mph on the islands of Culebra and Vieques to the east of mainland Puerto Rico. Peak windspeeds recorded on the mainland were 120 mph (National Oceanic and Atmospheric Administration, undated-a).

Figure 3.8. Estimated storm total rainfall from Hurricane Maria (inches)

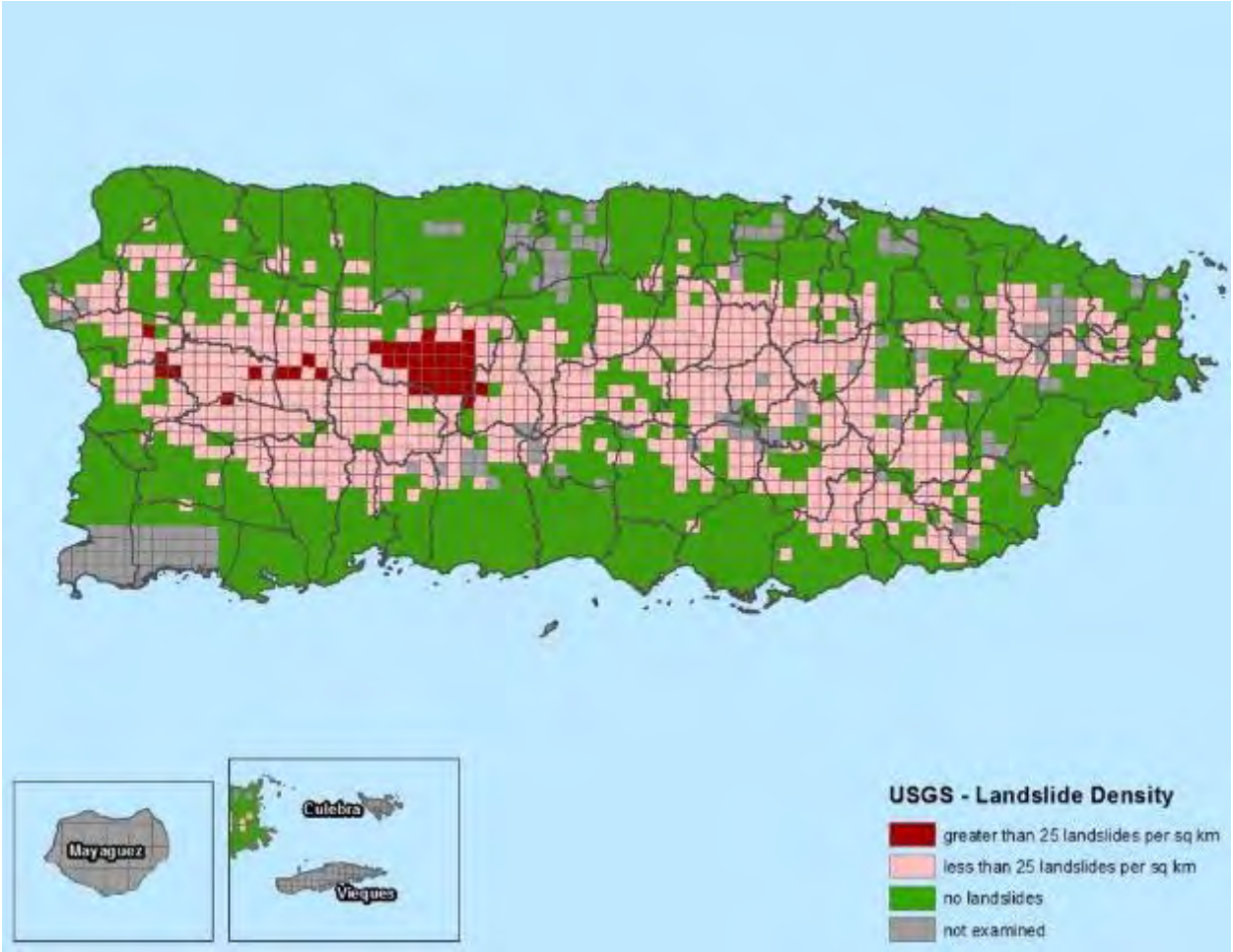


SOURCE: (Pasch, Penny and Berg, 2018)

The concentrated rain from the two storms led to more than 41,000 landslides, which occurred across a significant portion of Puerto Rico.[16] Figure 3.9 shows the concentration of landslides by municipality. Estimates show at least one landslide per square kilometer across most of the entire mountainous region in Puerto Rico. Utuado suffered more than 25 landslides per square kilometer across a large portion of the municipality.

[16] Personal communication with Dr. Stephen Hughes at the University of Puerto Rico-Mayaguez

Figure 3.9 Landslide density in Puerto Rico following Hurricane Maria



Source: (Bessette-Kirton et al., 2017)

Hurricane Maria represented a worst-case scenario for Puerto Rico. The storm's path took it directly across the main island, only 25 miles from San Juan, the area of Puerto Rico with the highest population density. The storm also lost speed as it made landfall, resulting in prolonged periods of heavy winds and rain. Puerto Rico's mountainous terrain led to increased rainfall, wind intensification (wind tunnels), flash flooding in rivers, streams, and valleys (National Oceanic and Atmospheric Administration, 2017b). Following Hurricane Maria, a second Major Disaster Declaration (DR-4339-PR) was issued on September 20, 2017 and FEMA extended eligibility for both PA and IA to all 78 of Puerto Rico municipalities (Federal Emergency Management Agency, 2017). As documented through the remainder of this report, Maria's effects on Puerto Rico were catastrophic, widespread, and long-lasting.

Congressional requirement for a recovery plan

In response to the unprecedented damage inflicted on Puerto Rico by Hurricanes Irma and Maria, Congress passed the "Further Additional Supplemental Appropriations for Disaster Relief Requirements Act, 2018," which was signed into law on February 9, 2018 (*H.R.1892 - Bipartisan Budget Act of 2018*, 2018). This law requires the Governor of Puerto Rico, in coordination with FEMA, the Department of Treasury, Department of Energy, and other federal agencies with responsibilities under the National Disaster Recovery Framework (NDRF) to submit a report to Congress that describes Puerto Rico's 12- and 24-month economic and disaster recovery plan within 180 days of enactment of the legislation. Specifically, the plan should define "the priorities, goals, and expected outcomes of the recovery effort for the Commonwealth based on damage assessments prepared pursuant to Federal law, if applicable" for the following sectors: housing; economic issues; health and social services; natural and cultural resources; governance and civic institutions; electric power systems and grid restoration; environmental issues; and other infrastructure systems. In this recovery planning effort, this language is expanded to the following sectors: Community Planning and Capacity Building (CPCB); Municipalities; Economy; Health, Education, and Social Services (HESS); Housing; Natural and Cultural Resources (NCR); Energy; Water; Communications/IT; Transportation; and Public Buildings.

4. Review of Methods for Damage and Needs Assessment

This chapter provides a review the major government stakeholders' processes and procedures for conducting damage and needs assessments and their mechanisms for releasing funding. In addition, we explore the academic literature on best practices and lessons learned in conducting assessments. Specific damage and needs assessments and major international actors' processes and procedures are highlighted as case studies to help inform the Puerto Rico damage and needs assessment.

We reviewed 20 documents to assess how the damage and needs assessment for Puerto Rico's recovery plan aligns with other damage assessments developed in response to disasters. The document and literature review specifically focused on FEMA and U.S. disaster response, but also includes other exemplar recovery plans for different regions and across disaster types.

In the case of Puerto Rico, the most relevant damage assessments conducted were completed by FEMA, HUD, and USACE. These agencies all have guidelines for determining and categorizing damage following a disaster and quantifying the needs for recovery. This chapter also highlights two key United Nations agencies and the World Bank's process for conducting damage assessments.

FEMA damage assessments

There are three primary types of assistance that can be provided by FEMA through the Stafford Act in response to a disaster: Public Assistance (PA) , Individual Assistance (IA), and hazard mitigation (Federal Emergency Management Agency, 2016). Completing a damage assessment is a required first step for governments, private non-profits, individuals, and households to receive PA, IA, or hazard mitigation assistance. Assistance from the Stafford Act must be requested by the Governor of the State or Chief Executive of the Tribe within 30 days of a disaster, though an extension may be considered in extreme cases. As a result, damage assessments typically must also be completed in this timeframe. In severe cases, such as in the case in Puerto Rico following Hurricanes Irma and Maria, rapid assessments can be conducted to determine Stafford Act assistance eligibility prior to the completion of a full damage assessment (Federal Emergency Management Agency, 2016).

Damage assessments may be conducted locally or by a state or tribal government, with the state or tribal government having the ultimate responsibility in signing off on the assessment or the Joint Federal, State, or Tribal Government Preliminary Damage Assessment (Joint PDA) if the damage is severe. FEMA can provide technical assistance when requested. Joint PDAs occur when requested by the state or tribal government and when the severity of damage exceeds the capabilities of the local, state, or tribal government. FEMA will then work with FEMA regional

office to deploy personnel, alongside other federal agencies (OFAs) and state and tribal governments, and may involve a federal disaster recovery coordinator (FDRC) if necessary. The deployed personnel will validate the findings of the state and tribal governments and work with them to reconcile differences (Federal Emergency Management Agency, 2016).

FEMA has standardized the process of creating damage assessments across the agency, non-governmental stakeholders, and the private sector. Emergency management personnel are expected to use this standard approach when assessing damage following natural disasters. Only in rare cases does FEMA utilize alternate rapid assessment methods to determine Stafford Act assistance needs (Federal Emergency Management Agency, 2016). Although the contents of the damage assessment are standardized, the methodology for collecting damage assessment data can vary widely. For example, methods used may be influenced by the type of incident. Different incidents will lend themselves to different timelines: some disasters (e.g., tornadoes) have obvious damage, allowing an assessment to be done quickly, whereas others (e.g., floods) may require more hands-on assessment.

Assessments can be done through local-level initial self-reporting with verification by assessment teams, flyovers to rapidly assess damage visible by air, surface-level assessments by vehicle via windshield surveys, door-to-door and site assessments for more depth and accuracy, geospatial analysis and Geographic Information Systems (GIS) analyses from satellite imagery, and predictive modeling. Geospatial analysis is an emerging tool for FEMA because of its ability to quickly assess large areas of interest to determine the types of assistance needed (Federal Emergency Management Agency, 2016). Some sources of geospatial data used in this damage and needs assessment include GPR, ESRI, NASA, and National Oceanographic Atmospheric Administration (NOAA). Geospatial data sources and analysis also have important limitations; examples encountered in Puerto Rico by the NCR sector include the large size of the datasets, computing limitations, and challenges in obtaining satisfactory baseline datasets for comparison post-disaster.

Public Assistance program

Public Assistance provides governments—local, state, or tribal—and eligible private non-profits with assistance funds to remove debris, repair structures, and provide emergency services. In order to receive federal funds through the Stafford Act, a local, state, or tribal government must have a minimum of $1 million in PA damage. PA damage and assistance are determined through six key factors through which damage information is collected and analyzed (Federal Emergency Management Agency, 2016):

- estimated cost of assistance
- insurance coverage in force
- programs of other federal assistance
- localized impacts
- hazard mitigation

- recent multiple disasters

Estimated cost of assistance

The estimated cost of assistance is the most detailed factor in the PA program; therefore, we provide further detail on this factor in this report. FEMA divides the type of work needed into two main types: emergency work (Categories A-B: debris removal, emergency protective measures) and permanent work (Categories C-G: roads and bridges, water control facilities, buildings and equipment, utilities, parks and recreation). See Table 4.1 for further details.

Table 4.1. FEMA Work Type Groupings

Type		Category of Work	Description
Emergency Work	A	Debris Removal	Clearance, removal, disposal of debris that is central to the public interest
	B	Emergency Protective Measures	Activities to save lives, ensure safety, promote public health, and protect improved property
Permanent Work	C	Roads and Bridges	Restoration of public roads and bridges to pre-disaster condition
	D	Water Control Facilities	Restoration of publicly-owned water control facilities to pre-disaster carrying or storage capacity
	E	Buildings and Equipment	Structural and non-structural components of buildings to restore and upgrade as required by codes and standards; repair or replacement of damaged equipment to comparable value
	F	Utilities	Inspection, restoration, and replacement to pre-disaster condition of system components
	G	Parks, Recreation and Other	Restoration of publicly-owned facilities

In the estimated cost-of-assistance factor, there are four eligibility requirements that must be met: potential applicant, facility, work, and cost. Although the approach to documenting damage and costs may vary, the assessments and submitted claims must be verified if necessary. FEMA generally requires additional documentation to receive PA if the projects are very large or raise eligibility questions (Federal Emergency Management Agency, 2016).

The damage assessment and cost estimations describe what is needed to restore to pre-storm design and conditions. Restoration to the pre-storm state is the standard for PA funding. In special circumstances, structural upgrades may be considered in instances when codes, specifications, and standards were not being met pre-storm. This was certainly the case across many sectors in Puerto Rico, as documented in later chapters of this report. Replacement of equipment and supplies may occur when repairs exceed 50 percent of the replacement cost. When claiming damage to a facility, the applicant must prove ownership of or legal responsibility. When documenting damage, the specific United States National Grid location should be specified, annotated maps should be provided, photographic evidence is encouraged, and needed dimensions and materials should be listed. Applicants for assistance should

document costs in the form of labor (e.g., hourly rates, benefits), equipment (e.g., hourly rates, mileage), leased equipment, supplies, contract services, and mutual aid agreements (Federal Emergency Management Agency, 2016).

The following are the remaining five factors for determining assistance from the PA program:

- **Insurance Coverage in Force:** PA costs are reduced by the estimated, or actual when available, insurance payouts
- **Programs of Other Federal Agencies (OFA's):** If a disaster is the responsibility of an OFA, assistance under the Stafford Act will generally not be granted. FEMA may work with the relevant OFA's to review the damage assessment and determine the responsible agency.[17]
- **Localized Impacts:** Impact statements are short narratives that describe the impact of the disaster at the local level. They typically include statistics, the direct and indirect effects of the damage to the community, and the impact on community functions. These narratives help provide context to determine if supplemental federal assistance is needed to alleviate negative impacts of the disaster and improve the recovery process
- **Hazard Mitigation:** A description of existing hazard mitigation efforts prior to the disaster should be included in the damage assessment. A determination of whether these mitigation efforts helped reduce the overall impact of the disaster should also be made, as any mitigation measures that were in place prior to the disaster may have resulted in the estimated cost of assistance falling below per capita indicators
- **Recent Multiple Disasters:** Any disasters that have occurred within 12 months are considered when evaluating the jurisdiction's assistance request, as FEMA understands that recent disasters have an impact on the recovery process.

Individual assistance program

IA programs support individual and household disaster survivors who have serious unmet needs with assistance for housing and property, medical care, and disaster-related expenses. Some programs also support state or tribal governments in providing individual support services (e.g., counseling, legal services, case management, unemployment) at the community level. IA does not have a set threshold established. There are five primary factors considered when evaluating the impact of a disaster including (1) concentration of damage, (2) trauma, (3) impact on populations with greater need, (4) ability of governments and voluntary organizations to address needs, and (5) uninsured/underinsured home and personal property loss (Federal Emergency Management Agency, 2016). Documenting impacts related to these factors such as the number of individuals missing, injured, or deceased as a result of the disaster; disruptions to normal

[17] For example, the Small Business Administration (SBA) can provide disaster assistance to private non-profits, the Federal Highway Administration (FHWA) typically removes debris from and restores public roads, the U.S. Coast Guard (USCG) and U.S. Army Corps of Engineers (USACE) have authority to maintain navigable waterways, and the Environmental Protection Agency (EPA) and USACE remove hazardous materials (FEMA Damage Assessment Manual, 2016).

community functions like impacts on schools or transportation; the demographics of the affected population; availability of governmental resources; and the availability of emergency resources and supplies (Federal Emergency Management Agency, 2016).

Damage to homes is a major focus for IA. Assistance provided as a result of damage to homes may not restore the home to pre-storm conditions; rather, it is intended to provide individuals and households with a "safe, sanitary, and functional dwelling from which they can continue their recovery" (Federal Emergency Management Agency, 2016). FEMA requests that the following information is collected during damage assessments regarding damage to homes (Federal Emergency Management Agency, 2016):

- *cause of damage*, which should be related to a natural hazard and will be used to assess of the home is covered by insurance
- *information on jurisdictions impacted and concentration of damage*, which is used to identify the concentration and magnitude of the damage
- *types of homes*, including single family, multi-family, and manufactured homes and information about the type of construction in order to help assess the length of time repairs may take
- *homeownership rate of impacted homes*, including both ownership status (owner, renter) and occupancy status (primary, secondary, vacant)
- *percentage of affected households with insurance coverage appropriate to the peril*: duplicative assistance will not be issued when individuals are receiving funds through insurance claims, though FEMA may provide supplemental assistance with items not covered under hazard policies
- *number of homes impacted and degree of damage*, with the latter described in four standardized methods: destroyed, major, minor, and affected (also, inaccessible when assessment is not available):
  - destroyed: residence is a complete loss and un-habitable
  - major: extensive repairs required to structural damage (e.g., water on floors, displaced from foundation)
  - minor: minimal damage that requires repairs (e.g., windows and doors, HVAC), but no structural damage
  - affected: cosmetic damage to non-habituated aspects of the home only (e.g., garage, porch); damage does not affect habitability
- *inaccessible communities*, e.g., if a road is flooded or otherwise blocked and not safely reachable
- special flood hazard areas, sanctioned communities, coastal barrier resource system zones and other protected areas
- *primary or secondary residence*; assistance is not provided to secondary residences.
- *other relevant PDA data*, such as income levels, poverty, trauma, and special needs.

Community conditions assessment (CCA)

FEMA has developed a CCA designed to provide a quantitative municipal-level view of risk and impact to determine damage and needs; it is focused on four components: hurricane damage,

hazards, vulnerability, and capacity. The CCA has indicators within each of these components developed from government data sources collected before and after the hurricane. CCA damage scores are currently a combination of four equally weighted variables, each of which has one to five measurement indicators. These damage variables currently offer an overview of housing-related damage; it does not include indicators for other important sectors (e.g., electricity, roads, HHS, etc.) nor does it employ strategies to weight sectors based on their importance, including their interdependency with other sectors. CCA vulnerability scores consist of 11 equally weighted variables with 30 indicators, and the CCA provides hazard related data for flooding and several variables and indicators of capacity. The components of the CCA cover the areas that CPCB needs to understand at the municipal level, and many of the HSOAC sectors used the CCA as a starting point for developing a municipal-level risk assessment profile. FEMA also conducts a companion qualitative CPCB Opportunities and Needs Assessment that describes the disaster-related issues and needs of communities (National Integration Center, 2015).

Damage assessments by other U.S. agencies

Department of Housing and Urban Development (HUD)

Preliminary Disaster Assessment

HUD conducts a Preliminary Disaster Assessment (PDA) for its multifamily housing units in the designated disaster area. HUD headquarters designates the Affected Portfolio List (APL) and the regional director uses the list to begin the process of gathering damage assessments of those properties. A construction analyst is responsible for assessing properties and assigning them a disaster code based on the severity of the damage (none, minor, modest, severe) and the power (outage, damage). This code may be re-assessed and can change over time. The PDA aims to describe unmet needs of the residents (e.g., food and water, health risks and vulnerabilities) and is used as a means to coordinate services with FEMA. HUD uses the PDA to prioritize properties based upon the damage reported in the assessment (Housing and Urban Development).

In addition, a Vacancy Utilization/Displaced Resident Report lists available properties for displaced residents to use for temporary—or if possible permanent—residence. Displaced residents will not be moved into a unit if it is deemed in poor repair (inspection score below 60) or there are other legal barriers to the unit (Housing and Urban Development).

A construction analyst will perform a damage assessment on-site of properties that were listed in the PDA. Photographic evidence and a report from the resident on damage is obtained at this time. Each final damage assessment covers items personal to the residents, such as injuries, evacuation needs, and unmet needs, as well as property assessments such as access to water, power, and if flooding occurred. The final disaster assessment for a multifamily property will include information from damage reports, the number of properties affected, vacated units that need repaired, displaced residents, and other recovery information. They are detailed and specific

about information like debris removal needed, damage to the exterior and interior, and damage to critical systems (e.g., plumbing, electrical). Following the damage assessment, HUD creates recovery plans for damaged properties. HUD is dependent on FEMA's eligibility determination; therefore, all residents must apply through FEMA in order to receive assistance (Housing and Urban Development).

Community Development Block Grant-Disaster Recovery (CDBG-DR)

Community Development Block Grant-Disaster Recovery (CDBG-DR) grants provided by HUD are determined by the Disaster Impact and Unmet Needs Assessment. CDBG-DR grants are intended to fund unmet long-term recovery needs; thus, the assessment may take months following the disaster as accurate and complete data on disaster impacts becomes available. The grants are intended not only to help restore and repair, but may also support longer-term growth by addressing weaknesses that existed prior to the disaster. In order to receive CDBG-DR grants, sectors must provide damage estimates and existing dedicated resources for the types of needs (e.g., water and sewer, retail district, affordable rentals). By describing the dedicated resources, the CDBG-DR will be able to assess unmet needs more accurately (Housing and Urban Development, 2013a).

The impact of the disaster is determined by both direct (e.g., fixed assets, raw materials) and indirect damage and secondary impacts (e.g., housing market shifts, loss of tax revenue). There are three critical components that grantees must address when assessing disaster impact:

1. *Pre-disaster baseline data, post-disaster market data, and data on assistance provided*: It is essential to understand the community conditions prior to the disaster in the housing, infrastructure, and economy sectors in order to assess past trends. These data can be obtained through traditional government resources (e.g., Consolidated Plan, Comprehensive Economic Development Strategy) or by accessing data on market indices, such as demographic shifts, employment figures, labor statistics, future environmental risks, etc. These data can be obtained through a variety of sources, including the U.S. Postal Service (USPS), state and federal agencies, insurers, utility companies, and more. Finally, information must be obtained about assistance provided through the Stafford Act or other sources (e.g., Red Cross, charities, SBA). Duplication of benefits is not permitted (Housing and Urban Development, 2013a).
2. *Analyzing data collected in light of the impact of short-term recovery efforts:* While analyzing the data obtained in the first step, six elements must be considered:

   > (1) Activities and results of emergency and short-term recovery efforts (e.g., FEMA-funded activities); (2) Among the existing and anticipated emergency and short term efforts, which ones only provide interim solutions (such as FEMA temporary housing) versus those that will result in permanent solutions (such as repairing a water pump facility): (3) Key parties involved in relief and recovery efforts, to date, at the federal, state, and local level; (4) Estimated duration of the emergency and short-term recovery efforts; (5) The condition of the most PDADs; and (6) Initial planning initiatives at the neighborhood, city, county or regional level (Housing and Urban Development, 2013a).

At this stage, considerations of ancillary impacts of initial response, key stakeholders' post-initial recovery efforts, public engagement, and community-established priorities should come to the forefront.

3. *Identifying existing, anticipated, and potentially available funding sources:* Other sources of funding such as state, local, and private sources may help provide some create solutions. Since CDBG-DR is deemed a last resort funding source, applicants must display a significant gap in public resources, insurance payouts, special appropriations, and nonprofit and private sources (Housing and Urban Development, 2013a).

U.S. Army Corps of Engineers

Following a disaster, the USACE conduct damage assessments of critical infrastructure and public facilities (e.g., schools, hospitals, buildings to be used for temporary shelters) to determine if the structure is safe for entry and use (Kornacki, 2018a). Upon inspection, a standardized safety rating (inspected, limited entry/restricted use, unsafe) is assigned and the USACE will provide an estimate of the resources required for repairs (USACE; USACE, 2012a). Assessments are conducted in partnership with local assessors and programs, and USACE training officers provide local field inspectors with training to complete the assessments (USACE, 2012b).

Assessors use a standardized forms including the "ATC-20/45 Rapid Evaluation Safety Assessment Forms, detailed inspection forms, sub-tasking documents and inspection placards" (USACE, 2012a). There are three stages in the ATC-20/45 process: rapid evaluations, detailed evaluations, and engineering evaluations. Rapid evaluation focuses on identifying the obviously unsafe structures, whereas the detailed evaluation requires a more thorough inspection both inside and outside. All essential facilities such as hospitals immediately receive the detailed evaluation rather than starting with the rapid evaluation. Finally, the engineering evaluation is not an inspection, but rather a design process in which revised design calculations are created; therefore, this type of evaluation is a separate technical assistance mission that is not an automatic service by the USACE. Buildings may be re-inspected if necessary (USACE, 2012b; USACE, 2012a).

In addition to damage assessments, the USACE also provides a wide range of technical assistance services such as engineering, electrical, geotechnical, and more as well as search and rescue support and water/wastewater infrastructure repairs (USACE, 2012b). As described, the engineering evaluation process is also a technical assistance service (USACE, 2012a).

Damage assessments by international actors

Identifying exemplar damage assessments done worldwide is especially critical in Puerto Rico due to its geography and pre-storm conditions (particularly infrastructure and governance), which are unique from most other pre-disaster conditions in the United States. The United Nations and the World Bank have been enlisted following many natural disasters in small island nations to conduct damage and needs assessments. Other island nations have also established their own national protocols for assessing damage. These exemplars are highlighted, alongside specific examples, to illustrate other commonly used methods worldwide.

United Nations' Post-Disaster Needs Assessment (PDNA)

The United Nations' PDNA is a component of the post-crisis cooperation joint agreement between the European Union, the World Bank and the United Nations Development Group. As part of the joint agreement, the partners completing the PDNA agree to support the affected government's own damage assessment process following a disaster. The sectors represented in the PDNA process include the following: social (housing, education, health, culture); infrastructure (water and sanitation, infrastructure, energy, transportation, telecommunications); productive (agriculture, fisheries, commerce, industry, tourism); macro-economy (GDP, trade, fiscal balance); finance (banking and financial institutions); human development (poverty and human development); and cross-cutting (governance, risk reduction, employment, environment, gender) (United Nations Development Programme (UNDP), 2014).

Economic, social services, governance, and underlying risks and vulnerabilities data alongside information on physical damage are incorporated into the PDNA to understand socio-economic effects of the disaster. The PDNA considers the damage to a region's productive sectors of the economy and macro-economic situation to be as important as the damage to physical infrastructure and assets. The PDNA includes four components: (1) cross-sector damage assessment that compares post-disaster conditions against baseline data, (2) recovery vision and strategies by sector with a description of the resources needed, (3) resource mobilization tool, and (4) plan for the recovery process. The design of the PDNA emphasizes resiliency and a "build back-better" approach (United Nations Development Programme (UNDP), 2014). The data generated through the PDNA feeds into the Disaster Recovery Framework (DRF), which defines the recovery vision overall and interventions by sector. In this spirit, the PDNA aims to be both coordinated and holistic in order to minimize risk of error and maximize objectivity, and realistic to assist governments with making sound decisions regarding comprehensive recovery. To do so, the PDNA established standardized approach for conducting damage and needs assessments across sectors (United Nations Development Programme (UNDP), 2015).

The PDNA approach follows a four-step analysis. First, the assessment outlines the pre-disaster information on the physical and social structures of the region. These data are collected by each sector primarily through secondary data sources (e.g., Census, government reports), estimations, or pre-disaster satellite imagery. Next, the effect to infrastructure and physical assets, access to goods and services, governance, and vulnerable people is assessed. Similar sources may be used as the baseline data collection (secondary data, satellites), and visual inspections, field visits, and stakeholder focus groups may also be conducted. The PDNA also estimates the monetary and economic cost of these disaster effects. Then, the impact of the disaster at the macro and micro economic level as well as on human development is analyzed. Finally, a recovery strategy is proposed based on the quantified cross-sector short-term, medium-

Box 4.1 The PDNA in Dominica following Hurricane Maria

In October 2017, a PDNA was requested by the Government of the Commonwealth of Dominica. The assessment gathered data over 10 days primarily from government sources. It found that Hurricane Maria resulted in $930.9 million in damage and $380.2 million in losses, or 226 percent of Dominica's 2016 GDP. The PDNA calculated damage and losses by four sectors and 17 sub-sectors: productive (agriculture, fisheries, forestry, commerce and micro business, tourism), social (housing, education, health, culture), infrastructure (transport, electricity, water and sanitation, telecommunication, airports and ports), and cross-cutting (disaster risk management, environment, gender). The social sector, especially housing (38 percent) and education (7 percent) suffered the most damage followed by transportation (20 percent) in the infrastructure sector. Agriculture faced the greatest losses (33 percent). For each sector and sub-sector, the PDNA briefly described Dominica's history and context, the damage and losses, recovery needs (and extensiveness of each), and what will be needed for the sectors to recover.

The hurricane will result in costly human and social impacts, with a 20 to 26 percent decline in the QLI, 3.1 million workdays estimated lost, an estimated 25-percent reduction in consumption, and a 67-percent increase in poverty. The losses and poverty impacts will require $8.2 million in public spending on social protection and governmental safety nets, but the loss in workdays will result in a reduction of those contributing to such programs. Economic output at the macro scale was estimated to drop 16 percent in 2018 and significantly impact the fiscal balance deficits.

Based on the damage and losses, the PDNA made recommendations for Dominica based on four main components: reconstruction of physical assets; resumption of production, service delivery and accesses to goods and services; restoration of governance and decision-making processes; and reduction of vulnerabilities and risks. The proposed budget was $1.368 billion and needs and strategies were presented for the short, medium, and long term (Commonwealth of Dominica, 2017).

term, and long-term needs of the region (United Nations Development Programme (UNDP), 2015).

United Nations Disaster Assessment and Coordination (UNDAC)

The Multi-Sector/Cluster Initial Rapid Assessment (MIRA), led by the requesting Government (of the nation affected by a disaster) and conducted under the United Nations Resident Coordinator/Humanitarian Coordinator (RC/HC), is conducted within the first two weeks of a disaster. Emergency specialists and other UN and local government staff perform these rapid assessments, which are intended to provide a broad overview of damage and needs following a disaster. Eight components comprise the MIRA framework: drivers and underlying factors, scope and humanitarian profile, population status, national capacities, international capacities, humanitarian access, coverage and gaps, and priority needs. The MIRA produces a report of the most pressing needs and potential scenarios of how needs will evolve. The MIRA results in a situational analysis (SA) that the sectors utilize in order to conduct in-depth sectoral and multi-sectoral assessments.

The in-depth assessments are done through secondary and primary data collection. Secondary data include baseline information pre-disaster and any in-crisis information available from national institutions, news, social media, and satellite and geospatial data. All data are analyzed with consideration of biases and limitations, vulnerabilities to sub-groups, and credibility among other important assumptions. Primary data are collected in the form of the community level assessment (CLA). The CLA consists of field visits and qualitative data collection through observation and interviews that utilize a standardized, structured assessment form. Assessors are encouraged to sample purposefully with a wide and appropriately stratified population, but time prohibits random sampling (Office for the Coordination of Humanitarian Affairs, 2013).

World Bank

The World Bank task team leaders (TTLs) are charged completing with disaster impact assessments at the request of the affected government for the purpose of determining required government interventions and their financial implications. TTLs conduct the assessments either independently with a team of specialists and affected government representatives, or in conjunction with United Nations partners as a part of the PDNA (described above). The Damage and Loss Assessment (DaLA) should cover the aspects needed to make a full recovery of social conditions, economic stability, physical assets and infrastructure, and resiliency for future risk. It includes every sector of economic activity from the affected government at the onset, and may cull sectors later in the assessment if they are deemed unaffected by the disaster. The assessment is not solely for the purpose of World Bank funding – it encompasses what is needed for short-term interventions and sustained recovery that will be funded by many international and national actors (Global Facility for Disaster Reduction and Recovery (GFDRR), 2010b; Global Facility for Disaster Reduction and Recovery (GFDRR), 2010a).

The DaLA utilizes the a United Nations-designed methodology that is conducted sector by sector. It incorporates objective and quantitative data from the country's system of national accounts, and avoids any qualitative and subjective information. First, all members of the DaLA team receive a standardized training before beginning any aspect of the assessment. Next, baseline data on country characteristics (cartographic, demographic, social, economic) is collected from the government and private institutions when necessary during the week following the disaster. The TTL and team also collect and analyze all other reports, regardless of data quality and completeness as a means for additional input into the DaLA. An estimated valuation of asset damage and economic losses to the economy is calculated for each sector using the secondary data collected along with some primary data collection through pre-designed sample surveys of industry and commerce and field visits to select locations. The findings are aggregated and accounting overlaps and gaps are identified and rectified in order to provide the disaster's overall effect on the national economy and society and the macro and micro levels. This assessment is intended to delineate the impacts on different scales (e.g., national economy, livelihoods of individuals) and in different temporal scales (e.g., temporary, longer-term) (Global Facility for Disaster Reduction and Recovery (GFDRR), 2010b; Global Facility for Disaster Reduction and Recovery (GFDRR), 2010a).

Once the damage and losses are assessed, the needs of the disaster-impacted area are determined and financial requirements are assigned. Needs are broken out by sector and consider short-, medium-, and long-term recovery. The DaLA also estimates reconstruction needs with the following formula: *Needs = Value of damage + quality/technological improvement + mitigation measures + multi-annual inflation*. The assessment incorporates the capacity of the affected government and puts a lens on improving rather than simply restoring to pre-storm conditions ("building back better"), and incorporating resilience and risk management components. The assessment also includes a suggested calendar of activities, priorities by sector and region, and financial requirements with potential funding sources (e.g., cash grants, commercial lines of credit, temporary fiscal relief schemes) (Global Facility for Disaster Reduction and Recovery (GFDRR), 2010b; Global Facility for Disaster Reduction and Recovery (GFDRR), 2010a).

Damage and needs assessments in small island nations

Puerto Rico's geography lends itself to comparisons in how damage and needs assessments are conducted in small island nations around the world. Many of these countries lean on international actors such as the United Nations and World Bank to perform assessments. Some have national standardized damage assessments. For example, in Trinidad and Tobago, the government utilizes four types of damage assessments. The first is an Initial Situation Overview (ISO) that is conducted within the first eight hours following a disaster. This overview is based on observations, aerial reports, and sometimes satellite imagery and highlights the most critical damage to lifelines and key facilities. Subsequently, the government may conduct an Initial Damage Assessment (IDA), Damage Assessment and Needs Analysis (DANA), and/or a

Damage and Loss Assessment (DALA). In the DANA, for example, the assessment is conducted by trained personnel in government agencies or international organizations. The assessment is done on paper and covers six primary components: nature of the event, affected population (e.g., injured, deceased), secondary effects (e.g., free text box on sanitary conditions, food), actions performed to date, needs analysis, and available resources (human, material, economic). In the needs section, the type, quantity, local solutions, outside help, and priority of need are listed for types of medication, health supplies and equipment, water and environmental sanitation, food, shelter and utilities, logistics and administration, and personal needs. It also includes an option to write about the human resources and equipment needed for emergency services and the economy both locally and nationally (Trinidad and Tobago Ministry of National Security, 2010).

Best practices in damage and needs assessments

Damage and needs can be described quantitatively or qualitatively. In the quantitative approach, using ratios of destroyed objects or areas, or total numbers or percentages of damaged structures could be used. Qualitatively, as is done in most U.S. agency damage assessments, damage is described in descriptive categories (e.g., severe, minor) (Voigt et al., 2011).

Damage and needs assessments following a disaster are typically conducted by the affected government, with support as necessary from national and international actors. This top-down approach prioritizes coordinated management, policies, and planning (Patterson, Weil and Patel, 2010). In some models, on the other hand, community members play a more direct, "bottom-up" role. For instance, during Hurricane Katrina, the Vietnamese community leaders provided data on the damage by taking pictures and uploading them in real time, and community members and churches identified infrastructure and utilities damage in the community and made repairs themselves. The Executive Yuan (executive branch of the government of the Republic of China on Taiwan) launched the Integrated Community-Based Disaster Management (ICBDM) model, which starts before a disaster strikes (Chen, Liu and Chan, 2006). In the ICBDM, a community determines its own risk tolerance and names problems and solutions accordingly. The model suggests that the community would employ strategies based on their pre-determined goals in the event of a disaster (Patterson, Weil and Patel, 2010). In the model, experts and specialists, community planning teams, public agencies, and other organizations would all contribute to the community-based disaster mitigation effort. Experts and specialists in aspects of disaster response would contribute their knowledge, whereas public agencies (e.g., governments, emergency responders, etc.) would contribute resources. The community planning teams, which are intended to be identified in the pre-disaster period, would be the facilitators (Chen, Liu and Chan, 2006).

The literature tends to explore damage assessments by sector. For example, a systematic review of keywords in bibliographies in the environmental sector found that there are five most common types of methodologies employed: contingent valuation (9.9 percent), travel cost

method (2.9 percent), choice experiments method (2.9 percent), market valuation method (1.5 percent), and hedonic pricing method (1 percent) (Wu and Wang, 2018). Two primary approaches to assessing the damage cost from a natural hazard are utilized by economists: economic loss and financial loss. The economic loss assessment focuses at the macro scale; it assesses the entire nation's economic impact rather than only the affected area(s). Financial loss assessments, on the other hand, are conducted at the micro (household) and/or meso (local community) scale. Economic analyses use the real opportunity cost and exclude tax, whereas financial analyses calculate monetary transfers and loss in market price for replacement items inclusive of taxes. Both types of assessments may incorporate direct and indirect, and tangible and intangible losses in various ways (Olesen, Lowe and Arnbjerg-Nielsen, 2017).

Common challenges and limitations

Organizations conducting damage and needs assessments are typically collecting data from a variety of sources. Although this is beneficial for resource allocation and reducing the time needed to complete an assessment, it presents challenges when different sources provide conflicting information (de la Torre, Dolinskaya and Smilowitz, 2012). There are also basic data management challenges such as cleaning and merging sources, or reconciling the varying levels of detail that are present (Voigt et al., 2011; Olesen, Lowe and Arnbjerg-Nielsen, 2017; de la Torre, Dolinskaya and Smilowitz, 2012). Different assessors may use different analysis techniques and methods, resulting in divergent interpretations of the results (Voigt et al., 2011). Some assessments may lean on developing models that are largely based on past disasters rather than casting a wide net for data as a solution, despite the limitations of modelling (de la Torre, Dolinskaya and Smilowitz, 2012). For example, following a historic flood in 2010 in the City of Cranston, Rhode Island, the City utilized historic FEMA data from flood insurance claims to calculate unmet needs for recovery by tracing 30 years' worth of neighborhood claims and their geographic proximity to the river (Housing and Urban Development, 2013b).

Box 4.2 Recovery Assessment for the Unified New Orleans Plan

Following Hurricane Katrina, the New Orleans city and district planning teams conducted a recovery assessment across 13 sectors: Population; Flood Protection; Housing; Economy; Infrastructure and Utilities; Transportation and Transit; Education; Health Care; Public Safety; Environmental Services; Recreation and Library Services; Municipal and Cultural Resources; and Historic Preservation and Urban Design. The teams used many primary and secondary sources to collect the damage data, including FEMA housing damage inspections, media reports, reports released by other agencies, EPA, and more. Because so many different sources were used for each sector, the rigor of the data and analysis varied (City of New Orleans, 2005).

The availability of reliable data, especially the timeliness of such data, is one of the biggest challenges in conducting damage assessments (Olesen, Lowe and Arnbjerg-Nielsen, 2017; de la Torre, Dolinskaya and Smilowitz, 2012; Global Facility for Disaster Reduction and Recovery (GFDRR), 2010a). For some disasters, data are sparse and it may be challenging to adequately describe damage and needs based on limited data. On the other hand, data are becoming increasingly overabundant particularly with the advent of earth observing satellites. This was the case in the 2010 Haiti earthquake, when over 2.5 terabytes of earth observation data alone were collected (Voigt et al., 2011). Analysis of data from the Haiti disaster using this satellite imagery provided another challenge: despite atmospheric conditions being ideal for satellite image gathering (cloudiness causes aerial image capture difficulties), the differences in solar illumination and angles at which images are captured limited the amount of automatic change detection that was possible for rapidly assessing damage (Voigt et al., 2011).

Another challenge is over- or under-estimation of damage, which may be attributed to biases of the assessors or other technical or bureaucratic challenges (Moe et al., 2007). Resources to conduct the assessment may also be limited; typically new people (who may be volunteers) will need to be trained in the various assessment methods and tools used by different sectors (Patterson, Weil and Patel, 2010; Olesen, Lowe and Arnbjerg-Nielsen, 2017). Also, connectivity via phone or internet may be limited due to infrastructure damage. When faced with limited connectivity, data may be harder to obtain and transmit, resulting in inaccuracies or delays (Voigt et al., 2011).

Damage and needs assessment for Puerto Rico's recovery plan

This report describes a damage and needs assessment conducted by eleven HSOAC sector teams during the period February to June 2018, using a structure aligned with the federal post-hurricane NDRF process. Across all sectors, over 100 separate data sources—with hundreds more individual datasets examined within those sources—were used to assess the condition of Puerto Rico prior to the storms, damage inflicted by the storms, and current needs facing the Commonwealth. The data sources span all data types (qualitative, quantitative, primary, secondary) and cover a variety of time periods (historic, baseline, immediately post-storm, post-storm recovery). The Federal Emergency Management Agency (FEMA), other Federal partners, and the Government of Puerto Rico provided the majority of data, in the form of both quantitative datasets and documents and qualitative data gathered through interviews and discussions with subject-matter experts. Other sources of data and analysis included literature reviews, interviews with subject-matter experts and key stakeholders, media reporting (to gather or cross-check data), and open-source data available through a variety of platforms including U.S. federal government websites (e.g., U.S. Census Bureau), Government of Puerto Rico websites, foundations that have worked in Puerto Rico, OpenStreetMaps, and others. The team also collaborated closely with Federal Recovery Support Functions for related sectors, as well as

members of the Government of Puerto Rico through briefings, workshops, meetings, and interim document reviews.

Some datasets emerged as particularly important to assessing damage such as FEMA IA and PA requests, CCA findings, and datasets provided by the USACE and HUD. Nevertheless, ***key data and information gaps were still present (at the time of writing) as FEMA and other supporting federal and territory agencies transition into hurricane recovery***. In these cases, HSOAC has sought to apply new analysis where possible.

Chapters 5 through 15 of this document take a sector-by-sector approach to describing the pre-storm conditions in Puerto Rico, damage inflicted by Hurricanes Irma and Maria, post-storm conditions, and remaining needs and priorities for Puerto Rico to build back better. In each of these sector-specific chapters, we took a standard approach to describing key background information (including governance, assets, and functions of the sector), pre-storm conditions (including recent trends and challenges leading up to Hurricanes Irma and Maria), hurricane damage (direct damage and associated impacts of the storms), post-storm recovery efforts (e.g., emergency response and repairs to date), and remaining short and longer-term recovery needs. For sectors with multiple subsectors (e.g., electricity and fuel), background, damage, and recovery activities to date are discussed separately for each subsector.

The specific data sources and methods applied to assess damage and needs vary widely by sector. As a result, each of the chapters below also includes separate sections describing key data sources and methodologies applied to assess pre- or post-storm conditions and estimate hurricane impacts. The reader is encouraged to review Chapters 5 to 15 for further detail on the wide range of data and methodologies used for this assessment.

5. Puerto Rico's Economy

Overview

International best practices for disaster assessment emphasize assessing and planning for economic recovery. For example, the United Nations' Post-Disaster Needs Assessment considers the damage to a region's productive sectors of the economy and macro-economic situation to be as important as the damage to physical infrastructure and assets (United Nations Development Programme (UNDP), 2015). Just as improved building codes and changes to zoning regulations can improve the resiliency of a community against future disasters, mapping a community's economic structure may be necessary to determine how to best focus available resources and "build back better" an economy that provides the goods, services, and jobs necessary to support other recovery efforts.

This chapter documents the damage and needs assessment conducted for the Economics sector in support of 180-day Plan development. First, HSOAC describes the data sources; methods used to estimate economic damage; and the gaps, assumptions, and uncertainties of the data and methods. Second, HSOAC provides a brief history of economic activity in Puerto Rico and a "snapshot" of the economy prior to Hurricanes Irma and Maria, including both formal statistics and informal "off the books" economic activity. Next, HSOAC documents pre-storm conditions and challenges related to the Puerto Rican economy. HSOAC then presents a summary of the damage to Puerto Rico's economy caused by Hurricanes Irma and Maria, focusing in large part on disruptions to aggregate economic activity and economic sectors deemed important by the Economics Recovery Support Function (RSF). Next, HSOAC describes post-hurricane conditions in Puerto Rico's economy. Lastly, HSOAC discusses priority needs for the economic sector to be addressed in the Recovery Plan.

Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Economy" Sector Report.

Data sources and methods

Data sources

To describe Puerto Rico's economy, HSOAC used publicly-available quantitative data sets and forecasts from Puerto Rico, Federal, and worldwide sources (see full list of data sources in Table 5.1).

Statistical estimates proxying overall economic damage to value added, employment, and other metrics were based on time series data from indicators compiled by Development Bank of Puerto Rico and BLS and augmented by anecdotal evidence from site visits by the Economics

RSF and media reports. Agricultural background and damage data were provided by the Puerto Rico Department of Agriculture. Table 5.1 summarizes the key damage assessment data sources.

To illustrate damage at the individual firm or person level (as opposed to aggregate statistics), qualitative data were collected from interviews and site visits. These data provide important context for the ongoing recovery effort.

Table 5.1. Summary of Key Damage Assessment Data Sources

Dataset	Source	Date of Last Update	Evaluation Notes
Quarterly Census of Employment and Wages (QCEW) data	U.S. Department of Labor, Bureau of Labor Statistics (BLS) https://www.bls.gov/cew/	2017 Q2 latest as of 03/08	
Indicator data (time series, various sources	compiled by Government Development Bank (GDB) of Puerto Rico http://www.aafaf.pr.gov/pr-economic-indicators.html	Latest data Dec, 2017 as of Feb, 28th update	
Current Employment Statistics, State and Metro Area Employment, Hours, & Earnings	BLS https://www.bls.gov/sae/	Feb. 2018 data available; March 2018 to be available 4/20/18	
Serie Historica Empleo y Desempleo	Puerto Rico Department of Labor and Human Resources (Departamento del Trabajo y Recursos Humanos)	Feb. 2018 data available	2013-2017 data adjusted by BLS; data doesn't perfectly match GDB
BLS/Bureau of Economic Analysis (BEA)/Census data			
Sales tax data	Hacienda		
Population and economic forecasts	April 5, 2018 New Fiscal Plan	April 5; Financial Oversight and Management Board (FOMB) certified their fiscal plan in late April, 2018	
FEMA Claims Data	FEMA		
Current Population Survey	BLS https://www.census.gov/programs-surveys/cps/data-detail.html		
American Community Survey/Puerto Rican Community Survey	https://www.census.gov/programs-surveys/acs/data.html		
New York Federal Reserve Bank	https://www.newyorkfed.org/data-and-statistics		
Puerto Rican Diaspora Study	Penn State		
Climate Impact Lab	UC Berkeley		
	International Monetary Fund		
	World Bank		

Dataset	Source	Date of Last Update	Evaluation Notes
New Immigrant Survey			
Government Development Bank for Puerto Rico GDB Economic Activity Index			
External Trade Data	Puerto Rico Planning Board, Puerto Rico Institute of Statistics		
Monthly Operational Report Fiscal Year 2017	Autoridad de los Puertos de Puerto Rico	December 2017	

Methods

In estimating the economic effects of Hurricanes Irma and Maria, HSOAC used a mixed methods approach to fully capture the range of impacts experienced by the Commonwealth. Where possible, such as in the agricultural sector, HSOAC reports the estimated damage to crops and infrastructure as provided to HSOAC by the responsible agency (in this case, the Puerto Rico Department of Agriculture). In addition, unless otherwise stated, dollar figures are reported in current year (i.e., nominal) amounts.

In other cases, such as estimating the overall impact of the storm on economic activity, HSOAC relies on estimates of what a particular variable (such as overall employment) would have been in the absence of the storms and recovery effort. Because data from this world are unavailable, one must assume or infer what the values would have been to compare the observed data against this baseline (called the counterfactual) to obtain damage estimates.

As such, HSOAC generally provides a number of estimates based on different methods. These methods differ primarily in the assumptions they make about the baseline values. For example, one approach is to compare the value of a metric in a pre-storm period (say, quarter 2) against the observable value in a post-storm period (say, quarter 4). The difference is thus an estimate of the impact of the storms (net any recovery effort). This approach implicitly assumes that the measure in quarter 2 is a good estimate of what might have happened in quarter 4 after the storms.

More complex approaches use statistical techniques to estimate the counterfactual. This can be important if there are non-storm-related trends in the data (e.g., considerable outmigration), since ignoring these trends in the calculation of what might have been would result in incorrectly assigning these impacts to the storms themselves. The statistical approaches attempt to control for (and explain) as much of the pre-storm path of a variable as possible, and then use the resultant model to estimate the counterfactual. While these approaches are more complex and potentially more accurate, the implicit assumption is that underlying relationships estimated by the model would have persisted in the absence of the storm.

Finally, while aggregate data can be useful in getting a sense of overall damage, it is not useful for highlighting the experiences of individuals affected by the storms. Such experiences can be useful in illustrating the specific costs faced by individuals and firms in the aftermath of

the disaster, though they may not be fully representative of the entire population. HSOAC includes several such case studies/anecdotes to help illustrate the particular challenges of the recovery effort.

Data gaps

Gaps in the data used for this assessment are primarily due to data lags at the time of writing. Reliable migration data are essential to estimating the economic impact of the 2017 hurricane season. Issues with data quality, while in some cases pre-existing, may also be a direct or indirect impact of the storms. The present data problems can be rectified with extant data sources, such as FEMA claims data and school registration data, in combination with Respondent-Driven Sampling (RDS). Once in place, this data infrastructure can become a long-term resource.

The lack of reliable data on PR's relatively large informal sector poses a problem for investing in Puerto Rico's workforce development. Analysts could also use RDS and other survey techniques to rectify this problem. Apropos of challenges around the informal sector, conversations with Department of Agriculture staff suggest a few reasons for caution with the preliminary estimates provided due to issues of oversampling of larger farms and lack of consideration for future growing cycles for crops like coffee trees. However, HSOAC does not know the details of the statistical analyses performed with these survey data to generate the estimated damage, nor what constitutes infrastructure for purposes of the provided estimates, though it is likely any non-labor input excluding feed, seed, and fertilizer.

Assumptions and uncertainties

As noted above, HSOAC's necessary reliance on secondary data to estimate net economic damage from the storms means that any flaws in the underlying data will necessarily pass through to damage estimates. If, for example, population levels following the storm are, for whatever reason, overestimated relative to the true, unknown population, then HSOAC's estimates of additional emigration as a net result of the storm will be underestimated, all else equal. Moreover, there is likely a great deal of difference between experiences based on preparedness, geography, luck, and a host of other factors.

In addition to the caveats about the data, the major assumption regarding damage estimates from secondary time-series data is that the forecast of what would have been, absent the hurricanes and resultant recovery effort, is an accurate representation of what a measure would have been in that world. As such, if a forecasted measure in the non-storm universe, such as employment, were underestimated for whatever reason, then any estimated decline in employment attributable to the storm would be underestimated (or biased downwards).
Also, because measures of gross domestic product (GDP), an alternative measure of goods and services produced, and gross national product (GNP), a measure of total goods and services produced, are flows, rather than stocks, an increase in these measures year over year does not necessarily mean that the overall wealth of a society has increased (especially if the activity that

causes the increase is in response to degradations in capital stocks). This is because the GDP/GNP measures do not, and are not designed to, capture the opportunity costs of the forgone alternative; i.e., what could have been produced if the activity could have been put to the service of something else.[18] In disaster situations, the activity associated with capital stock replacement (i.e., rebuilding of capital) can often serve to increase flow measures of economic activity, but this clearly does not mean that the society is immediately better off than before the disaster.

Background

This section briefly describes the history of economic development in Puerto Rico prior to Hurricanes Irma and Maria, as well as the structure of the economy of the Commonwealth immediately prior to the storms. It is intended to provide a "snapshot" of the economy, including major sectors of interest and the role of the informal economy, as well as the economic trends leading up to the present.[19]

Brief history of economic development in Puerto Rico

Since it became a U.S. territory, Puerto Rico's economic development can be at least partially attributed to a history of tax policy and incentives. These incentives have come and gone at various intervals since World War II, when Puerto Rico began to transform from an agrarian society to an industrialized economy. Toro (2014) describes four periods of development:

- Agrarian capitalism (1898-1930s)
- State-driven reforms and growth (1935-1948)
- Industrialization (1952-1970)
- Non-constant growth (1970s-1990s)

To this, HSOAC adds the experience of the 2000's, which was characterized by early growth, followed by a period (2006 until the time of this writing) of *economic contraction*, corresponding with policy changes that phased out the tax advantages related to United States (CONUS)[20] firms producing in the Commonwealth. **Table 5.2** gives an overview of major tax policy related to economic development.

Federal tax exemptions to enhance and support the economy of Puerto Rico had been in place since the passage of the Foraker Act in 1900 (shortly after Puerto Rico became a United

[18] This is often termed the "broken window fallacy".

[19] Major sectors of interest were determined by the authors primarily through a review of government documents regarding strategic objectives with respect to economic development and the continuing discussion of potential post-storm courses of action.

[20] For the purposes of exposition, HSOAC refers to CONUS as the fifty states plus Washington D.C., even though this is a non-standard definition. HSOAC prefers this notation to distinguish data from the fifty states plus Washington D.C. from U.S. territories such as Puerto Rico and the U.S. Virgin Islands.

States territory in 1898).[21] In 1917, the Foraker Act was superseded by the Jones-Shafroth Act, which granted U.S. citizenship to Puerto Ricans, and exempted Puerto Rican bonds from federal, state, and local taxes, regardless of where the bondholder resides. Several years later, section 262 of the Revenue Act of 1921, a section later called section 931 of the Internal Revenue Code of the United States, provided a tax exemption to all U.S. corporations receiving income from U.S. possessions or territories (Rockas, 1983). At the time, Puerto Rico's local income taxes all but nullified the federal tax exemption under section 262.

Agrarian capitalism (1898-1930s)

Prior to industrialization, agriculture was the main economic sector for Puerto Rico, with production focused on exports to CONUS and Europe such as sugar, coffee, tobacco, and rum (Toro, 2014; Rivera, 2018a). The sector comprised 43 percent of the workforce in 1940.[22]

State-driven reforms, growth, and industrialization (1935-1970)

Early in the 1940s, a series of government actions anticipated the coming industrialization policy, including the establishment of the Puerto Rico Development Company, the Government Development Bank of Puerto Rico, and the Puerto Rico Planning board, as wells as the passage of minimum wage and child labor laws. Later in the decade, formal industrialization polices, known as Operation Bootstrap, were enacted, which provides provided tax incentives, managerial training, and subsidies for non-residential fixed capital in an attempt to attract CONUS manufacturing (Toro, 2014). The Industrial Incentives Act of 1948 officially launched Operation Bootstrap, which effectively exempted U.S. corporations from most Puerto Rican taxes, thus enabling U.S. corporations to take advantage of section 262 of the Revenue Act of 1921.

Statistics on Puerto Rico's industrial growth after the initiation of Operation Bootstrap show the program achieved its aims. For instance, in 1949, the U.S. Department of Commerce estimated that the 1,998 manufacturing establishments in Puerto Rico employed 55,000 Puerto Ricans, with an average workforce of 27.5 persons per establishment. By 1967, 2,367 manufacturing establishments employed 121,537 Puerto Ricans, with an average of 51.3 per establishment. Jobs were concentrated in garments and textiles, which comprised about a third of all manufacturing employment (Toro, 2014).

The focus on industrialization was coupled with an intent to dramatically transform, if not destroy, the sugar industry that had previously dominated Puerto Rico's economy. Between 1934 and 1980, agriculture went from 45 percent of GNP to just 5 percent (Dietz, 1986).

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[21] Tax benefits under the Foraker Act, which also established the government of Puerto Rico, were related to excise taxes.

[22] The corresponding share of the CONUS workforce was about 18 percent. Source: (Spielmaker, 2018).

Non-constant growth (1970s-1990s)

Despite the success of Operation Bootstrap in incentivizing manufacturing employment, the Puerto Rican economy was in recession (as was much of the world) in 1973 and 1974. The government had difficulty financing a large, unexpected deficit. Manufacturing employment declined, partly due to competition compounded by the full application of the federal minimum wage to Puerto Rico, which disproportionately affected low-skilled workers (Toro, 2014). Although Puerto Rico had had a minimum wage law since the passage of the Fair Labor Standards Act of 1938, industry boards had set separate minima by industry and occupation. In 1974, the U.S. Congress, supported by the Puerto Rican government, imposed the U.S. federally mandated minimum wage on the Commonwealth (Castillo-Freeman and Freeman, 1991). The public sector, however, continued to grow at a rate of 5 to 6 percent during this time (Toro, 2014).

Between 1973 and 1976, extensive congressional hearings on tax reform were held. These discussions culminated in the Tax Reform Act of 1976, which created Section 936 of the Internal Revenue Code of the United States (IRC), also known as the "Possession Tax Credit". Section 936 of the IRC granted qualified U.S. corporations a tax exemption on income originating from U.S. territories, including Puerto Rico.

The pharmaceutical industry benefited the most from Section 936. A pharmaceutical company could develop a drug in its U.S. research facilities and subsequently transfer the drug patent to its wholly owned subsidiary operating in Puerto Rico (U.S. Government Accountability Office, 1992). The subsidiary would then produce the patented drug and claim the income obtained from its sales as tax-free income. This practice subjected Section 936 to criticism, as it not only allowed CONUS companies to avoid paying federal income taxes on their profits from work conducted in Puerto Rico, but also became a mechanism for sheltering profits. In 1993, the United States General Accounting Office estimated Section 936 would cost taxpayers $15 billion for the five years covering the 1993-1997 fiscal years (U.S. Government Accountability Office, 1993). Legislation phasing out Section 936 over the next decade was signed into law in 1996. During the last two decades of the twentieth century, the Puerto Rico economy saw continuing declines in manufacturing employment, but growth in the services and public sectors (including financial firms, which could take advantage of Section 936) (Toro, 2014).

Section 936 repeal and economic recession (2000s-2017)

Following completion of the phase-out of Section 936 in 2006, economic growth has generally been negative, with low labor-force participation and high unemployment relative to CONUS. While the phase-out of the tax incentives contributed to the decline of Puerto Rico's economy, recessionary pressure in the United States in 2001 and during the Great Recession (late 2007 – 2009), high fuel prices, and high costs of doing business, among other factors, also contributed. **Table 5.2** lists major tax legislation related to economic development in Puerto Rico since 1900.

Table 5.2. Major Tax Legislation Related to Economic Development in Puerto Rico (PR)

Legislation/Description of Law	Year	Description
Foraker Act [U.S.]	1900	Excise taxes
Jones-Shafroth Act [U.S.]	1917	Established citizenship for Puerto Ricans; exempted PR bonds from taxes
Revenue Act of 1921 [U.S.]	1921	Tax exemption for corporate income produced in U.S. territories (later section 931)
Industrial Incentives Act of 1948/ "Operation Bootstrap" [U.S,]	1948	Effectively exempted U.S. corporations from most Puerto Rican taxes
Local tax policy [P.R.]	1974	Exempted tax-exempt manufacturing firms from interest, rents, and dividends earned on investments for certain local eligible assets
Tax Reform Act of 1976/ Section 936 [U.S.]	1976	"Possession Tax Credit," tax exemption on income originating from U.S. territories for of U.S. corporations/eliminated exemption for income derived in foreign countries
Phase-out of Section 936 [U.S.]	1996	Section 936 exemption benefits phased out over 10 years
Section 936 exemption ends [U.S.]	2006	End of section 936 benefits. Prior to phaseout, some multinationals converted subsidiaries to Controlled Foreign Corporations (CFCs).
Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA) [U.S.]	2016	Establishment of Fiscal Oversight and Management Board (FOMB) and bankruptcy-style proceedings to restructure debt
Federal Tax Reform (2017) [U.S.]	2017	Established 10.5 percent Federal tax on income related to intangible assets

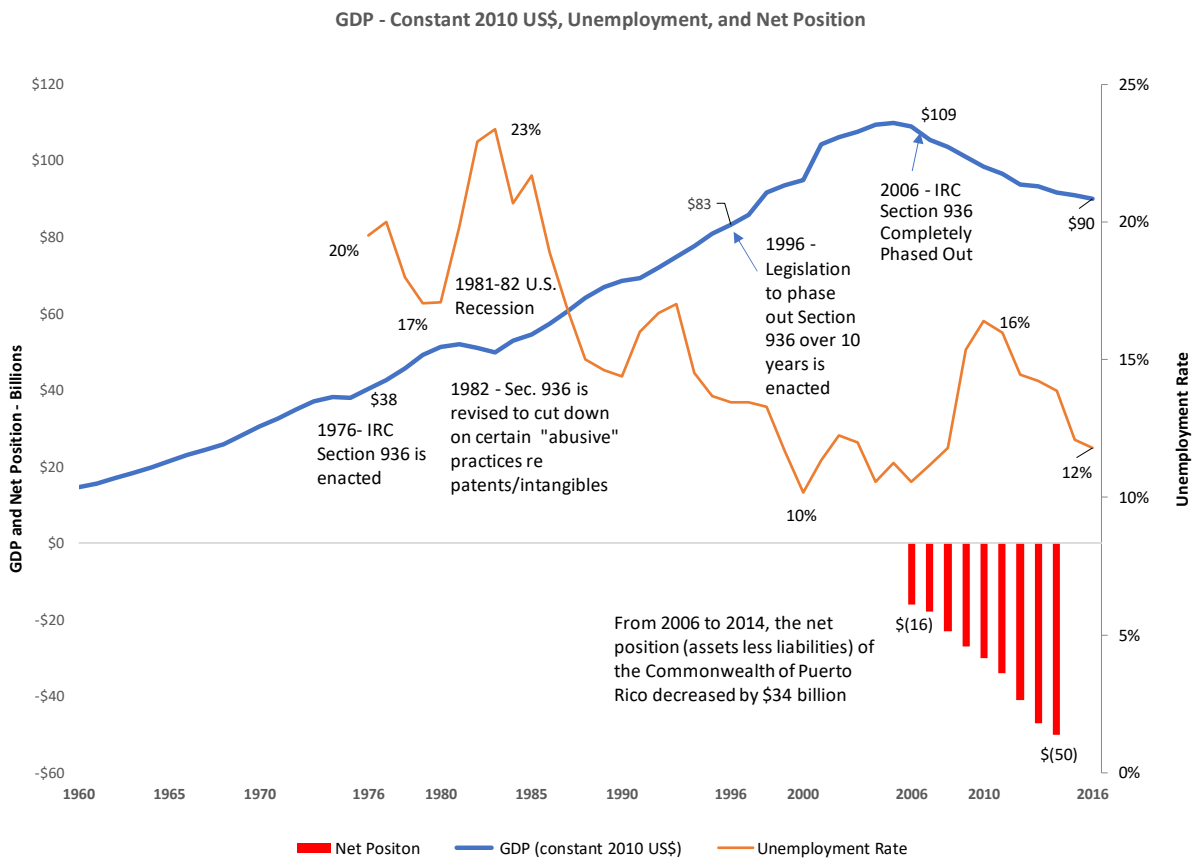
Source: Authors' compilation. Square brackets indicated either U.S. policy [U.S.] or local Puerto Rico [P.R.] policy.

In conjunction with the contraction of the economy, lower revenues, high rates of expenditure, and heavy borrowing of the Commonwealth and its public corporations[23] resulted in high and unsustainable levels of debt. Despite stabilization efforts by the government, Puerto Rico's credit rating dropped to below investment grade in early 2014, followed by a series of defaults on debt payments. The financial crisis ultimately resulted in the passage of H.R. 5278, the Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA), in 2016, which established the Fiscal Oversight and Management Board (FOMB) and provided the framework for restructuring the Commonwealth's debt. The FOMB's purpose is "to provide a method for [Puerto Rico] to achieve fiscal responsibility and access to the capital markets" by certifying financial plans, approving and monitoring budgets and related activities, providing advice on issues of financial stability and management, and certifying restructuring and approving actions related to debt issuance (H.R. 5278 Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA), 2016).

Changes over time in key economic indicators are shown in the figures below. Figure 5.1 shows the developmental trajectory of Puerto Rico on multiple economic indicators from 1960 through 2016, in terms of GDP, unemployment, and the net position of the Commonwealth government, as well as major events related to Section 936.

[23] See, e.g., Fisher and Horowitz (2016).

Figure 5.1. Gross Domestic Product, Unemployment, and Net Position of Puerto Rico over Time, 1960 – 2016



Source: (Federal Reserve Bank of St. Louis, 2018a)

In the last decade, Puerto Rico has tried many different incentive programs aimed at encouraging economic development. These include the Economic Incentives Act of 2008, Green Energy Act of 201, Tourism Development Act of 2010, Individual Investors Act of 2012, and Export Services Act of 2012. Taken together, these incentives could provide a basis for economic development. However, growth has continued to decline despite these efforts, suggesting that there are considerable non-tax related costs that make investment in Puerto Rico not as attractive as other locations worldwide.

Economic structure of Puerto Rico

Gross Domestic Product and Gross National Product

GDP and GNP are measures of the value-added, or the market value of goods and services, produced by labor and capital. GDP measures the market value of goods and services produced by labor and property within Puerto Rico (including U.S.-based firms), while GNP measures the market value of goods and services produced by Puerto Rico's citizens, regardless of where they

live (Bureau of Economic Analysis, undated). Gross national income (GNI), as measured by the World Bank, is another term for GNP. Another way to measure these values is by adding the total returns to workers (compensation) and to capital (profits). Generally, except for measurement error, this total is equal to the market value of goods and services. Due to the large amount of value added (generally in the form of profit) generated within Puerto Rico by CONUS manufacturing firms, which are either and transferred to CONUS or deposited into banks neither located in CONUS or Puerto Rico, GNP is preferred as a measure of welfare that affects Puerto Rican residents.

However, measures of GNP and other statistics compiled by the Puerto Rico Planning Board are likely flawed (MacEwan and Hexner, undated) for the following reasons:

- Real GNP and its components are calculated using 1954 prices, which is problematic due to changes in the "market basket" that have occurred over time;[24]
- A large revision to the Puerto Rican Consumer Price Index (CPI) was completed in 2010, making the current series not comparable to the time series prior to this change; and
- Financial (e.g., the comprehensive annual financial report, or CAFR) and other data suffer serious time lags.

In addition, the Puerto Rico Planning Board still uses 1968 accounting standards, lacks modern internal controls to manage and store data, does not have a formal auditing system in place, may use unrepresentative samples, and lacks documentation about the methods used to compile data (Cruz, 2017). As such, the statistics presented here may not accurately represent the true state of the Puerto Rico economy. Accordingly, we will compare the Planning Board estimates of Puerto Rico's production to those from outside sources when available.

The World Bank reports Puerto Rico's 2016 GNI at $66.3 billion (current dollars), with GDP estimated at $105.0 billion (current dollars), or a ratio of GDP/GNI of 1.58 (World Bank, 2018a). The Puerto Rico Planning Board reported FY2016 GNP at $70.1 billion and GDP of $105 billion, or a ratio of 1.50. Again, HSOAC emphasizes that the Planning Board GNP and GDP figures are computed based on standards established in 1968. These statistics show that estimated GDP is much higher than GNP regardless of the data source of these estimates. Because expatriated profits from U.S. firms that produce goods from establishments in Puerto Rico would be counted in GDP but not GNP, this suggests that a large share of production comes from non-Puerto Rican firms (Puerto Rico Planning Board, 2016, Table 1).

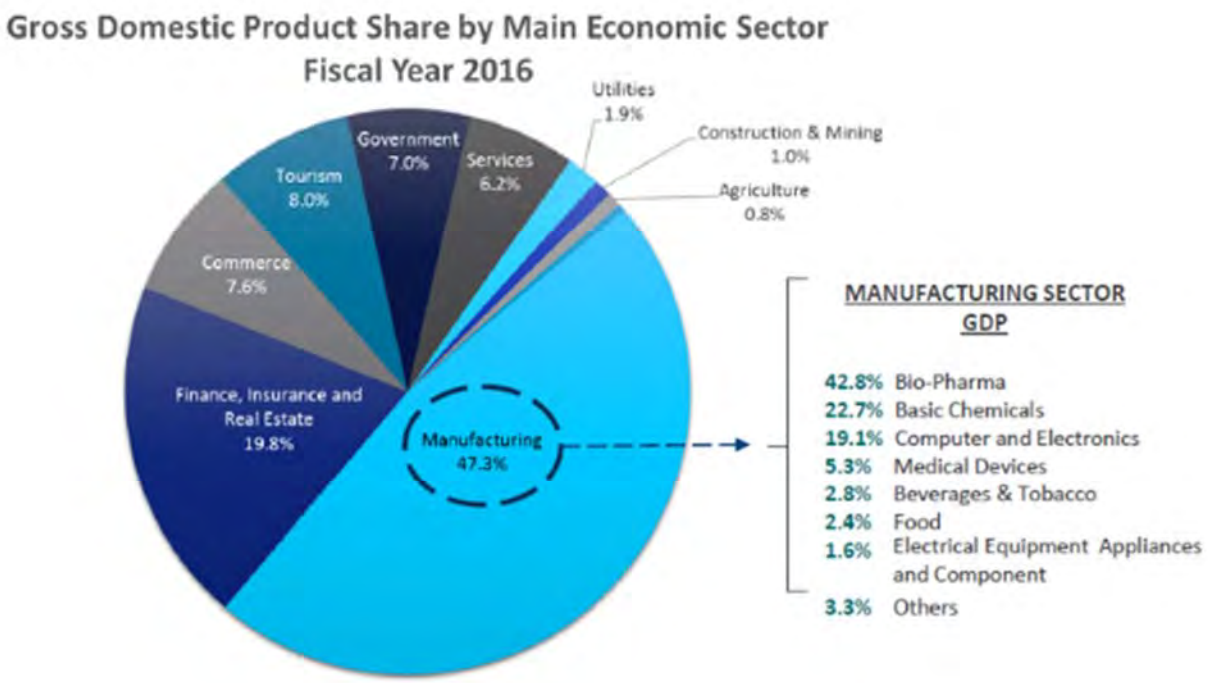
The World Bank reports GNI per capita at $19,430 for Puerto Rico for 2016, compared to $56,810 in the rest of the U.S. The World Bank reported 2016 GDP per capita at $30,790 (current dollars) for Puerto Rico, while Planning Board reported GDP per capita for fiscal year 2016 at $30,516 (current dollars) (Puerto Rico Planning Board, 2016, Table 1). By comparison,

[24] GNP and GDP are measured in dollar values. To measure inflation (and thus make real growth comparable over time), a representative "market basket" of goods is used to create price indices. Significant changes in the market basket that represent overall economic behavior can lead to problems in price indices, and thus the measurement of real economic activity.

GDP per capita in the U.S. in 2016 was $57,638 (current dollars), about 1.9 times the GDP per capita estimated for Puerto Rico. However, these published estimates exclude production from the informal economy, discussed below in further detail.

Figure 5.2 shows the estimate of GDP by main economic sector from the Puerto Rico Planning Board.[25] The figure shows that the two largest contributors to GDP come from manufacturing (47.3 percent) and finance, insurance, and real estate (19.8 percent). Within manufacturing, 42.8 percent comes from Bio-Pharma, 22.7 percent comes from basic chemicals, and 19.1 percent comes from computer and electronics. Commerce, government, services, and tourism each make up 6 to 8 percent of GDP.

Figure 5.2. Gross Domestic Product Share by Main Economic Sector Fiscal Year 2016



Source: Puerto Rico Planning Board via Build Back Better, November 2017

Given that manufacturing may largely consist of firms controlled by non-Puerto Rican entities, HSOAC also looks at the distribution of production by sector, excluding manufacturing (i.e., to what extent does each sector contribute to the 52.7 percent of GDP when manufacturing is left out). Outside of manufacturing, the largest sector is finance, insurance, and real estate. This sector accounts for 38 percent of non-manufacturing production. Commerce and tourism each contribute 15 percent to non-manufacturing production, followed closely by government at

[25] Readers are referred to the introduction of this section for appropriate caveats about this data.

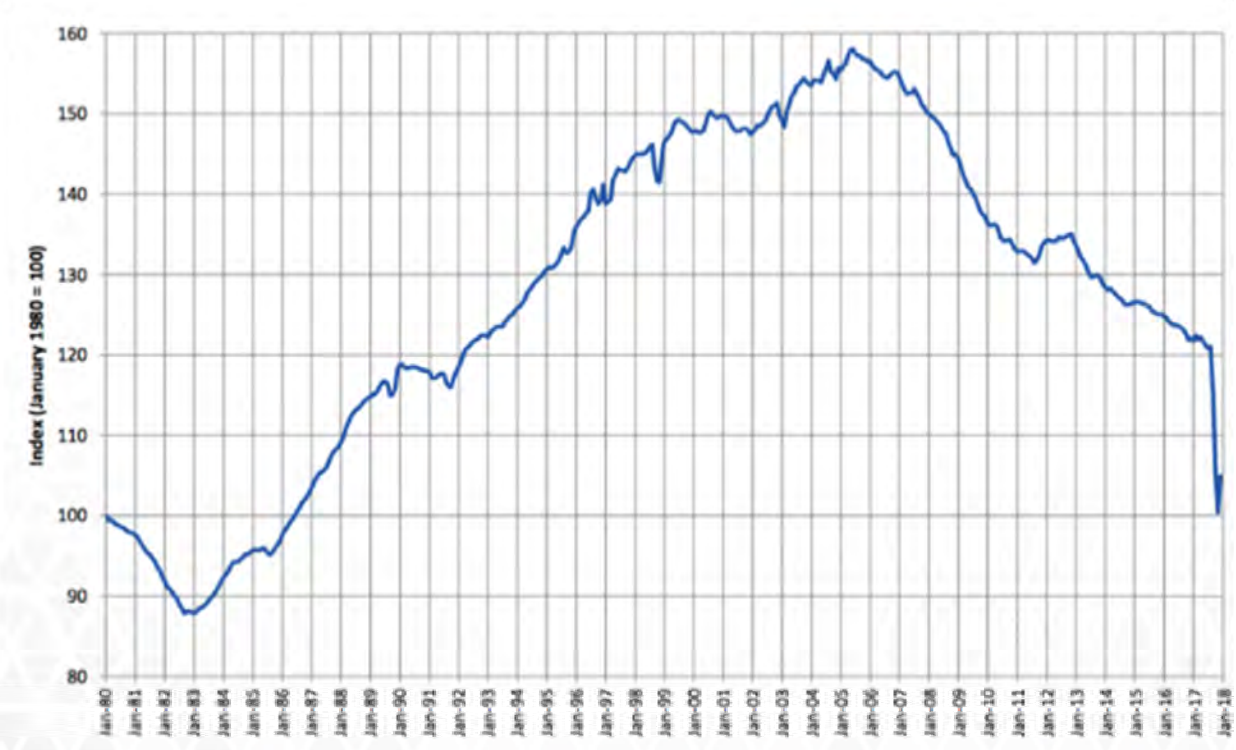
13 percent and services at 12 percent. Although government production makes up only 13 percent of GDP, government is the largest employer in Puerto Rico and has the largest payroll.

Economic Activity Index

The Planning Board uses an Economic Activity Index (GDB-EAI) to measure economic growth in Puerto Rico. The GDB-EAI is generated using four monthly indicators: total non-farm payroll employment, cement sales, gasoline consumption, and electric power generation. GDB-EAI is usually available prior to formal calculations of GNP and is generally strongly correlated with actual trends in the economy. The methodology is similar to the methodology used for the Conference Board's coincident index of the United States economy.

Figure 5.3 shows the Economic Activity Index from 1980 to 2018. The index peaked in 2005 at about 160 and has generally declined each year thereafter. Immediately prior to Hurricane Maria, the index was about 123.4, down 1.7 percent from August 2016. After Hurricane Maria, the index declined sharply, falling more than 20 percent to about 100 at the trough of the decline.

Figure 5.3. Economic Activity Index, by Year (1980 – 2018)



Source: (Government Development Bank of Puerto Rico, 2017).

Establishments

The most recent available data indicate that a sizable proportion of Puerto Rico's establishments are small. According to the Q2 2017 Quarterly Census of Employment and Wages (QCEW)[26] from the U.S. Bureau of Labor Statistics (BLS), 24,994 (53 percent) of the roughly 45,099 private entities or business units and 1,849 public administration units with employees operating in Puerto Rico have fewer than five employees.[27] In addition, the Office of Advocacy at the U.S. Small Business Administration (SBA) estimated that 553,000, or about 80 percent of private sector workers in Puerto Rico, worked at small establishments (Congressional Task Force on Economic Growth in Puerto Rico, 2016a).

According to the Federal Reserve Bank of New York's Puerto Rico Small Business Survey, in 2015, 19 percent of small businesses had been in business for two years or less, and 18 percent had been in business for three to five years; the remaining 63 percent of small businesses had been in business for six or more years (Federal Reserve Bank of New York, 2016).

Workforce and employment

Bureau of Labor Statistics (BLS) Quarterly Census of Employment and Wages (QCEW) provides employment statistics at the sector level by 2-digit sector code under the North American Industrial Classification System (NAICS). Using employment data from the QCEW, HSOAC finds that, across the sectors[28], total employment in June 2017 was almost 852,700. The three largest sectors in terms of employment were public administration (15 percent); retail trade (15 percent); and healthcare and social assistance (11 percent) (Bureau of Labor Statistics, 2018j).

As shown in Figure 5.4, based on annual averages from the BLS QCEW, employment across the major 2-digit NAICS sectors grew from 831,500 to 852,700 between 1990 and 2017, or about three percent. Between 1990 and 2005, employment grew over 20 percent, reaching its peak of 1,021,400 in 2005 before the complete phase-out of 936. Since that time, employment has declined. The steepest drop occurred between 2005 and 2010, with employment falling by over 10 percent. Puerto Rico experienced growth in 2012, with employment growing 1.5 percent before resuming its downward trend in 2013 onwards. Since then, employment has steadily decreased between 2012 and 2017 by about 1 to 3 percent per annum. Over the last five years,

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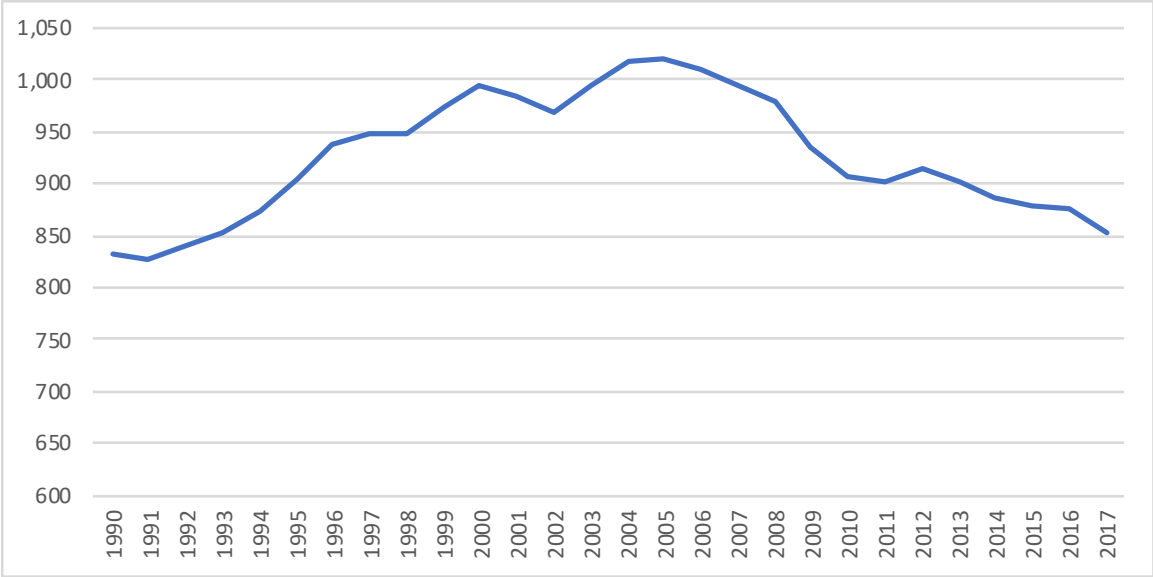
[26] The QCEW data are the product of a federal-state cooperative program. The data come from summaries of employment and total wages of workers covered by state and federal unemployment insurance. State Workforce Agencies provide this information to BLS.

[27] Because Hurricanes Irma and Maria struck Puerto Rico in September, the June 30, 2017 data gives the best picture of the number of businesses and entities at the time.

[28] Sectors in BLS QCEW dataset include public administration; retail trade; healthcare and social assistance; educational services; accommodation and food services; manufacturing; admin and support and waste management and remediation services; professional, scientific, and technical services; wholesale trade; finance and insurance; other

declines in employment have varied substantially by region, with the majority of losses concentrated particularly in two metropolitan regions: San Juan and Ponce (Bureau of Labor Statistics, undated).

Figure 5.4. Total Employment by Year, in Thousands, 1990-2017



Source: U.S. BLS, QCEW, Annual figures for 1990-2016. 2nd quarter June employment for 2017

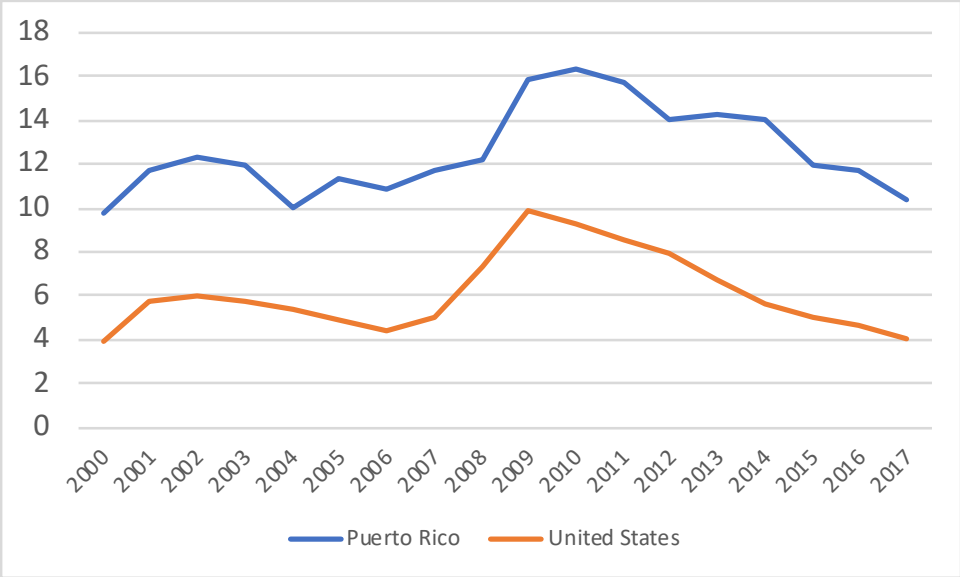
As shown in Figure 5.5, the unemployment rate in Puerto Rico has generally stayed above 10 percent between 2000 and 2017 based on U.S. Bureau of Labor Statistics data. While the unemployment rate hovered between 10 percent and 12 percent between 2000 and 2008, it rose to about 16 percent during the Great Recession (2009 to 2011). Between 2011 and 2017, the unemployment rate fell from about 16 percent to 10 percent. While CONUS and Puerto Rico unemployment rates follow similar trends, CONUS unemployment rate is on average less than half the rate for Puerto Rico. According to BLS, Puerto Rico's unemployment rate in August 2017 was 10.44percent; by contrast, the unemployment rate of CONUS was 4.4 percent (Bureau of Labor Statistics, 2018c).

Labor force participation in Puerto Rico was low prior to the storms. In August 2017, the seasonally adjusted civilian labor force (people who are working plus people who are actively looking for work) in Puerto Rico was 1.09 million, with 0.98 million employed and 0.11 million unemployed (Bureau of Labor Statistics, 2018j). The size of the labor force was significantly smaller than the civilian population, which was estimated to be approximately 3.4 million in 2016, of which about 2 million were between the ages of 18 and 64. The labor force participation rate in Puerto Rico was 39.9 percent in August 2017, which was substantially lower than the U.S. labor force participation rate of 62.9 percent, in part due to the size of the informal economy and

related policies that tend to provide incentives away from formal work (Bureau of Labor Statistics, 2018d).[29]

Compared to the overall unemployment rate, the youth (age 15-24) unemployment rate has generally been 1.5 to 2 times greater, remaining above 20 percent from 2000 to 2017. The youth unemployment rate hovered between 20 and 25 percent from 2000 to 2006. In 2006, when Puerto Rico entered recession, youth unemployment began to rise sharply, increasing from roughly 23 percent to roughly 30 percent in 2010 and then falling to 23.8 percent in 2017. Similar to the overall unemployment rate, the youth unemployment rate in Puerto Rico is much higher than that for CONUS as a whole. In particular, the youth unemployment rate in CONUS in 2017 was 10 percent, or less than half the rate for Puerto Rico (23.8 percent) (Federal Reserve Bank of St. Louis, 2018b; Federal Reserve Bank of St. Louis, 2018c).

Figure 5.5. Unemployment Rate in August, by Year, 2000 – 2017



Source: (Federal Reserve Bank of St. Louis, 2018a; Bureau of Labor Statistics, 2018a)

Public debt and revenue

U.S. tax policy has played a large role in the economic development and tax base of the Commonwealth of Puerto Rico. The Jones-Shafroth Act of 1917 included an exemption of federal, state, and local taxes for purchases of Puerto Rico bonds. The combination of high-grade credit and triple tax exemption incentivized investment in the bonds in a way that persisted in spite of changes in repayment risk. As discussed in the "Brief History of Economic

[29] More detail on these policies are provided in the remainder of the report.

Development" section, the Jones-Shafroth Act was only the first of a series of tax incentives used to incent investment in the territory.

Operation Bootstrap was a major force in the industrialization and growth in manufacturing in Puerto Rico, as depicted in Figure 5.6. Section 936 benefits were phased out between 1996 and 2006 despite arguments from then Governor Pedro Rosselló that, without the incentives, the Puerto Rico economy would collapse. Following the phase-out, Commonwealth debt began to increase, contributing to the growth in total debt and the debt-to-GDP ratio.[30]

Since 2005, a series of tax acts have been implemented to incentivize various economic activities. For example, Act 22 of 2012 aimed to "promote the relocation of investors to Puerto Rico" through a

> 0% tax on dividend and interest income for New Puerto Rico Residents, 0% tax on short- and long-term capital gains for New Puerto Rico Residents, 0% federal taxes on Puerto Rico source income, Incredible tax savings on your investment portfolio returns, [and] 82°F weather all-year round and 300 miles of paradise beaches (Puerto Rico Does It Better).

Under Act 20, qualifying businesses in Puerto Rico are subject to a four-percent corporate tax rate on income earned in Puerto Rico, a 100-percent exemption on profit, and a 100-percent exemption of property. Furthermore, Acts 73 and 273 of 2008 and 2012, respectively, provided further incentive to business activity in Puerto Rico through tax exemptions, tax credits, and lower tax rates.[31]

Puerto Rico's public debt increased by more than 150 percent, from $42.8 billion in 2007 to $67.3 billion in 2014. In 2015 and 2016, gross public debt decreased, reaching $64.3 billion in 2016. These estimates do not show Puerto Rico's entire debt portfolio, as it excludes pension

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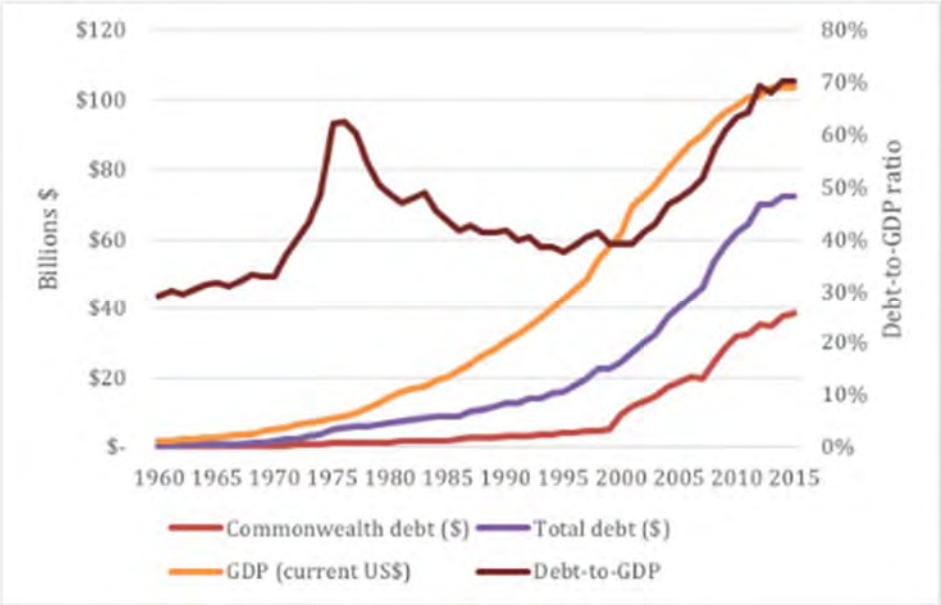
[30] The causal effects of the phase-out are not without controversy. For example, using a causal inference methodology, Feliciano and Green (Feliciano, Z. and A. Green, 2017, U.S. Multinationals in Puerto Rico and the Repeal of Section 936 Tax Exemption for U.S. Corporations, Working Paper 23681, National Bureau of Economic Research) find that wages and establishments declined in the Puerto Rican manufacturing sector following the phase-out, but could not causally establish employment declines. MacEwan (MacEwan, A., 2016, Quantifying the Impact of 936, GDS Working Paper, Center for Global Development and Sustainability, The Heller School for Social Policy and Management, Brandeis University) argues that benefits on 936 to the island are overstated (due to the outflow of profits to CONUS), and that the drop in employment in 936 sectors following the phase out was due more to global forces, including the Great Recession in the United States (2007-2009), technological change, and the expiration of patents for intellectual property. Furthermore, MacEwan argues that shifting to CFC status (see Manufacturing section in "Trends in the Puerto Rico Economy) allowed former 936 firms to keep their tax advantages, but did not include incentives to maintain employment, leading to a shift towards capital. Makoff and Setser (Makoff, G. and B.W. Setser, 2017, Puerto Rico Update: PROMESA, Population Trends, Risks to the Fiscal and Economic Plan – and Now Maria, CIGI Papers No. 146) agree, arguing that other industry-level shocks (including technology, competition due to NAFTA and China's entry into the WTO) and complementary trends (boom-bust in construction, banking difficulties during the U.S. recession, high oil prices, competition in tourism, and closing of military bases) played a major role in the economic contraction since 2006.

[31] Note that Puerto Rico was, prior to tax reform, and continues to be a foreign jurisdiction for income tax purposes.

obligations and may undercount the debt currently included based on published statistics from other resources.

Figure 5.6. Annual GDP Growth and Commonwealth Debt, 1960-2015



Sources: World Bank, GDB, (Joffe and Martinez, 2016)

Prior to the storms, the amount of government spending relative to the amount of tax revenue was unsustainable. A preliminary estimate of the Puerto Rico Commonwealth government net recurrent revenues for FY 2016 was $15.9 billion, of which 35 percent came from non-Commonwealth sources (Puerto Rico Planning Board, 2016). These estimates exclude revenues from government owned utilities. The estimated $15.9 billion in government revenues is roughly 25 percent of the estimated $64.3 billion public debt, suggesting a large discrepancy between revenues and spending. Commonwealth revenue was estimated to be $10.3 billion, while non-Commonwealth revenue was estimated to be $5.6 billion. The largest Commonwealth source of revenue was tax revenue ($9.0 billion), which included property taxes, individual and corporate income tax, excise taxes, and sales and use tax. Non-Commonwealth revenue came mainly through federal grants ($5.4 billion). The small amount of government revenue relative to public debt is partly due to the small tax base, which excludes the large informal economy that will be discussed in further detail in a later section, and to depressed property tax revenue due to limited collections in certain areas and to properties not having been reassessed recently.[32]

[32] This observation was offered by the Economics RSF.

The informal economy in Puerto Rico

Puerto Rico also has a relatively large informal economy, sometimes referred to as an underground or shadow economy. According to one definition, the shadow economy is "all market-based legal production of goods and services that are deliberately concealed from public authorities" (Schneider, 2004). Other definitions are more inclusive; for instance, summarizing research conducted in Puerto Rico, Estudios Técnicos defines the underground economy as "one in which value-added legal and illegal productive activities are carried out, which are not accounted for in the national statistics system" (Estudios Tecnicos Inc, 2017a). The existence of a large informal economy has a number of negative effects, chief among them the erosion of Puerto Rico's individual and corporate tax base (Congressional Task Force on Economic Growth in Puerto Rico, 2016b).

As noted, previous reports have noted a relatively large underground or informal economy in Puerto Rico, with estimates of its size generally ranging from roughly 15 to 30 percent of GNP (Enchautegui and Freeman, 2006; Estudios Tecnicos Inc, 2017a; Congressional Task Force on Economic Growth in Puerto Rico, 2016b; Schneider, 2004; Federal Reserve Bank of New York, 2014a). Some researchers suggest an even larger size (Peters, 2017; Laya and Levin, 2017). Although the estimated size of the informal economy in Puerto Rico is below the international average (about 35 percent) and the average in Latin American and the Caribbean (about 40 percent), it is well above the estimated averages in the OECD countries (17 percent) and in the CONUS (9 percent) (Estudios Tecnicos Inc, 2017a). However, determining the size of the informal economy is an inherently difficult task because information on informal activities is not reported to authorities and individuals are unlikely to be upfront about participation in the informal economy.

HSOAC's calculations of the share of the informal economy tested recent estimates in the literature. The most recent estimates in the literature, which were generated using indirect methods, placed the size of the informal economy at levels above 20 percent of GNP. HSOAC finds these estimates difficult to validate given the strong assumptions in the calculations and the scarce discussion of the validity of those assumptions and of the calculation procedures. Nevertheless, using similar methods, HSOAC finds evidence that, in the most recent years, the size of the informal economy has remained relatively stable (although possibly higher in comparison to pre-recession years). However, the size of the informal economy might have increased in the aftermath of the Hurricane Maria.

In the case of Puerto Rico, there are several factors other than taxes that influence participation in the informal economy (Estudios Tecnicos Inc, 2017a). Enchautegui and Freeman concluded that key reasons for the low participation of Puerto Rican men in the formal economy are their low levels of academic achievement and participation in welfare programs that, because of their design, disincentivize work in the formal sector. According to the authors, if individuals have no major incentives to be active in formal economy jobs, it is plausible that those

participating in social assistance programs will seek to add to the income received from social aids by participating in informal economy activities. The authors add that the low employment rate of Puerto Rican men in the formal economy can also be explained by other factors, such as the emigration to CONUS of men who wish to work and a GDP heavily weighted to capital intensive manufacturing (Enchautegui and Freeman, 2006).

Background and recent trends by sector

Tourism

Puerto Rico's travel and tourism industry contributed approximately $8.1 billion in direct and indirect revenues to the economy in 2016 ($2.8 billion in direct contribution).[33] It was estimated that tourism made up about 8 percent of Puerto Rico's GDP (World Travel and Tourism Council, 2017). Other estimates put tourist spending at $3.8 billion (Congressional Task Force on Economic Growth in Puerto Rico, 2016b). In 2015, visitor spending to Puerto Rico raised more than $215 million in state taxes and almost $20 million in city taxes. These figures don't include room taxes, casino taxes, or other expenditures made by tourists ("Tourism: A Driver for Economic Growth," 2016). The room tax, which is paid by guests when they register in any lodging facility, represents about $70 million annually to the government. Income generated by the tourism room tax increased consistently from 2009 to 2016. Moreover, the entry of Airbnb into Puerto Rico's tourism landscape has helped the Commonwealth's economy by $23 million, partially due to a (now temporarily suspended) agreement by Airbnb to pay a 7-percent tax starting in August 2017 ("Puerto Rico signs a tax agreement with Airbnb," 2017).

Between 2006 and 2015, annual tourist visits averaged about 4.6 million, with 5 million people visiting in 2015 (Congressional Task Force on Economic Growth in Puerto Rico, 2016b). Of these 5 million, about 30 percent arrived via cruise ships, and 88 percent were from CONUS (Congressional Task Force on Economic Growth in Puerto Rico, 2016b). However, the number of tourist arrivals in 2015 was lower than the decade before, with the number of hotel beds approximately the same as in the 1970s (Krueger, Teja and Wolfe, 2015; Congressional Task Force on Economic Growth in Puerto Rico, 2016b). Thus, there is significant room for growth in the Puerto Rican tourism industry, especially from non-U.S. citizens (Congressional Task Force on Economic Growth in Puerto Rico, 2016b).

[33] The direct contribution was estimated at $2.8 billion or 2.7 percent of GDP but total contribution, including indirect impacts, was estimated at $8.1 billion. See World Travel and Tourism Council (2017). The direct travel and tourism contribution includes residents' domestic spending, businesses' domestic travel spending, visitor exports, and individual government spending on accommodation services, food and beverage services, retail trade, transportation services, and cultural, sports and recreational services. Indirect spending includes investment spending, government collective spending on travel and tourism, and the impact of purchase from suppliers. The induced contribution includes the spending of direct and indirect employees on food and beverages, recreation, clothing, housing, and household goods. The direct, indirect, and induced spending is summed to produce the total travel and tourism contribution.

Both airports and cruise ships are critical assets to Puerto Rico's tourism industry. The main commercial airport in the Commonwealth is the Luis Muñoz Marín International Airport, which served around 9 million passengers in 2016 (Instituto de Estadísticas de Puerto Rico, 2017). Located in Carolina on the northern coast of Puerto Rico, this airport is a regional hub for the Caribbean islands, offering connections to the East Coast of the United States (Instituto de Estadísticas de Puerto Rico, 2017; Autoridad de los Puertos de Puerto Rico, 2017). In 2016, nearly 1.4 million passengers embarked from or passed through the Port of San Juan on over 500 cruise ship "calls" (Autoridad de los Puertos de Puerto Rico, 2017).

HSOAC examined employment within the tourism sector[34] in Puerto Rico, including the industry categories defined as leisure and hospitality based on the North American Industry Classification System (NAICS): amusements, gambling or recreation; accommodation; food services and drinking places; etc. Employment within the tourism sector rose steadily from 2009 to 2017 (Krueger, Teja and Wolfe, 2015). In the second quarter of 2017, approximately 82,000 Puerto Ricans were employed in these sectors at 4,901 establishments throughout the Commonwealth. In the aggregate, these employees earned $289 million in wages in the second quarter of 2017. Based on an estimate of 852,000 total employees in Puerto Rico, employment in these sectors accounted for approximately ten percent of the total (Bureau of Labor Statistics, 2018i, 2nd Quarter 2017).

Manufacturing

The development of high-value, low-weight, and capital-intensive industries (including pharmaceuticals, biotechnology, and software) in Puerto Rico is partially explained by the lower labor and transportation costs that they enjoy relative to other industries and to the historical policies offering tax incentives to attract business and investment (Krueger, Teja and Wolfe, 2015). The Section 936 tax incentives created under the Tax Reform Act of 1976, in conjunction with earlier incentives created in the Revenue Act of 1921, caused the manufacturing industry to grow. The pharmaceutical industry benefited the most from these tax incentives (U.S. Government Accountability Office, 1992). Because labor and transportation costs are relatively high in Puerto Rico, many businesses find it difficult to compete with CONUS firms. Industries in which labor and transportation costs make up a small portion of their overall cost structure were well placed to take advantage of the tax incentives and came to dominate the economy.

According to the Puerto Rico Planning Board, manufacturing accounted for a greater proportion of GDP (47.3 percent) than any other industry in fiscal year 2016.[35] Within manufacturing, the three largest sectors were bio-pharma (42.8 percent), basic chemicals (22.7

[34] Note that retail employment among establishments that serve tourists are not included in this discussion since HSOAC cannot disentangle which establishments cater to tourists. Furthermore, there could be services provided to tourists, such as food services, that are provided by the informal economy, which are excluded from the employment estimates. As a result, the employment estimates described below may understate tourism employment.

[35] HSOAC reminds readers of the methodological issues related to the statistical calculations of the Planning Board.

percent), and computer and electronics (19.1 percent). The U.S. Food and Drug Administration reported that Puerto Rico produced more of the pharmaceutical products that were imported into CONUS than any foreign country or other U.S. territory at $40 billion (Food and Drug Administration, 2017).

Employment in the manufacturing sector has steadily declined over the past two decades. Beginning in 1998, manufacturing employment started declining, falling from 155,000 in 1997 to 72,000 in 2017, or a reduction of 53 percent (Bureau of Labor Statistics, 2018g). The beginning of the manufacturing employment decline corresponds to the beginning of the phaseout of Section 936 tax incentives; however, the extent to which the phaseout caused this decline is unclear (MacEwan, 2016; Feliciano and Green, 2017; Makoff and Setser, 2017). Employment continued to decline even after the phaseout of the incentives completed in 2006.

Trade and associated transportation

Estimates of export activity from Puerto Rico vary. According to the U.S. Census Bureau (foreign trade statistics), exports from Puerto Rico to foreign nations totaled $20.2 billion in 2015 and $19.9 billion in 2016. However, the Puerto Rico Institute of Statistics estimates 2015 exports at $17.5 billion.[36] According to data from the U.S. Census Bureau (foreign trade statistics), Puerto Rico's total exports to foreign nations have increased by 63.4 percent, or an average of 3.3 percent per year, from 2002 to 2017. In 2002, total exports from Puerto Rico equaled $9.7 billion. In 2017, total exports equaled $15.9 billion. According to the New York Federal Reserve Bank Small Business Survey, few small businesses based in Puerto Rico export their products (over 90 percent of exports are from subsidiaries of U.S. manufacturers), with 81 percent of firms surveyed saying they derive no revenue from exports, and only 2 percent deriving more than 75 percent of their revenue from this source (Federal Reserve Bank of New York, 2016).[37]

In 2008, total imports to Puerto Rico equaled $19.5 billion. In 2017, total imports equaled $18.2 billion, a decline of 6.6 percent or 0.8 percent on average per year.[38] (U.S. Census Bureau, 2018b). Chemicals, machinery and parts, live/cut plants, pharmaceuticals, medical devices and instruments, apparel, and consumer goods were the major commodities imported.

The Census Bureau also reports movement of commodities between Puerto Rico and CONUS. In 2016, Puerto Rico shipped $56.1 billion worth of commodities to the United States,

[36] While these discrepancies may suggest that one of the two sources is less accurate, they could also reflect different methodologies used by the agencies to calculate exports.

[37] It is unclear if respondents included exports to the CONUS when answering this survey question.

[38] Note that these are nominal values so the real decline in exports between these years was even greater. It is possible that under the old tax laws, firms were importing inputs and exporting finished products. Once it became less profitable to do that, the input imports trade declined, as did exports of finished products from those inputs, and import and export industries diverged.

with nearly 57 percent of value shipped by vessel (the rest by air). The value of commodities shipped from the CONUS totaled $25.2 billion, with 42 percent shipped by vessel.

Transportation and warehousing have declined to below 1990 employment levels. Data from the U.S. BLS QCEW show that employment grew from 23,300 in 1990 to peak at 26,300 in 2000, growth of approximately one percent on average per year. However, since the peak, employment has fallen by two percent on average per year to roughly 19,000 in 2017. The average weekly wage in the second quarter of 2017 was $512.20, and aggregate wages paid in the quarter were $988,247,242.

Agriculture

The agricultural sector in Puerto Rico has experienced significant swings in productivity throughout its history. Puerto Rico's sugar industry, which comprises both the crops and factories to produce sugar, grew rapidly in the early 1900s when Puerto Rican sugar was allowed into the United States tariff-free. By 1930, Puerto Rico produced nearly 1,400 metric tons of sugar, five times the amount produced by Louisiana (Bridgman, Maio and Schmitz Jr., 2012). In 1934, all agricultural production comprised 45 percent of Puerto Rico's GNP, compared to 7 percent for manufacturing (Grau et al., 2003). However, the sugar industry had collapsed by the mid-1960s, and the percentage of Puerto Rico comprised of farmland decreased from 85 to 37 percent between 1940 and 1980 (Cruz Baez and Boswell, 1997). By 1980, agriculture represented just 5 percent of GNP while manufacturing accounted for nearly 50 percent (Dietz, 1986). This negative trend has continued over time, with agriculture representing just 0.8 percent of GDP in 2016 (World Bank, 2018b).

The latest agricultural census figures (the somewhat outdated 2012 Census of Agriculture from the United States Department of Agriculture) indicate that the majority of farms in Puerto Rico were small in size and operations. Of 13,159 farms, 83 percent were less than 50 cuerdas in size (1 cuerda = 0.97 acre). Puerto Rico's farms sold a total of $547.6 million in agricultural products, with average per-farm sales of $41,616; however, 53 percent of farms had sales of less than $5,000 in 2012 (U.S. Department of Agriculture and National Agricultrual Statistics Service, 2015). Milk and other dairy products were the highest grossing commodities at $189.4 million, with plantains the next highest grossing crop at $80.5 million.

Puerto Rico's small farms and operations mean that agriculture makes up a relatively small share of total employment and wage income in the Commonwealth. In 2012, 58 percent of farmers reported something other than farming to be their primary occupation, and only 17 percent of farmers derived at least 75 percent of their income from farming. According to more-recent data from the QCEW, in June 2017, the aggregated NAICS sector for agriculture, forestry, fishing and hunting employed 12,188 Puerto Ricans across 2,051 distinct business establishments (Bureau of Labor Statistics, 2016). These figures likely include only formal registered operations. Nonetheless, agricultural operations and incomes are small.

As the data presented above show, Puerto Rico agriculture has contracted considerably from its peak in the early half of the last century. However, there were recent indications of a potential revival of Puerto Rico's agricultural sector. For example, statistics from the governor's office showed that farm incomes grew by 25 percent to more than $900 million from 2012 to 2014 (Associated Press, 2016). In addition, the agricultural sector had been enjoying annual growth rates between 3 and 5 percent in the six years prior to the 2017 storms (Robles and Ferre-Sadurni, 2017).

Fisheries and the ocean economy

Prior to the hurricanes, Puerto Rico was in the process of establishing a promising ocean economy backbone, as evidenced by findings from the Ocean Economy Survey for Puerto Rico and the US Virgin Islands, which was conducted by the U.S. Department of Commerce (DOC), National Oceanographic Atmospheric Administration (NOAA) in 2016 using 2012 employment data, and national employment statistics. The report shows that Puerto Rico is more reliant on ocean-related activities than most U.S. States, which is not surprising given the Commonwealth is completely surrounded by water. National employment statistics show that the ocean economy in Puerto Rico supports seven percent of the total employment in Puerto Rico, which is three times more than the average of two percent for ocean and Great Lakes states.

Total angler expenditures on marine recreational fishing totaled nearly $72 million in 2011. Trip expenditures were $16 million, and expenditures on durable goods were $56 million (Lovell et. al. 2013). Anglers' estimated annual expenditures for billfish fishing trips in Puerto Rico totaled $26 million. Annual consumers' surplus estimates totaled $18 million, resulting in a total economic value of nearly $44 million for billfish alone (Ditton and Clark 1994). Moreover, there are approximately 124,674 anglers who fish saltwater species that contribute to the Commonwealth's overall economic activity (NOAA 2016).

Furthermore, the natural capital assets of Puerto Rico directly benefit the tourism and recreation sectors, as well as the local populace, through the provision of ecosystem services. These assets include the aesthetic value of the reef and waters, which provide recreational opportunities and contribute to the cultural identity of the local community. The reef ecosystem also provides seafood and marine products, such as ornamental jewelry and other souvenirs (U.S. Environmental Protection Agency, 2016b).

The total ocean economy in Puerto Rico represents over 68,600 jobs in about 4,500 establishments. As in the tourism sector, this direct measure captures neither interdependencies in the economy (i.e., businesses that help supply those related to the ocean economy) nor those excluded from official statistics, such as self-employed individuals. One more inclusive estimate of the total employment related (directly or indirectly) to the ocean economy is approximately 156,000 jobs (Abt Associates Inc., 2016).

Nonprofit

In the last two decades, the nonprofit sector in Puerto Rico has undergone compositional changes. In 1996, fewer than 4,000 distinct, direct service nonprofits could be identified in Puerto Rico. By 2007, there were more than 6,000 distinct, direct service nonprofits and, by 2015, there were 11,570 (Suarez, 2017). Despite this increase in the number of nonprofits, however, the nonprofit workforce overall has contracted by 10.8 percent (Suarez, 2017). This underscores a shift away from large, well-resourced nonprofit operations (especially as divisions of larger organizations) and towards community organizations, which made up 22 percent of all nonprofits in 2015 (Suarez, 2017).

This trend is further borne out in funding data. In 2000, the average expenditure by a nonprofit operating in Puerto Rico was $661,257, and this figure grew to $1,057,131 by 2006. In 2014, however, average nonprofit expenditures fell to $269,266, nearly 25 percent of its 2006 value (Estudios Tecnicos Inc, 2015). The main explanation for the contraction in nonprofit expenditures and hiring is the recession of 2006, which may have caused contraction by larger organizations that operate primarily in the United States. However, Puerto Rico's continued economic stress may also explain the increase in community organizations, as local operators attempt to continue providing direct services with fewer financial resources at their disposal. The trend towards the proliferation of small and minimally-resourced nonprofits will have to change for the nonprofit sector to contribute significantly to hurricane relief efforts.

Pre-hurricane conditions

Prior to Hurricanes Irma and Maria, Puerto Rico faced four major challenges to economic development: (1) outmigration of labor, (2) outmigration of capital, (3) low labor force participation, and (4) public debt. Each of these challenges has multiple root causes that may be under the control of multiple actors, including the Puerto Rico government, U.S. federal agencies, and Congress. We illuminate these four big issues by looking at the specific aspects of the economic environment that have caused these problems. Specifically, we consider the roles of the cost of doing business, tax structure, labor policies, and the Jones Act.

These long-term economic stressors, in addition to the shock presented by Hurricanes Irma and Maria, are considerable when viewed through the lenses of sustainability and resilience. This section describes the pre-storm landscape and trends that pose challenges to achieving sustainability. Resilience to future shocks and stressors will likely require structural changes to the policy landscape at both the local and federal levels. While infrastructure is important and documented elsewhere, it is only a necessary, but not sufficient, condition for economic development.

Cost of doing business

The World Bank's 2018 Ease of Doing Business report tracks 190 economies using 11 indicator sets (World Bank Group, 2018). For Puerto Rico, the business city selected was San Juan, and calculations were done on pre-storm data collected in 2017. Overall, Puerto Rico ranks 64th of 190 studied economies in terms of the overall ease of doing business, while the United States ranks 6th overall. Based on this ranking, it is easier to do business in Russia and Rwanda than Puerto Rico. With respect to efficiency, **Puerto Rico is approximately 17 percent less efficient in terms of ease of doing business than the United States as a whole** (World Bank Group, 2018).

Regionally, Puerto Rico outperforms the average for Latin America and the Caribbean. It is true that Puerto Rico is a Caribbean economy and, in some ways, it needs to outperform them to develop. However, investors and businesses often choose between Puerto Rico and CONUS, rather than other Caribbean economies. Thus, Puerto Rico needs to measure up to standards of the CONUS economy, rather than those of Caribbean economies.

In terms of the specific indicator sets reported by the World Bank, Puerto Rico performs particularly poorly on Dealing with Construction Permits, Registering Property, Protecting Minority Investors, Paying Taxes, and Enforcing Contracts. However, the Commonwealth performs in the top ten in terms of Getting Credit and Resolving Insolvency. Other studies confirm the World Bank's findings. For example, the New York Federal Reserve comments that "regulatory burdens, transportation costs, and most notably, energy costs on Puerto Rico can raise the cost of operating businesses" (Federal Reserve Bank of New York, 2014a). The Fed also notes challenges resulting from bureaucracy and red tape (i.e., transaction costs related to the public sector). Krueger, Teja and Wolfe (2015) note similar issues.

In sum, most of the indicator sets collected by the World Bank, and the complementary analyses appearing in the literature, suggest that the cost of doing business in Puerto Rico exceeds that of the CONUS, with serious deficiencies in the system of recording and enforcing property rights, the corporate tax burden, and the transaction costs of the tax and permitting process.

Tax structure

Puerto Rico has a unique tax structure. In general, non-federally employed residents of Puerto Rico are not required to pay U.S. income tax on work or business income derived from activities in the Commonwealth because Puerto Rico is considered a foreign tax jurisdiction (Internal Revenue Service, 2018). Similarly, corporations organized in Puerto Rico are generally treated by the United States as foreign corporations for tax purposes (Congressional Task Force on Economic Growth in Puerto Rico, 2016b). As such, corporations organized in Puerto Rico were not required to pay federal taxes on Puerto Rico-source income until funds were repatriated to

CONUS, at least until tax reform in December 2017. However, they may use the "Made in the USA" branding where necessary.

As much of the investment in manufacturing is in the pharmaceutical and medical device manufacturing sectors, federal tax reform in December 2017 poses an additional barrier to investment in Puerto Rico (especially in the manufacturing sector) and may provide incentives for firms to relocate to CONUS or not locate in Puerto Rico. The primary effect on manufacturing comes from a new tax called Global Intangible Low Tax Income (GILTI). This tax is aimed at products that have intellectual property underlying their production and are imported to the U.S. Because Puerto Rico is treated as a foreign tax jurisdiction, there is a new 10.5 percent rate (less applicable foreign taxes) applicable to profits from pharmaceutical, medical device, and other related manufacturing imports from Puerto Rico to CONUS. In addition, the 2018 law lowers the top U.S. corporate tax rate on profits from 35 to 21 percent. Because of this, there may be little incentive to move production outside of CONUS.

Local taxation also presents a challenge to economic development. Under local property tax law, firms are taxed on the average value of unsold inventory every month. This discourages investment in stockpiling, which may have negative implications for supply chain resilience and emergency preparedness, and may depress economic activity in the warehousing and transportation sectors.

As of 2012, the state and local tax burden in Puerto Rico for personal income was generally high compared to most U.S. states, but property taxes are generally lower (Federal Reserve Bank of New York, 2014a). However, the system suffers from low collection rates and distortions due to specific tax benefits (Federal Reserve Bank of New York, 2014a; Krueger, Teja and Wolfe, 2015).

Labor policy

Overall, labor costs in Puerto Rico are high relative to the state of the economy, especially due to policy and generous benefits packages. Given its territorial status, Puerto Rico is subject to the U.S. federal minimum wage, and government benefits provide a high income relative to the minimum wage. Full-time employment at the minimum wage is equal to 77 percent of per capita income (as compared to 28 percent in the rest of the United States). For a family of three, welfare benefits may exceed take-home income for a single earner paid minimum wage (Krueger, Teja and Wolfe, 2015).In addition, Puerto Rico residents are not eligible for the federal earned income tax credit (EITC), and economic theory suggests that social welfare benefits in the form of transfer payments may depress the labor force participation rate. This provides a considerable disincentive for younger and less-skilled individuals to seek work (Federal Reserve Bank of New York, 2014a). The labor force participation rate in Puerto Rico was 39.9 percent in August 2017, which was substantially lower than the U.S. labor force participation rate of 62.9 percent (Bureau of Labor Statistics, 2018f). Investing strategically in Puerto Rico's workforce and labor is difficult because **little reliable data on the current labor**

supply are available. This lack of reliable data is due to both conditions in Puerto Rico and a lack of information on the composition of migration outflows.

Disparities in educational achievement between Puerto Rico and CONUS are an additional challenge to Puerto Rico's economic development. Although disparities in educational achievement have narrowed in recent decades, education levels are lower in Puerto Rico than in CONUS, with Puerto Rico having a greater proportion of individuals who have not completed high school (Federal Reserve Bank of New York, 2014a; Krueger, Teja and Wolfe, 2015). These educational outcomes have negative implications for Puerto Rico's workforce and individual earning capacity.

Transportation and the Jones Act

Congress enacted the Merchant Marine Act of 1920, commonly referred to as "the Jones Act," to both strengthen national security and sustain a robust maritime industry and merchant navy.[39] One objective of the statute was to ensure that there would always be a sufficient number of U.S.-flagged vessels that could be called upon should the need arise to project American forces abroad in a time of crisis. Another goal was to promote foreign and domestic commerce, which would be facilitated by a healthy fleet of U.S.-flagged vessels.

The Jones Act ("the Act") governs *coastwise trade*[40] within the United States and determines which ships may lawfully engage in that trade and the rules they must follow. The primary requirements of the Act are that maritime transport of cargo between points in the United States (and certain territories such as Puerto Rico) be carried by vessels that are: (1) owned by U.S. citizens and registered under U.S. law; (2) built in the United States; and (3) operated with predominantly (75 percent) by U.S.-citizen crews.[41] Foreign vessels cannot pick up cargo from a port located in the continental U.S. and drop it off in Puerto Rico, a cabotage restriction rule. Cabotage is the right to operate within a territory, in this case the United States. In order to remain compliant with the law, only Jones Act compliant vessels can transport goods between ports in CONUS and Puerto Rico. This protection has ensured a stable market for Jones Act complaint vessels, which tend to be more expensive than non-compliant vessels (U.S. Government Accountability Office, 2013).

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[39] Note that the Jones Act should not be confused with the Jones-Shafroth Act of 1917, which granted U.S. citizenship to Puerto Ricans. When used in the sense of maritime law, the Jones Act refers to federal statute 46 USC section 883.

[40] Coastwise Trade applies to a voyage beginning at any point within the United States and certain territories, which includes Puerto Rico, and delivering a type of commercial cargo to any other point within the United States.

[41] A number of other statutes affect coastwise trade and should be consulted along with the Jones Act. These include the Passenger Vessel Services Act (46 USC section 289), which restricts coastwise transportation of passengers, and 46 USC section 12108, which restricts the use of foreign vessels to commercially catch or transport fish in U.S. waters.

Although the nearby U.S. Virgin Islands has been free of all Jones Act restrictions since 1922, Puerto Rico, as a U.S. territory, is subject to all Jones Act requirements with respect to shipping cargo. Officials have interpreted the Act and subsequent legislation to apply to nearly every type of commercial vessel. For example, according to one interpretation of the law, pleasure boats owned by companies and used to entertain clients are also subject to the law (Maritime Law Center, 2016). Almost everything that floats and is used for commercial purposes is subject to the Act.

For over a century, laws enacted by the U.S. government have shielded the domestic shipping industry from open competition, and shipping lines have traditionally formed "shipping conferences", essentially cartels, to fix prices charged to customers shipping goods along different routes.[42] Maritime transport is an industry with unusually high fixed costs, and in such industries, unrestrained competition and entry may lead to prices that fall below long run average costs. Advocates of protective policies in the shipping industry argue that cartels may encourage investment and productivity growth by stabilizing prices at levels that cover average costs.[43] On the other hand, because collusive arrangements limit competition and competitive pressures to cut costs, protective policies that encourage their formation could instead keep prices too high and reduce productivity growth.[44]

Since the 1980s, several deregulatory policies enacted by the U.S. government have tried to promote greater competition in the shipping industry. For example, the Shipping Act of 1984 revised antitrust exemptions for carrier arrangements. The Ocean Shipping Reform Act of 1998 enabled carriers to negotiate independent, confidential shipping contracts with customers, allowing carriers to deviate from cartel pricing (Sagers, 2006). Recently, two large carriers operating shipping routes from the U.S. to Puerto Rico were investigated by the DOJ for collusive practices and fined for violations of the Sherman Antitrust Act[45] and the False Claims

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[42] For an overview of the history of U.S. maritime regulations and shipping conferences, see Sagers, C. (2006) "The Demise of Regulation in Ocean Shipping: A Study in the Evolution of Competition Policy and the Predictive Power of Microeconomics" Vanderbilt Journal of Transnational Law 39, 779-818. Note that shipping conferences are not uniquely a U.S. phenomenon, but are common worldwide.

[43] Several researchers have studied ocean shipping and concluded that the price fixing generated by shipping conferences help to stabilize the industry. See, for instance, Sjostrom, William (1989): "Collusion in Ocean Shipping: A Test of Monopoly and Empty Core Models," Journal of Political Economy, 97(5): 1160–79; Pirrong, S. (1992): "An Application of Core Theory to the Analysis of Ocean Shipping Markets." Journal of Law and Economics, 35(1): 89–131.

[44] For a discussion of the economic rationales for and against cartels in industries with high fixed costs, see Levenstein, M. and Suslow, M. (2006) "What Determines Cartel Success?" Journal of Economic Literature 44, 43-95.

[45] In 2011, a Jones Act carrier, Sea Star Line LLC, plead guilty and agreed to pay a $14.2 million criminal fine for its role in a conspiracy to fix prices and surcharges for water freight transportation between CONUS and Puerto Rico from May 2002-April 2008. Sea Star Line and co-conspirators agreed during meetings and communications to rig bids

Act.[46] Additionally, five former shipping executives from the two companies were sentenced to pay nearly $85,000 in criminal fines and to serve more than 11 years in prison, collectively.

Although the impact of deregulation warrants further study, it does not seem like the Jones Act, by itself, has succeeded in maintaining a sizeable U.S. merchant fleet. According to data from the U.S. Bureau of Transportation Statistics, in 1960, there were nearly 3,000 U.S. flag carriers with more than one thousand gross tons of capacity in the U.S. merchant fleet.[47] However, by 2010, as the global market of such vessels nearly doubled, there were only 221 such vessels in the U.S. fleet, and these constituted only 0.7 percent of the global market.

Over the past 50 years, the reductions in the U.S. merchant fleet are probably explained by a variety of factors, including the decommissioning of older vessels that were in operation during WWII, increased foreign competition, the rise of cargo air carriers, changing technologies, and U.S. policies (Sagers, 2006). Nevertheless, the downward trend in these data is stark.

Data on Jones Act compliant vessels are only available from MARAD from 2000 to the present. In 2000, of the 282 U.S. flag vessels over 1,000 gross tons, only 193 were Jones Act eligible. In 2000, the total capacity of the large merchant fleet was over 12 million gross tons, with 6.1 million gross tons of capacity in Jones Act compliant vessels.

While the number of non-Jones Act eligible vessels and total capacity have both been relatively stable over time, by 2016, there were only 92 large Jones Act eligible vessels, and these vessels had a total capacity of only 3.2 million gross tons. In 16 years, the total number of Jones Act eligible vessels had fallen by over 50 percent, while the total capacity of these vessels had fallen by 47 percent.

According to the most recent MARAD data, as of May 1, 2018, there were 99 Jones Act eligible carriers larger than 1,000 gross tons; these carriers consisted of 41 cargo ships and 58 tankers (including petroleum, chemicals, and liquid natural gas carriers). The 41 Jones Act eligible cargo ships were operated by 10 different companies. Currently, only 4 cargo shipping companies serve routes to and from Puerto Rico: (1) Crowley Maritime Corp.; (2) Trailer Bridge,

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and fix the rates and surcharges charged to water freight customers. Horizon Lines LLC was also sentenced to pay a $15 million criminal fine for its role in the conspiracy. The conspiracy violates the Sherman Anti-Trust Act. See https://www.justice.gov/opa/pr/florida-based-sea-star-line-llc-agrees-plead-guilty-and-its-former-president-indicted-price

[46] In 2014, these two Jones Act shipping lines, Sea Star Line LLC and Horizon Lines LLC, which serviced Puerto Rico, were also found guilty of price fixing. The government alleged that former executives of these companies used personal emails to communicate confidential bidding information when bidding for government cargo transportation contracts between CONUS and Puerto Rico. As a stipulation of a settlement agreement for violating the False Claims Act, these companies paid a total of $3.4 million in fines to the U.S. Justice Department. https://www.justice.gov/opa/pr/two-ocean-shipping-companies-pay-34-million-settle-claims-price-fixing-government-cargo

[47] Note that because these data only reflect large vessels with more than 1,000 gross tons, they do not indicate what has been happening over time to smaller vessels, such as tugs and barges.

Inc.; (3) Sea Star Line LLC; and (4) National Shipping of America (U.S. Department of Transportation Maritime Administration, 2018).

Overall, the downward trend in the U.S. merchant fleet since the 1960s and the recent decline in Jones Act compliant vessels and capacity since 2000 could indicate that the industry has been experiencing increasing concentration and potentially destructive competition as protective regulations have been removed. However, another reading of these trends is that, prior to deregulation, there was excess capacity in the industry, and the reductions in supply are consistent with market forces causing the exit of inefficient, unproductive firms (Sagers, 2006).

Unfortunately, data on changes in freight rates are not publicly available, but a recent GAO report finds that the average freight rates of the four Jones Act carriers serving Puerto Rico fell between 2006 and 2010, possibly due to the overall economic downturn over the period. However, freight rates were often, but not always, larger than those charged by foreign carriers for shipments of similar products and distances (U.S. Government Accountability Office, 2013). According to another study conducted in 2012 by the Federal Reserve Bank of New York, shipping a container from the U.S. East Coast to Puerto Rico costs $3,063, but shipping the same container to Kingston, Jamaica, costs only $1,607 (Federal Reserve Bank of New York, 2014a). A 2011 study by the U.S. Department of Transportation Maritime Administration (MARAD) stated the operating costs of U.S.-flagged ships were 2.7 times higher than foreign-flagged ships (U.S. Department of Transportation Maritime Administration, undated). To the extent that the Jones Act results in higher freight rates for shipments of products between Puerto Rico and other U.S. ports, it could lead to increased consumer prices for many products imported to Puerto Rico from the mainland U.S. and transported by waterways. Such products are already more expensive, given Puerto Rico's isolated geography.

The impacts of the Jones Act could be particularly large in the energy sector. Puerto Rico does not have any coal, natural gas, or oil reserves, and it currently relies on imported fossil fuels to produce energy. According to the U.S. Energy Information Administration, in 2016, 47 percent of Puerto Rico's electricity came from petroleum, 34 percent from natural gas, 17 percent from coal, and 2 percent from renewable sources (U.S. Energy Information Administration). Because most energy sources are imported, and potentially because the Jones Act inflates shipping costs, this leads to higher electricity prices. Even at subsidized prices, Puerto Ricans pay 21 cents per kilowatt-hour of electricity, compared with an average of 11 to 12 cents or less in the continental United States. This places Puerto Rico at an enormous disadvantage compared with other states that produce electric power at less than half of Puerto Rico's price. This high cost of electricity creates additional disincentives to locate businesses in Puerto Rico.

Relaxing Jones Act restrictions could also reduce natural gas prices paid in Puerto Rico, and this could incentivize greater adoption of liquified natural gas (LNG) capacity, which improve environmental outcomes. There are currently no Jones Act eligible tankers capable of carrying

liquified natural gas (LNG) to take advantage of the low prices of natural gas on CONUS, and as a result, Puerto Rico imports the LNG it uses from more expensive international suppliers.

- A handful of analytical studies of the Jones Act have concluded that it imposes a net cost to the U.S. economy (inclusive of its territories). For instance:
- In a 1999 study, the U.S. International Trade Commission estimated the Act costs U.S. consumers $1.32 billion annually and is equivalent to a 65 percent tariff on shipping services (U.S. International Trade Commission, 1999).
- A 2012 Federal Reserve Bank of New York study, updated in 2014, found that the Jones Act hurts the Puerto Rico economy (Federal Reserve Bank of New York, 2014a).
- A 2013 study by the U.S. Government Accountability Office (GAO) found that the Jones Act distorts the shipping market between Puerto Rico and the United States. Lower shipping rates for foreign shippers can lead companies to source products from foreign countries rather than the U.S. However, the study also suggested modifying the Jones Act could have "highly uncertain" effects, and that more research is needed (U.S. Government Accountability Office, 2013).
- A recent working paper studies how the Jones Act affects the multimodal network of trade between U.S. states, territories, and foreign countries. It finds that repealing the Act would result in an annual cost savings of $1.91 billion for U.S. firms, because of reduced shipping costs (Swisher and Wong, 2015).

However, other research suggests that there are many additional factors affecting freight rates, and it is difficult to attribute a significant blame to the Jones Act for higher consumer prices in Puerto Rico. While relaxing Jones Act restrictions could increase competition and reduce freight rates, it could also lead to further exit of U.S. merchant carriers, with some possible national security concerns (U.S. Government Accountability Office, 2013). Although LNG prices in PR may fall quickly if LNG vessels were exempted from the Jones Act, LNG electricity production capacity in PR is currently limited, and it may take years before cheaper LNG imports reduce PR's reliance on petroleum for electricity production. More research is needed to understand the impact of the Jones Act on the structure of the merchant shipping industry and how modifying or eliminating it could affect firms, workers, and consumers in Puerto Rico. The available evidence suggests that the Jones Act does not benefit and is likely harmful to Puerto Rico, but the magnitude of those costs is subject to considerable debate.

Hurricane damage

This section presents estimates of the damage caused by Hurricanes Irma and Maria to the economy of Puerto Rico. Except in a few cases, HSOAC focuses on aggregate economic indicators, including those that represent disruptions to the flow of economic activity. HSOAC first presents a summary of key impacts, highlighting some of the estimates of damage that appeared in print shortly after the storm. Because these estimates were often based on little verified data, HSOAC terms these "ex ante" estimates. HSOAC then presents various "ex-post" estimates of disruptions from the hurricanes using differing methods, assumptions, and data

sources that include data from after the storms. Differing methods are shown to provide a degree of sensitivity analysis across the damage estimates, thus guarding against false precision in the damage estimates. The "ex-post" estimates represent the most accurate estimates of the storms' overall effects. HSOAC also presents qualitative and anecdotal information to complement the quantitative analysis.

Summary of damage and economic impact

Hurricanes Irma and Maria devastated the Commonwealth, which was already in a deep economic, social, and debt crisis. The losses were large, with hundreds of thousands of people depending on external help to meet basic needs for an extended period of time.[48] Hurricane Maria essentially destroyed Puerto Rico's already fragile electric grid, such that all of Puerto Rico was without power for the first eight days after this storm (see the Energy chapter for more information). Because of numerous challenges, power restoration after Hurricane Maria has moved substantially slower than after other major U.S. disasters, which has caused additional economic hardships for surviving small and large businesses.

Communications (internet, cellular, and landlines) were also severely disrupted, resulting in substantial commercial issues (see the Communications/IT chapter for more information). Many of the multinational corporations operating in Puerto Rico are highly dependent on enterprise software to operate. Because the software is internet-based, the business unit is unable to conduct normal operations when there is no internet service.

Coupled with additional destruction of various capital stocks (including residential and non-residential private capital stocks and public infrastructure stocks; see later chapters of this report), the short-term impact to economic activity was severe (Kuligowski, 2018). Although data are limited at the time of this writing primarily because of time lags, estimated impacts from post-storm data for the months following the storms (September–December 2017) include the following:

- Short-run decline in the Economic Activity Index (correlated with GNP) of approximately 12 percent relative to an estimated no-storm world
- Agricultural production losses estimated at $227 million for crops being grown at the time of the storms, with $45 million attributable to Irma and $182 million to Maria; non-crop infrastructure losses for agriculture estimated at more than $1.8 billion
- Losses to Puerto Rico's tourism industry of over $547 million in direct revenues during the three months following the storm
- Negative impacts to trade, which were large in the months immediately following the storm, with exports most negatively affected and imports reflecting the response and recovery effort
- Average private payroll employment declines of approximately 4.35 percent during the three months following the storms

[48] Almost eighty days after Hurricane Maria, FEMA was still in a response mode, delivering over 300,000 meals.

- Average manufacturing payroll employment declines of 1.27 percent in the three months following the storms
- Decreases in the labor force, both the count of employed individuals and the number of individuals in the labor force

It is important to note that these damage estimates use only available data (generally through December 2017), and include economic activity from the recovery effort. In many cases, damage persisted after this time period, likely into and past the time of this writing. As such, no total damage figure is currently available.

Damage predictions immediately following the hurricanes

Damage Reported in the Build Back Better Plan

The "Build Back Better" plan, submitted to Congress by Governor Ricardo Rosselló in November 2017, provided an early estimate of the effect of the storms based on "the best available disaster damage" available at the time (Governor of Puerto Rico, 2017a). The document states that nearly every firm in Puerto Rico was closed at some point following the storm, largely due to damage to the power grid, infrastructure, social services, and disruptions in the supply chain. As of November 2017, up to half of all small to medium-sized business and 15 percent of large multi-national firms remained closed.

At the more aggregate level, the document cited significant increases in applications for unemployment benefits, with (perhaps temporary) job losses in the "tens of thousands." Agricultural damage were particularly severe, with nearly 80 percent of crop value destroyed (approximately $250 million), animal mortality of 45 to 50 percent, and infrastructure losses in excess of $1.8 billion. Tourism losses were also highlighted, with nearly 40 percent of lodging facilities unavailable in November 2017 and new bookings "stalled" at the time of the writing. More qualitatively, the plan notes that increased perceptions of risk could depress foreign direct investment, and several major employers have moved production to other locations.[49]

Damage Reported in the New Fiscal Plan

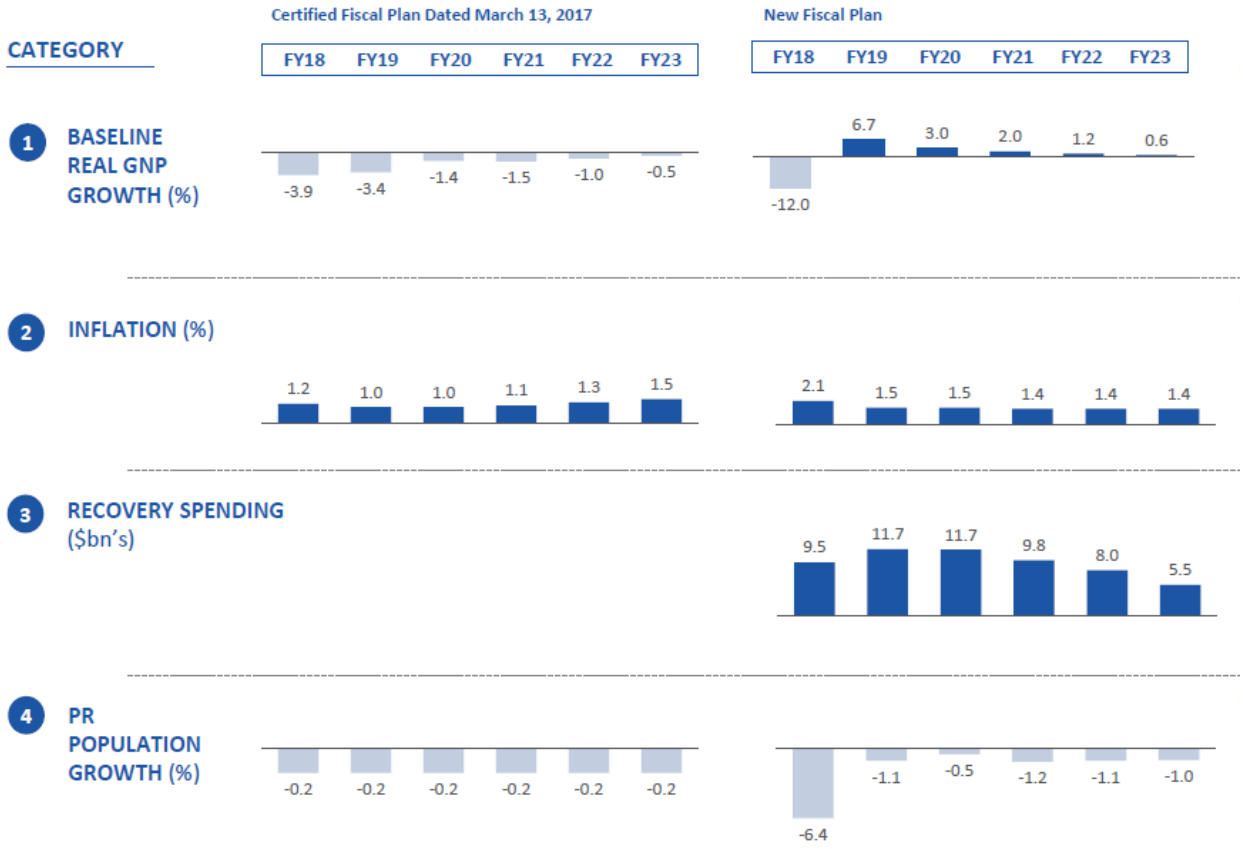
Prepared following the hurricanes, the New Fiscal Plan for Puerto Rico (April 5, 2018, draft) includes economic and demographic forecasts from a pre-storm baseline[50] and then describes the hurricane damage and proposed fiscal and economic reforms. For fiscal year 2018, post-storm real GNP is predicted to be 8.1 percentage points lower than baseline, with inflation 0.9 percentage points greater (due largely to expected disaster relief funds) and population 6.2 percentage points lower than baseline. These figures reflect an expected lack of disaster assistance to fully offset the damage done by the storms.

[49] Detailed information about the relocated firms was not provided in the Build Back Better plan.

[50] Pre-storm baseline is from the Certified Fiscal Plan dated March 13, 2017.

In 5 years (FY 2022), projections are that real GNP will be 4.9 percent greater than baseline, with slightly less inflation (-4.6 percentage points) and lower population (9 percent). These modeled results are likely the combined result of $55.4 billion in Federal Government recovery assistance and insurance payments coupled with accelerated population decline following the storm.[51] Figure 5.7 provides additional details.

Figure 5.7. Economic Forecasts from the New Fiscal Plan, Pre- and Post-Storms



Source: (Government of Puerto Rico, 2018b)

Additional Damage Reports

Estimates of total economic losses due to the storms vary widely. Early in the recovery effort, Economic Development and Commerce Secretary Laboy Rivera estimated total economic losses at a minimum of $20 billion (Alvarex, 2017). In October 2017, Moody's estimated losses to be

[51] Although precise methodological details are not given, the plan states that population is estimated jointly with GNP, with main drivers of population growth being past GNP growth (a positive relationship), past population growth (positive), growth of net federal transfers (positive), effects of the storm (negative), and relief spending (positive). Explicit drivers of GNP growth are not documented, though the plan implies that population changes are not a driver of GNP growth. This runs counter to the assumptions of many Solow-style growth models, which considers labor/population an input into economic output.

as high as $40 billion of economic output and $55 billion in property damage (Flannery, 2017). Modeling firm AIR Worldwide estimated up to $72 billion in total losses (Morriss, 2017).

Reports sourced to the Puerto Rico Department of Labor and Human Resources suggested that, in October, emergency unemployment benefits increased by over 15,000 persons from the prior year, and government sources predicted that up to 300,000 may eventually leave the Commonwealth (Flannery, 2017). As of January 2018, the mortgage delinquency rate was 26.8 percent, which had decreased from 35 percent in November 2017 (Black Knight Financial Technology Solutions, 2018). According to Black Knight Financial Services, this trend matches the post-Katrina pattern in declared counties/parishes in 2005.

Looking forward, the Economist Intelligence Unit[52] predicts that real GNP will decline by 8 percent (year over year) in 2018 (which includes the effects of recovery efforts, assumed to be on the order of 2-3 percentage points), followed by a slight upturn in 2019 due to federal spending related to recovery. Exports are expected to decline largely due to declines in pharmaceutical manufacturing activity. Due to the recovery effort, inflation is expected to increase to 5.4 percent for 2018.

Estimated damage and impacts by sector

In this and the following sections, HSOAC uses select economic indicators from the GDB to estimate the net effect of the storms and subsequent recovery effort. To do so, HSOAC uses statistical techniques to forecast what the indicator would have been absent the storms and compares this estimate to the observed data.

Economic Activity Index

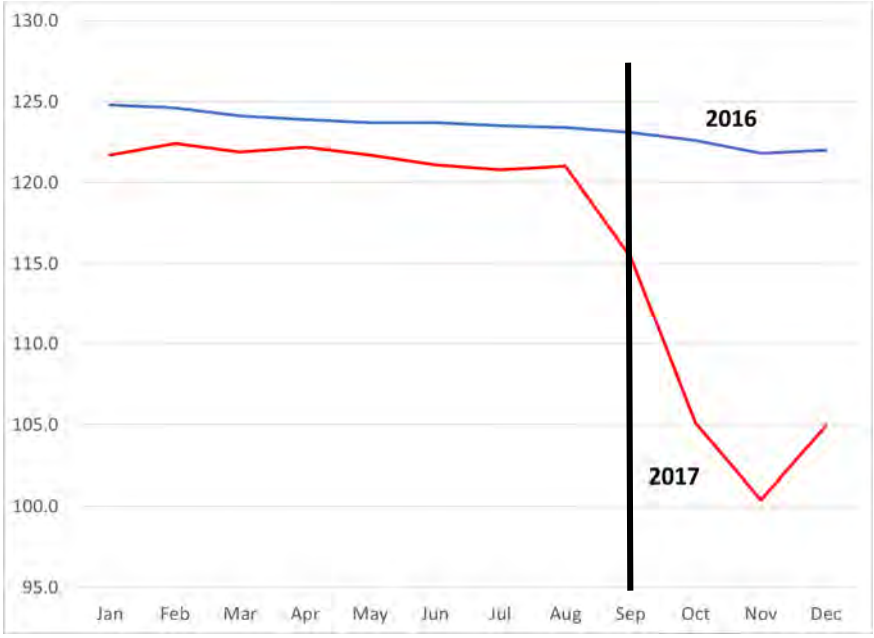
Given data lags in their computation, measures of real GNP following the storm were not available at the time of this writing. As such, we rely on the Government Development Bank for Puerto Rico Economic Activity Index (GDB-EAI), a coincident index that is highly correlated with GNP levels and growth rates.[53] While this index does not provide completely accurate measures of real economic activity, it can be used as an indicator of overall economic activity in Puerto Rico.

As shown in Figure 5.8, GDB-EAI dropped from 121 (1980 = 100) to 115.4 in September, 105.1 in October, 100.4 in November, and 104.9 in December. The index for each month in 2017 is lower than that of 2016, indicating contraction pressures prior to the storms in September 2017.

[52] Forecast closing data was January 16, 2018 (The Economist, 2018).

[53] The reader is reminded of potential problems with GNP figures as published by the Planning Board.

Figure 5.8. GDB Economic Activity Index (GDB-EAI), 2016–2017



NOTE: GDB-EAI is an indicator of general economic activity, generally highly correlated with the level of real GNP. Thick vertical line indicates the month of landfall for Hurricanes Irma and Maria (monthly time series). Source: (Puerto Rico Fiscal Agency and Financial Advisory Authority, undated)

Using data from July 2008 to December 2017, a statistical difference model, which controls for month and year effects, shows a statistically significant decline in the index of 13.7 points, on average, in the time period after the hurricanes.[54] This represents an approximately 12 percent decrease from the value of the index in previous periods and is broadly consistent with previous estimates of severe disruption in the flow of economic activity as a result of the storms.

Employment

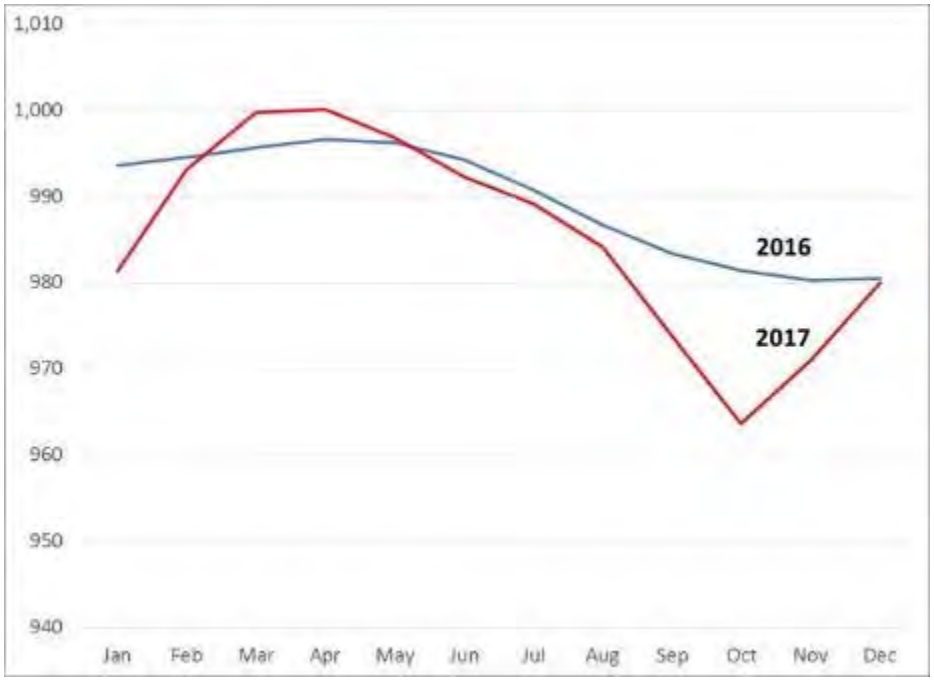
Figure 5.9 shows the estimates for total employment in the labor force in 2016 and 2017, as measured by the BLS Current Population Survey (CPS). Unlike the GDB-EAI, estimates of total employment in March and April of 2017 exceeded those for March and April of 2016 but were generally comparable across the summer months of 2016 and 2017.

Following the hurricanes in September, total employment declined to about 940,000 in October. Total employment had rebounded to 2016 levels (~980,000) by November and was essentially back to baseline in December, primarily due to the recovery effort. However, using data from July 2008 to December 2017, a difference model which controls for month and year effects shows a slight statistically significant decline in total employment of about 1 percent on average in the time period after the hurricanes. The cities of San Juan and Ponce experienced the largest post-hurricane employment losses, initially losing a combined total of 31,000 employed

[54] Because this data series is an index, a linear regression model rather than a Poisson model was used.

individuals. These drops are distinct from their pre-hurricane downward trends. Comparing the three months before and after the hurricanes, San Juan lost four percent of its employed individuals, while Mayaguez lost more than five percent (Bureau of Labor Statistics, 2018h).

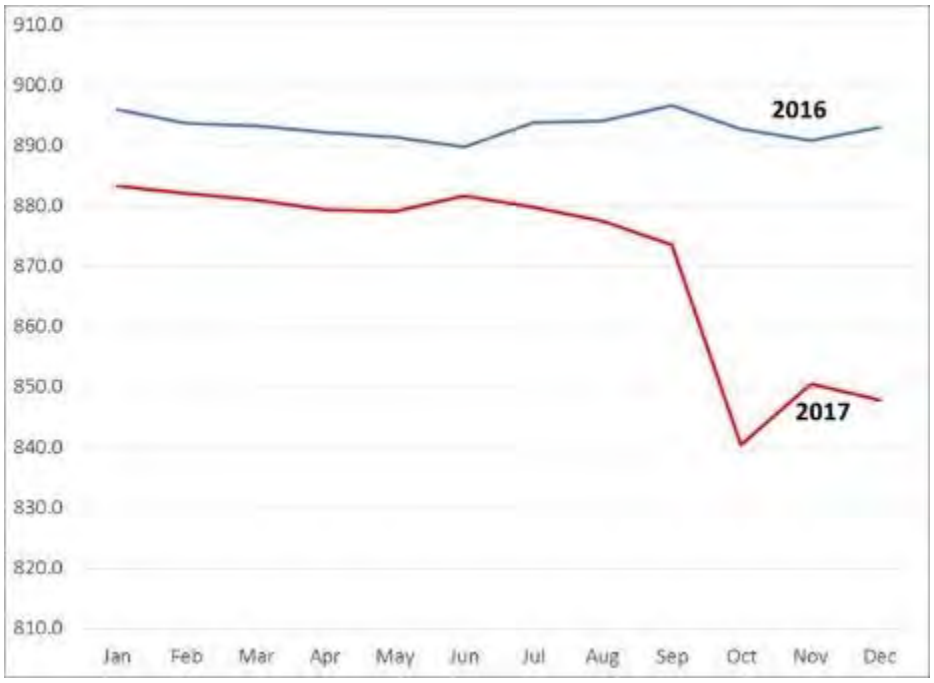
Figure 5.9. Total Employment in the Labor Force (Thousands) for 2016 and 2017



Source: U.S. Bureau of Labor Statistics. Seasonally adjusted. Includes persons employed but not working.

In contrast to the CPS data, which include people on unpaid leave from their jobs, another BLS data source, the Current Employment Statistics (CES) survey, includes businesses and government, only wage workers, and only people who received pay for the reference pay period. Figure 5.10 shows total payroll employment in thousands for 2016 and 2017 from this source.

Figure 5.10. Total Payroll Employment (Thousands) for 2016 and 2017



Source: United States Department of Labor. Bureau of Labor Statistics, Establishment Survey. Seasonally Adjusted

Unlike the previous analysis, these data show that payroll employment was 2.4 percent lower on average in each month from September to December 2017 (a statistically significant result) than what would have been expected had the hurricanes not occurred. However, this analysis includes the effects of the hurricanes and the recovery efforts, which likely offset some of the effects of the hurricanes in terms of payroll employment. When compared to the CPS data, this suggests that, although individuals may have been employed, a significant number of them had not returned to work by December 2017. This could have been due to either personal or employer reasons.

Average hourly earnings in Puerto Rico dropped about 20 cents per hour in the first few months following the hurricane, with variation by municipality in the amount of decline experienced. In Guayama, wages fell almost 40 cents per hour, although they had been steadily declining over the last year. Wages also declined in San German from 13.11 in August 2017 to 12.10 in December 2017, and then rose to 12.48 in January 2018. By contrast, in Ponce, wages increased slightly post-hurricane, returning to their pre-hurricane levels in January 2018. In Mayagüez, where wages had been steadily increasing throughout the prior year, there was a modest decline in hourly wages.

The data presented above have some limitations worth noting. First, some industries were more heavily affected by the storms than others, and the total figures reported above mask differences between subsectors. Second, these data reflect only total employment, not number of hours worked..

Tourism

The storms severely impacted the Puerto Rican travel and tourism industry. Many hotels (including several major resorts), restaurants, and tourist attractions were closed for weeks or months following the storms (25 percent of hotels were still not taking reservations in December 2017) (Puerto Rico Tourism Company, 2017b). Some properties that were still closed as of April 2018 are considered crucial for the recovery of tourism by industry representatives: the Caribe Hilton, Condado Plaza in San Juan, El Conquistador in Fajardo, Royal Isabela in Isabela and W Hotel in Vieques. The W Hotel, the largest hotel in Vieques with 156 rooms, will be re-opening in January 2019. Famous tourist sites such as the 28,400-acre El Yunque National Forest, a biologically diverse tropical rain forest that was popular with ecotourists, were "decimated."[55] Aerial footage shows massive defoliation, plus landslides and downed trees (Long, 2017).

Hotel registrations decreased significantly after Hurricane Maria. There was a decrease in hotel registrations of 28 percent during September of 2017 when compared with the same month in the previous year (2016), with year-over-year declines in registrations of 76 percent and 65 percent in October and November, respectively (Puerto Rico Tourism Company, 2017a). The distribution of unavailable rooms was mostly even across Puerto Rico, except for the western and southern regions.

Airline travel was also impacted by the hurricanes. TSA screening data for 2016 and 2017 for passengers coming into one of Puerto Rico's three main airports, Luis Munoz Marin International, Mercedita, and Rafael Hernandez, show a decline after August 2017. That is, TSA data from 2017 tracks well with 2016 data until the month of the hurricanes. The average difference for a given month between January and August 2017 and 2016 was 1,178 passengers, while the average monthly difference between September through December in the same years was a decrease of 86,194 passengers. This represents an average monthly decline of about 21 percent between 2017 and 2016. A similar pattern of findings is apparent from another data source on air passengers, the Autoridad de los Puertos de Puerto Rico. Using data from July 2013 to December 2017, a difference model, which controls for month and year effects, shows statistically significant average declines of 42 percent in the number of air passengers entering Puerto Rico and 29 percent in the number of passengers leaving Puerto Rico during the period after the hurricanes.

Because air passengers may include business travelers as well as government aid workers, and to better isolate the possible effect of the hurricanes on tourists specifically, we also examine data on cruise ship passengers from the Autoridad de los Puertos de Puerto Rico. As with the TSA and air passenger data, we can see that the 2017 numbers track fairly closely with the 2016 numbers until September 2017, when we see a large drop likely due to the hurricanes. Using data from July 2013 to December 2017, the same difference model shows statistically significant

[55] John Hopewell, "Hurricane Maria decimated the nation's only tropical rain forest outside Hawaii," *The Washington Post,* September 29, 2017.

average declines of 58 percent in the number of cruise ship passengers entering Puerto Rico and 52 percent in the number of cruise ships stopping in Puerto Rico ("cruise calls") in the post-storm months.

While HSOAC has presented data on declines in many different aspects of the visitor economy, including lodgings, airline passengers, and cruise ship passengers, there is not a comprehensive measure to estimate the number of tourists who did not come to Puerto Rico due to the hurricanes. HSOAC has an estimate of the total dollars that tourism contributed to the economy in 2016 from the World Travel and Tourism Council (World Travel and Tourism Council, 2017); however, it is impossible to know exactly what this number would have been in 2017 if the hurricanes had not happened.

Although the exact decline in the number of visitors to Puerto Rico due to the hurricanes is unknown, HSOAC uses the decline in the number of cruise ship passengers (58 percent) as a proxy to provide the largest reasonable number.[56] While cruise ship passengers may differ from other types of tourists that visit Puerto Rico, cruise ship tourism appears to be the part of tourism that decreased the most after the hurricanes. In light of the qualitative and anecdotal evidence of large damage to the sector, HSOAC assumes that all aspects of tourism decreased by this much.

To obtain an overall estimate of the economic activity affected by drops in visitation, HSOAC uses direct spending and total contribution estimates from the World Travel and Tourism Council for 2016.[57] These estimates include all spending on tourism for the entire economy. HSOAC then reduces the amount of revenue attributable to September to December by 58 percent each month. Because tourism is seasonal, HSOAC apportions 2016 total revenues to months using the number of cruise ship passengers from 2016.

Using these rough estimates, HSOAC calculates that the hurricanes cost the Puerto Rican tourism industry over $547 million in direct revenue and the Puerto Rican economy over $1.6 billion if direct and indirect benefits from the tourism industry are included. These numbers represent approximately 20 percent of total 2016 tourism revenues. Using instead the decline in the number of airline passengers entering Puerto Rico (42 percent) yields estimates of $396 million in direct revenue declines and $1.2 billion if direct and indirect benefit declines are included. Using the decline in hotel registrations (56 percent) produces estimates of $528 million in direct revenue declines and $1.55 billion in direct and indirect benefit declines.

These estimates reflect only the revenue lost to the Puerto Rico tourism industry from September – December 2017 due to the decline in the number of visitors to the Commonwealth.

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[56] Cruise ships generally dock in San Juan and HSOAC does not have good data on where cruise ship passengers travel to or how they spend their time while in Puerto Rico. HSOAC also does not have data on the geographic breakdown of where tourism dollars come from or what percent of total tourism dollars come from San Juan and the surrounding areas. Note, however, that around 90 percent of passengers who visit Puerto Rico fly into San Juan and that approximately 64 percent of lodging registrations (in facilities endorsed by PRTC) in 2017 were in the Metropolitana area (Puerto Rico Tourism Company, 2017a).

[57] Cruise ship passengers are likely the best proxy for tourists as few non-tourists travel on cruise ships.

They do not include the cost of any damage to tourism assets in the country, such as the cost of repairs to El Yunque National Forest, hotel properties, or any other tourist attractions. These estimates also do not include ongoing costs to the sector due to declines in visitors from January 2018 to the present. While conditions for tourism in the country are gradually improving, the effects of the hurricanes on the visitor economy will likely be felt for years to come. More comprehensive estimates can be calculated as updated data become available.

Manufacturing

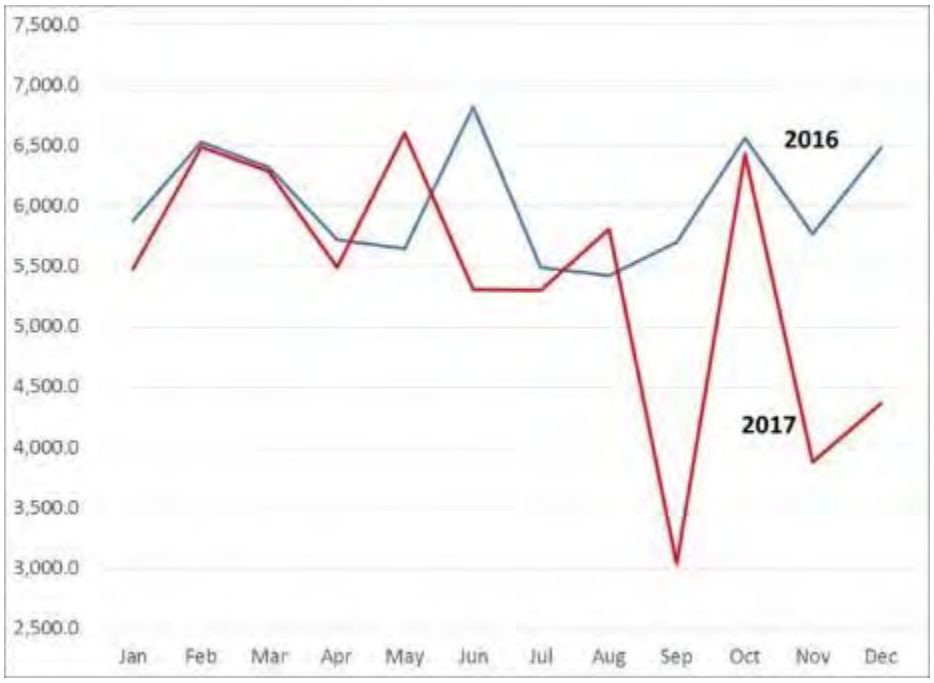
The best damage estimates to the manufacturing sector come from payroll employment data. Payroll employment in manufacturing dropped by an average of 1.27 percent in the months after the hurricane (using the difference model estimates). While informative, payroll employment tracks the number of employees who received pay from firms in a given industry, not the total output of that industry or sector. Declines in output may have been much steeper than declines in payroll employment if, for instance, employees were assisting in clean-up and rebuilding efforts and not producing products for sale. For instance, the chemical manufacturing sector, which includes pharmaceuticals, registered no average decline in employment; however, the disruption in production caused by Hurricane Maria has caused shortages of drugs and medical supplies, most notably IV bags, in CONUS.[58]

Trade

Using monthly import and export data from the Puerto Rico Institute of Statistics, HSOAC can use difference models to estimate post-storm effects (net of the recovery effort) to these indicators. Figure 5.11 and Figure 5.11. External Trade, Exports, 2016-2017, Millions of Dollarsshow total exports into and imports out, respectively, of Puerto Rico in millions of dollars for 2016 and 2017. Although there was clearly a sharp decline in trade in September due to the hurricanes, there seems to have been a rebound effect in October, perhaps as products that were not able to be shipped in September were able to move again. Imports continued to increase throughout the year, perhaps because of reconstruction efforts, while exports dipped back down in November.

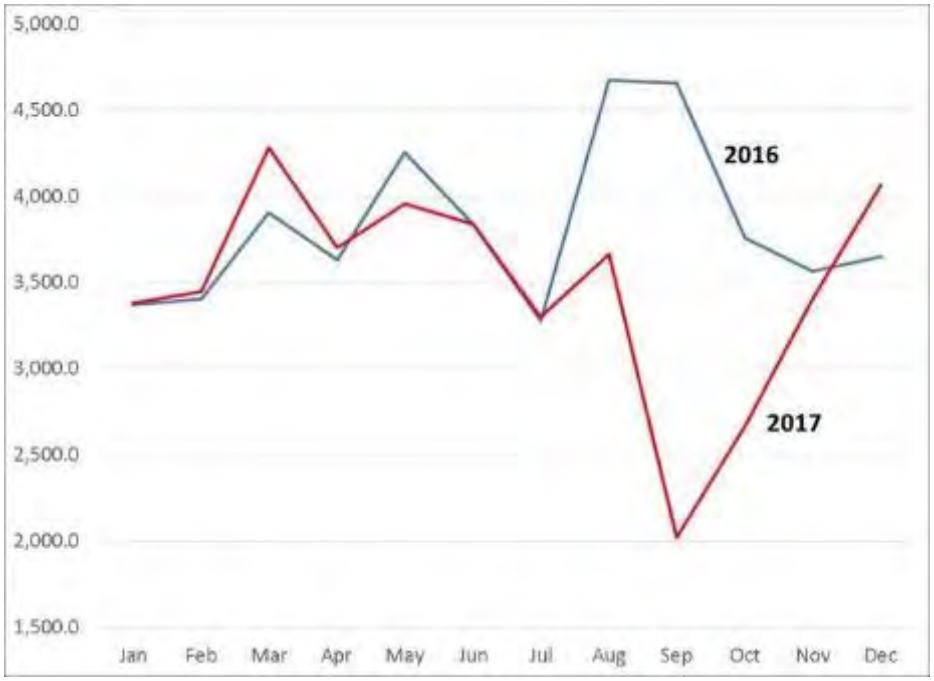
[58] https://www.cbsnews.com/news/iv-bags-in-short-supply-after-hurricane-maria-disrupted-production/

Figure 5.11. External Trade, Exports, 2016-2017, Millions of Dollars



Source: Puerto Rico Planning Board, Puerto Rico Institute of Statistics

Figure 5.12. External Trade, Imports, 2016-2017, Millions of dollars



Source: Puerto Rico Planning Board, Puerto Rico Institute of Statistics

Total dollars received from exports declined by 25 percent in the post-storm months. Although making up a much smaller percentage of exports, products sold outside the U.S. experienced a decline that was almost twice as steep (47 percent) as that of all products combined (25 percent). The decline in imports following the hurricane (17 percent) was smaller than the decline in exports, and, although still quite large, was not statistically significantly different from zero.

Agriculture

Agricultural damage were particularly severe, with nearly 80 percent of crop value destroyed (~$780 million) (Robles and Ferre-Sadurni, 2017) and animal mortality rates of 45-50 percent. Initial estimates from September 2017 show that, across the crops of milk/dairy, livestock, coffee, farinaceous foods, fruits, and vegetables and legumes, Hurricanes Irma and Maria resulted in a total estimated production loss of just over $227 million. Of this total, Irma accounted for an estimated $45 million in damage and Maria an estimated $182 million. Infrastructure losses, which are considered separately from the production losses of each crop and provided as a total for the entire sector, are estimated to be even more significant, totaling over $1.8 billion across the two storms, with Maria again comprising the bulk of this damage. The total combined damage thus exceed $2 billion.

Based on the value of estimated production losses, the hardest-hit crops were in the farinaceous category, which includes celery, sweet potato, dasheen, yam, plantain, bananas, cassava, tannian and breadfruit, among others. The hardest-hit food items in this category were plantains and bananas, suffering over $72 and $19 million in estimated damage across both storms, respectively, and collectively comprising 95 percent of the total damage to this food group. The plantain is a particularly important part of the Puerto Rican diet.

Fisheries and the ocean economy

The damage from Hurricanes Irma and Maria led to the inclusion of Puerto Rico in the fishery disaster declaration from the Department of Commerce on February 9, 2018, under the Interjurisdictional Fisheries Act and the Magnuson-Stevens Fishery Conservation and Management Act. The Declaration allows for Federal Emergency Management Agency Public Assistance (FEMA PA) to be used for fishery infrastructure. In addition, the National Oceanic and Atmospheric Administration (NOAA) was assigned additional funding that will be needed to complement the mitigation projects that will lead to a resilient fishery infrastructure beyond mitigation.

Hurricanes Irma and Maria caused the loss of seven out of eight fish aggregating devices (FADs), which were deployed north of San Juan Bay. FADs are free-floating or anchored structures that have traditionally been used by fisherman to attract fish. The Marine Ecology Division of Puerto Rico's Department of Natural Resources created the FADS with funding from

a U.S. Fish and Wildlife Sport Fish Restoration Program grant. According to NOAA, it will cost approximately $30,000 to replace each FAD.

Further damage includes the estimated loss of nearly 80 percent of the natural fishery infrastructure, which attenuates 97 percent of the initial strength of coastal storm surge responsible for damage and loss of life in coastal storm surge flooding. According to NOAA Fisheries Service, only 661,797 pounds of fish were caught in Puerto Rico 2017, compared to 3,738,919 pounds of fish in 2016 and 1,511,296 pounds of fish in 2015.

Nonprofit

Non-profit firms have been cited as the first responders following Hurricanes Irma and Maria due to the effective shut-down of the Puerto Rican government immediately following the storms (Levine, 2017).

Post-hurricane conditions

At the time of this writing, many economic sectors (e.g., tourism, trade) have not returned to pre-storm economic production levels, though there are emerging signs of improvement such as upticks in traveler counts and value of exports (Department of Labor and Human Resources, 2017). However, even when accounting for seasonal patterns and the influx of recovery funds and employment opportunities, employment and wages remain lower than they were pre-storm (Bureau of Labor Statistics, 2018g). High rates of poverty and unemployment, coupled with continued outmigration of working-age adults at the time of writing, are expected to present continued challenges to economic recovery. Furthermore, tax legislation passed in December of 2017 (Public Law No. 115-97) imposed a 10.5 percent tax on income attributable to intellectual property for CONUS firms operating in the Commonwealth. The recent Tax Reform Act of 2018 provides a further barrier to investment in Puerto Rico's manufacturing sector and may cause firms to relocate to CONUS. As of 2017, Puerto Rico was still considered a tax-advantaged jurisdiction over the rest of the United States and other Caribbean economies. Since the passage of the 2018 tax reform, however, this is no longer the case. Governor Ricardo Rosselló said the enacted tax reform legislation is "a devastating blow for Puerto Rico, in our greatest time of need"(Mazzei, 2017). Puerto Rico remains under FOMB oversight, and continued fiscal pressures will strain the Commonwealth's ability to operate and maintain repaired and rebuilt infrastructure (Department of Labor and Human Resources, 2017; Bureau of Labor Statistics, 2018g).

Remaining needs and recovery priorities

While Hurricanes Irma and Maria were extremely damaging to the economy of Puerto Rico, pre-storm conditions, including but not limited to the high costs of doing business; continued deficit financing resulting in the bankruptcy-type proceedings of 2016; the creation of the FOMB

following the passage of PROMESA; and certain Federal policies that put pressure on the government and economy of the Commonwealth have contributed to a reinforcing cycle of economic and population decline. In addition, high rates of poverty and unemployment, coupled with increasing outmigration of skilled workers, are expected to present challenges to recovery.

At the municipal level, many of the 78 municipalities also have very limited resources and capacity to wage an effective recovery. FEMA Mitigation has stated that 19 of the municipalities do not have a hazard mitigation plan, which makes them ineligible for certain recovery dollars. FEMA's Community Planning and Capacity Building Sector has reported that 45 of the municipalities may have to shut down or consolidate with others.

Past decisions and exogenous events have combined to place the Commonwealth in the difficult position of trading off between the following:

- austerity measures which can help balance the budget and put the fiscal stance of the government on a more sustainable path that is likely to support long-run economic growth, but also likely to depress growth in the short run; and
- structural changes to lower the cost of locating, investing, and doing business in Puerto Rico, possibly lowering revenues and worsening the fiscal situation in the short-run.

In some limited cases, there may be "free lunch" solutions that can either improve growth and fiscal positions, at least in the long term, or at least not significantly worsen conditions for one and improve the other. However, even in these cases, there will likely be winners and losers associated with any course of action.

To succeed, the Government of Puerto Rico, the FOMB, and the Federal Government must work together to ensure a balance between real economic recovery in the short term, economic growth in the medium to long run, and fiscal responsibility in the post-storm period. Continuation of controllable pre-storm policies that artificially increase labor and capital costs will not incentivize the growth desired following the storms, but changing these conditions will require vision, leadership, and, likely, political compromise.

Short-term

In the shorter term, economic recovery depends largely on the recovery of the other sectors, as they are typically demand- and supply-side factors that ultimately determine economic outcomes (in conjunction with the decisions of millions of autonomous individuals and firms acting largely in their own interests).

Longer-term

Recovery of the Puerto Rico economy post-Irma and Maria will involve not only rebuilding the public and private infrastructure, supply chains, human capital, and other contributors to economic output, but also reversing the pre-storm trends. In particular, to reverse the negative economic growth and associated outmigration experienced since the phaseout of section 936 manufacturing tax advantages in 2006, the recession that hit both the CONUS and Puerto Rico

just afterward, and the deteriorating fiscal situation of the Commonwealth that resulted in PROMESA and the establishment of the FOMB, steps must be taken to change the economic environment. Based on this analysis, policies related to the following broad areas should be considered to encourage growth:

- Increase the attractiveness of doing business in Puerto Rico by lowering the costs of doing business, including both financial and non-financial costs, and stemming the flow of outmigration
- Increase the formal labor force participation rate by reducing or removing disincentives for formal work
- Broaden the tax base and increase the fiscal and economic resiliency of the Commonwealth through a flattening of the tax structure and lower dependence on particular tax exemptions
- Increase fiscal discipline to ensure a sustainable and right-sized public sector.

Tackling these broad areas of interest should increase the probability that Puerto Rico can achieve economic growth that results in a more sustainable and resilient economy. To be certain, the various courses of action within each of these categories are likely to increase the welfare of some Puerto Ricans and decrease that of others; similarly, costs and benefits may be differentially distributed across the short, medium, and long runs. Such distributional issues, and how to best approach them, are ultimately decided using the political system. Given the complexity of economic systems, the dependence of outcomes on the policy specifics, and the presence of unknown future events, we cannot predict future results of any rebuilding strategies or policy changes with certainty. But the data show that, without changes in the costs of doing business, in the attractiveness of living and working in Puerto Rico, and in the way that the Puerto Rico government manages its finances, then the combined result of pre-storm trends and the destruction associated with Irma and Maria will likely increase emigration and hasten the rate of negative economic growth once the spending injections associated with the recovery effort have ceased.

6. People and Communities of Puerto Rico

Overview

This chapter focuses on the population and municipalities of Puerto Rico and includes damage and needs assessments developed by the HSOAC Community Planning and Capacity Building (CPCB) and Municipalities Sector Teams. The chapter is divided into two subsections: (a) Population of Puerto Rico and (b) Municipal governance. The first subsection describes the people and communities of the Government of Puerto Rico and introduces the demographics, population trends, and vulnerable communities; and the second subsection discusses governance structures that impacted pre-storm conditions and the road to recovery for Puerto Ricans. "Damage" associated with the people and communities of Puerto Rico is defined uniquely for each subsection: Damage experienced by the population of Puerto Rico is also discussed in the other chapters of this report, according to specific sectors. Thus, the Population of Puerto Rico subsection focuses on the experiences of those populations disproportionately affected by disasters (e.g., the elderly, children, and residents of informal housing). The Municipal governance subsection describes the impact that Hurricanes Irma and Maria had on the ability of Puerto Rico's municipalities to govern and deliver services to their constituents. Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Municipalities" and "CPCB" Sector Reports.

Data sources and methods

Population of Puerto Rico

Data sources

Table 6.1 shows the data sources used to assess the damage inflicted on Puerto Rico's communities and populations by the recent hurricanes, as well as their needs going forward. A brief description of the available information is also provided.

Table 6.1. Summary of Data Sources for Communities and Populations

Dataset	Source	Date Range	Data Description
American Community Survey (ACS)	Census Bureau	5 year estimates 2012-2016	Best source of data on pre-storm population characteristics and migration
Community conditions assessment	FEMA	Updated periodically	An index constructed from a range of population-generalizable data sources describing pre-disaster population social and

Dataset	Source	Date Range	Data Description
			economic vulnerability; pre-disaster municipality capacity vulnerability; pre-disaster environmental hazards risk vulnerability; and post-disaster assessment of (housing) damage.
Social Vulnerability Index (SoVI)	Puerto Rico Disaster Recovery Action Plan (Government of Puerto Rico, 2018a)	2012-2016	The SoVI was estimated using ACS indicators identified in previously published previous versions of the index (Flanagan, 2011)
Media reports	FEMA	10/17 – 3/18	Mix of English and Spanish language newspaper and television reports; collated by FEMA JFO
Subject Matter Expert/Community Interviews	HSOAC, NGO	4/18 – 5/18	Includes interviews with 34 SMEs and leaders from government, academic, non-profit and community-based organizations and interviews with 8 community members.
Puerto Rican Community focus groups	HSOAC, NGO	2/18 – 5/18	Includes detailed transcripts from NGO-led focus group discussions in 20 locations supervised by HSOAC and notes from focus group discussions conducted independently by NGO in 7 locations
Out migrant focus groups	HSOAC, University	4/18	Includes detailed transcripts from four focus groups; limited to two Florida locations; conducted by NGO with HSOAC oversight
Migrant Intake Forms for NYC	NYDIS		Includes zipcode of current and damaged address, as well as a household roster detailing the age, gender, and household composition of evacuee households
USPS Active Resident Listing	Institute of Statistics, Puerto Rico	December 2017- April 2017	Monthly counts of the number of residences actively receiving mail by zip code (households are categorized as inactive after 90 days of failing to receive mail)
Individual Assistance Data	FEMA	September 2017 – May 2017	Zip code of current and damaged address, as well as reported household income
Projected Population Estimates for the Bureau of Labor Statistics	Institute of Statistics, Puerto Rico	July 2000-December 2018	Includes the birth, death and migration data used to produce monthly projections
Public workshops	HSOAC	June 2018	

Methods

HSOAC used a primarily qualitative process for primary data collection and quantitative secondary data analysis (e.g., especially the ACS) to assess conditions of Puerto Rican communities and populations in the periods before, during, and after the recent hurricanes. In particular, HSOAC collected and analyzed data from subject matter expert (SME) and community member/leader interviews, community focus groups conducted with Puerto Rican residents and people who have left Puerto Rico for Florida, and media reports. Approximately 34 SME interviews have been conducted with people who represent organizations or communities that provide, assess, or receive disaster management and planning/preparedness services, including government, academic, non-profit and private sector stakeholders not covered in other data collection methods. Twenty focus group discussions were conducted by a NGO overseen by HSOAC in various Puerto Rican municipalities with communities that were highly impacted by the hurricanes. The groups ranged in size from eight to 12 individuals and consisted of equal numbers of males and females. The group members were selected by HSOAC using input on community characteristics from recovery stakeholders and taking into account the outreach capabilities of the NGO conducting the focus group discussions.

HSOAC has also used a mixed qualitative and quantitative approach to assess the shift in the Puerto Rican population that has occurred since the recent hurricanes and the experiences of individuals who have left Puerto Rico since their arrival on the mainland. The qualitative contribution is largely derived from four focus groups conducted in southern and central Florida in the spring of 2018. The quantitative contribution entails an evaluation of the impact of the storm on the projection of the size and geographical distribution of the Puerto Rican Population. From a quantitative perspective, HSOAC has compiled population projections made from both before and after the hurricanes to assess the range of projected population estimates. A critical factor determining potential change in the size and geographic distribution of the population (across municipalities) is migration, including both migration from Puerto Rico to the continental US and internal migration within Puerto Rico. HSOAC has compiled estimates of net migration (i.e., the difference between outmigration and immigration) to help inform the assessment of future population growth and redistribution and has also acquired primary data at the municipal level on migration within Puerto Rico.. These data include data from the US Postal Service (USPS) on an indicator of population displacement (i.e., change in active residences) provided by the Puerto Rico Institute of Statistics. They also include data from the FEMA Individual Assistance program on the location of the current and damaged residence of applicants, as well as their household income. Finally, we have identified data from a non-governmental evacuee assistance organization (New York Disaster Interfaith Services) on demographic characteristics (age, gender, household structure, and English language facility).

Data gaps, assumptions, and uncertainties

The qualitative data presented here cannot be used to draw conclusions that generalize to the broader population. For example, accounts of the experiences of focus group participants who left Puerto Rico after the hurricanes reflect their unique perspectives and provide insight into the specific types of problems that some encountered. However, the extent to which these experiences and perspectives were shared by the broader population of those who left Puerto Rico to go to the CONUS is unknown. A deliberate attempt was made to select communities from across Puerto Rico's major regions for focus group discussions of the hurricanes' impact and the recovery needs of various population groups. However, the selection sample was biased in favor of rural and relatively vulnerable communities. Also, focus group discussions were not held in all regions of the Commonwealth, e.g., the northeast coast. Furthermore, it is uncertain to what extent the views of focus group participants represent those of the communities, municipalities, or regions in which they reside. Although the media accounts used for illustrative purposes in this report were taken from a range of Puerto Rican and mainland—as well as Spanish and English language—publications, the selection strategy used by FEMA to collect these reports favors print over broadcast media, and the stories themselves have not been verified for accuracy or representativeness. Social media accounts were not consulted for this report.

The quantitative data sources used to estimate the numbers of individuals who left Puerto Rico after the hurricanes also have limitations. No official statistics have been released on the number or demographic characteristics of those who left, and the Census Bureau is not scheduled to release data on the resident population of Puerto Rico until December 2018. Thus, researchers have estimated the numbers of people who left after the hurricanes using alternative methods, each of which has its own strengths and weaknesses. For example, USPS active residence data may be the best systematically collected data from which the total current number of households in Puerto Rico can be estimated. However, a considerable proportion of the residences (especially in highly rural areas) have no physical addresses (residents use P.O. boxes). Similarly, HSOAC has compiled estimates of the number of those who left, those who enterest, and/or net migration flow using indirect estimation techniques and administrative data (e.g., port of exit data, school enrollment data, individual assistance applications to FEMA, USPS change-of-address data). Population and migration estimates derived using these data raise well established concerns about gaps in coverage and data quality detailed elsewhere (Plyer, Bonaguro and Hodges, 2010).

Municipalities

Data sources

Comprehensive first-hand municipal-level data on critical issues such as the services that municipalities deliver, public inventories of assets owned (e.g., police and firefighting equipment), and Key Performance Indicators (KPIs) (e.g., service calls answered and citizens

served) are not maintained in any central location in Puerto Rico. Given the substantial gaps in existing data regarding basic aspects of municipal government and governance, HSOAC undertook an ambitious data collection effort with the goal of reaching every municipal government in Puerto Rico. This undertaking, described below, includes gathering information from mayors and municipalities by working with the University of Puerto Rico (UPR) and the International City/County Managers Association (ICMA). HSOAC relied on four primary categories of data for this assessment:

1. **Quantitative Data**: HSOAC conducted site visits to each of Puerto Rico's 78 municipalities to deliver a standardized data collection instrument developed by the International City County Management Association (ICMA) in consultation with HSOAC, FEMA, and UPR. The survey includes questions about the municipality's capacity to provide services, how they are structured and operate, and the damage they incurred during the hurricanes. Each site visit was conducted by an interdisciplinary team led by professional city and county management staff identified by ICMA, or by a UPR professor. The objective of the site visits was to develop baseline data at the individual municipality level on municipal finances, capacity (including human capital), service delivery, as well as hurricane impacts and outstanding needs. As of June 22, 2018, HSOAC has analyzed survey data from 73 municipalities, as is currently in the process of updating the sample with data from the remaining municipalities. HSOAC has also analyzed municipal financial statements, budget submissions, and other available data concerning municipal operations and governance.
2. **Qualitative information**: HSOAC worked with the Government of Puerto Rico[59] to invite all of Puerto Rico's municipalities to participate in a series of twelve regional roundtables. Municipalities were grouped geographically, and each roundtable was structured to include a total of 5 to 7 municipalities. Roundtable discussions were moderated by a senior HSOAC researcher and by senior faculty from UPR using a scripted discussion guide, and HSOAC staff and UPR students took notes on the proceedings. Following the roundtables, HSOAC and UPR reviewed the notes to identify key findings and recurring and unique themes. The roundtable discussions had three main objectives:
    a. Provide municipalities with an opportunity to share their perspective on their vision for recovery for their municipalities and for Puerto Rico as a whole;
    b. Identify specific goals, strategic objectives, and potential courses of action related to achieving recovery in their municipalities; and,
    c. Discuss potential challenges and barriers to recovery.
3. **Subject matter experts**: HSOAC also consulted with subject matter experts, both individually and in groups, regarding municipal governance issues in Puerto Rico. HSOAC convened a group of UPR professors from the Schools of Planning, Public Administration, and Law who have studied municipal governance issues. HSOAC asked these subject matter experts to help identify sources of data, review draft data collection

[59] HSOAC owes a debt of gratitude to Omar Negrón, the Governor's Municipal Affairs Advisor, for his personal efforts to help convene municipalities and organize the roundtables.

instruments, assist with analysis, and suggest courses of inquiry in the assessment. HSOAC met weekly with UPR subject matter experts who provided extensive advice and data, and historical context and contributed a number of white papers. In addition, HSOAC met with subject matter experts on municipal issues from the Planning Board, the Government of Puerto Rico's Municipal Affairs Office, and other key stakeholders in Puerto Rico, including Abre Puerto Rico and Estudios Tecnicos.

4. **Open-source information**: HSOAC reviewed open-source information on municipal governance in Puerto Rico, including financial information, government reports, and previously conducted analysis. Key sources of data that HSOAC examined include Puerto Rican government databases such as DTOP (Transportation), DTRH (Labor and Human Resources), DRNA (Natural Resources), OCAM (Municipal Issues), information provided by the Foundation for Puerto Rico, and other open-source applications.

Methods

As previously noted, no single data repository exists for detailed information regarding Puerto Rico's municipalities' services and key assets. HSOAC has employed a variety of methods to create an organized repository of publicly-available municipal-level data, including scraping it from municipality-associated websites, extracting and/or inferring it from documents and larger data sets, and collecting primary data through interviews, regional roundtables, and site visits.

Quantitative Analysis

Our quantitative analysis team focused on descriptive data collected using the assessment tool and municipality financial statement data associated with pre-storm conditions, damage, and needs. We analyzed the trends for key variables for all municipalities combined, as well as the distribution of those variables using geospatial analysis. We also produced frequency tabulations for discrete variables, such as the provision of key services. In some cases, to better understand the data and uncover potential relationships, we conducted bivariate correlations of key variables.

Qualitative Analysis

HSOAC collected qualitative information during the roundtables with mayors and municipal staff (in the form of meeting notes taken by HSOAC and UPR personnel) and during the ICMA-led site visits (in the form of free-text fields in the ICMA instrument). Using triangulation of results from different sources, HSOAC conducted a thematic analysis of roundtable notes to identify the key themes that emerged in each separate roundtable and aggregated themes across roundtables to identify areas of consensus. We used a similar process to analyze the free-text fields from data collected through ICMA's municipal site visit assessment instrument. We also performed a content analysis for this qualitative data using specialized software.

Primary Data Coverage and Representativeness

HSOAC's goal was to give all 78 municipalities in Puerto Rico the opportunity to participate in this data collection exercise. For the 12 regional roundtables we invited representatives from all

the municipalities from that region, and had 28 mayors attend and 26 other municipalities send representatives island-wide.[60] Although mayors or their representatives from all twelve regions attended the roundtables, the overall participation rate for *individual* municipalities was 69 percent. Municipalities that did not participate have, on average, less revenues per capita, a higher unemployment rate, are more populated, and have mayors affiliated with the PNP (see

Table 6.2). However, none of these differences are large enough to be statistically significant. Across a wide range of indicators—including employees per capita, long-term debt per capita, share of intergovernmental transfer of total revenues in the General Fund, median household income, percentage of the population below the poverty line and the percentage of the population with a high school degree or higher—municipalities that participated in the roundtables have similar attributes to those did not participate.

Regarding the assessments, our teams have visited all 78 municipalities in Puerto Rico as of June 27. However, because of the lag in cleaning and uploading data only information from 73 municipalities was available for analysis at the time of writing this report. The five municipalities not included in the analysis are not statistically different across these key indicators from the 73 municipalities included in the analysis.

Figure 6.1 summarizes the geographical coverage of our primary collection sample. Between the roundtables and the site visits, we have collected and analyzed primary information for 75 municipalities as of this report. Because the municipalities participating in this study, either in roundtables, in the ICMA assessments, or in both, are not statistically different from those that do not, we regard the conclusions derived from our primary data collection as valid for assessing the situation prior to and after the hurricanes for all municipalities in Puerto Rico.

[60] The 24 municipalities that did not send any representative to the roundtables are Adjuntas, Aguada, Aguadilla, Aibonito, Arecibo, Arroyo, Barranquitas, Bayamón, Caguas, Carolina, Cidra, Guayama, Gurabo, Isabela, Juana Díaz, Las Marías, Luquillo, Maricao, Quebradillas, Rincón, Sabana Grande, San Sebastián, Toa Baja and Vieques.

Table 6.2. Comparison of Sample Mean Values of Selected Variables

	Roundtables			ICMA assessments		
	Mean values for not participating municipal-lities	Mean values for participating municipal-lities	p-value of difference in mean values (t-test)	Mean values for excluded municipal-lities	Mean values for included municipal-lities	p-value of difference in mean values (t-test)
	N=24	N=54		N=5	N=73	
	(1)	(2)	(1) vs (2)	(3)	(4)	(3) vs (4)
% PPD Party	45.8%	64.8%	0.12	40.0%	60.3%	0.38
Years Major is in Office	11.63	10.52	0.56	8.00	11.05	0.39
Municipal Employees per 1,000 residents 1/	17.4	17.6	0.96	25.8	17.0	0.10
Revenues per capita in the GF 2/	$ 534.3	$ 708.1	0.34	$ 821.6	$ 643.2	0.60
Long-Term Debt per Capita 2/	$ 1,135.7	$ 1,134.8	1.00	$ 1,508.2	$ 1,109.5	0.21
Intergov. Transfers / Revenues in GF 2/	40.2%	40.2%	0.99	39.1%	40.3%	0.90
Average population 3/	54,039	44,979	0.50	89,334	44,919	0.08
Average land area (sq. miles) 4/	44.1	43.8	0.95	45.4	43.8	0.88
Average population per sq. mile	1,335.5	1,208.6	0.70	1956.8	1199.1	0.21
Median Household Income 5/	$ 18,132.7	$ 18,158.9	0.98	$ 16,793.0	$ 18,243.9	0.50
% Below Poverty Line 5/	48.4%	48.8%	0.83	49.7%	48.6%	0.77
Unemployment Rate	12.8%	11.8%	0.24	13.3%	12.0%	0.39
% High School Degree or Higher 5/	70.0%	70.2%	0.89	67.5%	70.3%	0.33

Source: HSOAC analysis of multiple data sources, a subset of which are listed below. Assessment data from Adjuntas, Florida, Las Marías, San Juan y Vieques has been collected but not included for the analysis in the current report.
1/ Office of the Commission for Municipal Matters (OCAM). Numbers are for 2016
2/ Source: Foundation For Puerto Rico. Data corresponds to FY2014
3/ Data: suburbanstats.org - Demographics for 2017
4/ Source: welcome.topuertorico.org
5/ Source: Census 2010

Figure 6.1. Municipal Participation in Roundtables and Onsite Assessments

Source: HSOAC analysis. Assessment data from Adjuntas, Florida, Las Marías, San Juan y Vieques has been collected but not included for the analysis in the current report.

Data gaps, assumptions, and uncertainties

This assessment is based on the best data available to HSOAC at the time of writing. While the combined data from our roundtables and site visits that we have analyzed to date captures roughly 95 percent of the municipalities across the Government of Puerto Rico, it is nevertheless possible that the remaining municipalities could vary from the municipalities for which data are included in this assessment, affecting the results of the analysis.

The compressed deadlines of this assessment had an impact on how data were collected. Specifically, individual roundtables and site visits were conducted simultaneously, meaning a larger number of personnel were required to run roundtables and conduct each of the municipal site visits than may have ordinarily been included; this is not a systematic flaw, per se, but as the number of personnel conducting these efforts increases, the potential for variances in how these activities are conducted also increases, which could potentially impact how data are collected. The data collected may also contain inaccuracies due to recording and reporting errors.

The data collection effort that HSOAC has led appears to be the first to develop a baseline for municipal operations and service delivery in Puerto Rico. Because the data was collected after the hurricanes, it is difficult to assess how the services we surveyed were impacted by the disaster without including qualitative information—hence our efforts to collect both quantitative and qualitative data on service delivery. While we believe that these efforts represent the most comprehensive assessment to date, it could be beneficial to periodically reprise this data collection in order to measure how service delivery changes over time.

Lastly, as noted throughout this assessment, HSOAC could collect information only about whether certain services existed or were offered, but was not able to collect information from

municipal governments or from service recipients—that is, citizens—regarding the quality of the services being delivered. This kind of performance indicator information would have significantly enriched the assessment, but it does not generally exist in Puerto Rico currently. That is a key data gap that the Government of Puerto Rico could consider addressing in the future.

The assessment analysis presented here is at the municipal level. HSOAC was not able to conduct analysis of sub-groups of municipalities with common characteristics, such as size or geographic location, for this version of the assessment. As data collection is completed, HSOAC will conduct sub-group analysis, which may reveal differences in how municipalities were impacted by or are recovering from Hurricanes Irma and Maria.

The most significant limitation of this chapter is the same limitation identified earlier: namely, much of the information on which the assessment is based was provided by mayors and municipal staff, and therefore represents the views of these individuals and is limited by their knowledge of the issues covered in the assessment. Accounts provided by these individuals could be biased by any number of factors, or simply in error, without the individual providing the information being aware. Questions covering basic matters such as whether a service was offered by a municipality are less likely subject to error or subjectivity than questions regarding the best steps forward for recovery; regardless, the latter is of high interest to policy makers.

Population of Puerto Rico

Background

As of July 2017, just prior to Hurricanes Irma and Maria, approximately 3.3 million people resided in Puerto Rico (U.S. Census Bureau American Fact Finder, 2016a). The most populous metropolitan area in Puerto Rico is the capital, San Juan, which is located along the northeastern coast of the main island. San Juan was home to about 347,000 residents in 2016 (U.S. Census Bureau American Fact Finder, 2016b). In 2016, about 14 percent of Puerto Rico's population were young adults (15–24 years), 38 percent were prime-working-age adults (25–54 years), and roughly 23 percent were older than 60 years old (U.S. Census Bureau, 2018a). Elderly residents constitute a higher proportion of the population of Puerto Rico than anywhere else in the Caribbean or Latin America except for the U.S. Virgin Islands (Wyss, 2017). By comparison, roughly 19 percent of the U.S. population is over 60.

The great majority of Puerto Ricans are Hispanic/Latino and speak Spanish at home. Over 98 percent of Puerto Ricans self-identify as ethnically Hispanic/Latino; roughly 69 percent self-identify as white, 9 percent as black or African-American, and 7 percent as two or more races (U.S. Census Bureau, 2018a). Spanish and English are both official languages in Puerto Rico. However, according to 2016 U.S. Census data, 78 percent reported speaking English "less than

very well;" by comparison, over 94 percent of Puerto Ricans reported speaking Spanish at home (U.S. Census Bureau, 2018a).

The population of Puerto Rico is also characterized by high rates of poverty. In 2016, the median household income in the Government of Puerto Rico was $20,078. Forty-five percent of residents had an annual income below the federal poverty level, with high rates of poverty among those under 18 (57 percent) and those over 65 (approximately 40 percent). Poverty rates in Puerto Rico are higher than in any U.S. state, and twice as high as in the poorest state, Mississippi (U.S. Census Bureau, 2016, Table S1901).

Populations at high risk of disaster impacts

Puerto Rico's demographic, geographic, and economic profiles render many of its residents vulnerable, that is, uniquely susceptible to a disaster event. Vulnerability can be defined as "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a hazard" (Blaikie et al., 2014). Numerous theoretical models exist for identifying populations disproportionately affected by disasters (PDADs). However, a recent review identified several critical domains of vulnerability to disaster that were common to these models: social and economic; institutional; infrastructure; and environmental (Cutter, 2016). For example, social and economic factors leading to vulnerability can include issues such as economic disadvantage (e.g., poverty, low income, food insecurity, unemployment, lack of health insurance, poor quality housing, an absence of a vehicle); poor human capital (e.g., illiteracy, poor educational attainment, limited occupational skills); poor social capital (e.g., social networks, social cohesion); and political marginalization (e.g., economic inequality and racial segregation).

Social and economic vulnerability often interacts with environmental and institutional or capacity-related vulnerability. For example, geographically mountainous and rural areas are often removed from critical transportation and communication infrastructures and often experience high rates of poverty and poor education. PDADs have fewer resources to prepare for, respond to, and recover from disaster, and are more likely to live in areas exposed to high hazards. Thus, when disasters strike, they may not be able to obtain access to medical care, food, shelter, and other basic needs. Several critical populations were identified as especially susceptible to disasters within a Puerto Rican context:

- Elderly persons
- Female caregivers
- Children and youth
- Residents of informal housing (housing built without permits)
- Rural residents

Pre-hurricane conditions

Impact of urbanization and environmental degradation

Urbanization in areas that are at high risk of infrastructure failure (e.g., flood-prone, landslide-prone) and unplanned urban sprawl has increased the vulnerability of Caribbean islands to natural disasters in certain respects. Rapid changes to urban land cover and the consequent loss of soil capacity to absorb rainfall, combined with poor maintenance of urban drainage, contribute to increased runoff and associated urban floods, which were also frequent before the hurricanes (Lopez-Marrero and Tschakert, 2011).

Densely populated communities can provide a high quality of life and an environment that is resilient to disasters. For example, an interviewee from an NGO focused on youth socioeconomic development noted that, of the NGO's 13 urban youth centers across the island, those located in urban areas reopened much more quickly after the hurricanes than did sites in rural areas due to their ability to gain access to power and water more quickly. This early reopening provided critical support for urban parents anxious to return to work, while rural families relying on the organization's child care services had to find alternative sources of support for a longer period of time.

However, in Puerto Rico, urbanization has often been accompanied by unplanned and spontaneous settlement. For example, many urban, low-income, coastal communities developed in response to employment opportunities in the sugar industry during the early 1900s. Such communities face a higher infrastructure investment per capita because of the need for additional miles of paved roads and utility services. In addition, a higher amount of impermeable surface per capita contributes to flooding. Many of the residents of these communities live in insecure houses that cannot withstand the effects of floods and hurricanes, primarily because residents lack the resources to improve their housing conditions or do not have secure land tenure, which is a requirement for purchasing insurance. Residents' lack of secure land tenure and resultant inability to purchase insurance limits their incentive to make structural improvements to their houses (Lopez-Marrero and Tschakert, 2011). Besides a lack of quality housing and urban services, negative social characteristics associated with low density "urban sprawl" in Puerto Rico include discrimination and inequality and high rates of unemployment, violence, and crime (Lopez-Marrero and Tschakert, 2011).

Puerto Rico also faces the challenge of man-made environmental degradation, whose effects were exacerbated by the recent hurricanes. The Río Grande de Arecibo, which flows into the highlands from the northwestern municipality of Arecibo, has been polluted at multiple points along its route (Newkirk, 2017). In addition, Puerto Rico has 23 Superfund sites, which the EPA has designated as polluted sites that need to be cleaned up and removed, because they are at high risk of contaminating soil and groundwater. For over half a century, the U.S. military used the small island of Vieques, nine miles off the coast of the main island, as a bomb-test site, causing widespread contamination. In the southern coastal town of Guayama, uncovered coal ash

deposits are located adjacent to a low-income community of 45,000 people. Reportedly, this ash pile contains heavy metals like arsenic, mercury, and chromium (Atkin, 2017). During the last decade, Puerto Rico's environmental problems have worsened because of the economic crisis. For example, local governments claim they lack the funds to follow orders from the EPA to close overflowing landfills ("Puerto Rico struggles with massive environmental crisis," 2017). These factors are described in greater detail in the Health, Social Services, and Education; Natural Resources; and Water chapters of this report.

Populations disproportionately affected by disaster

Elderly

Even before Hurricanes Irma and Maria struck Puerto Rico, the Commonwealth's population was aging at a rapid pace. Due to a decade of recession and an unemployment rate of ten percent, many young people sought work on the U.S. mainland. According to the Government of Puerto Rico, in 2016, 23.3 percent of the population were over the age of 60, a proportion that is higher than anywhere else in the Caribbean or Latin America, except for the U.S. Virgin Islands (Wyss, 2017). Participants from a focus group on resilient communities in Mayaguez shared that "[their] community is primarily elderly individuals and those who had delicate houses were recommended to evacuate and helped secure their houses." Elderly individuals may not have the physical, emotional, social, or economic resources needed to leave Puerto Rico or improve their situations there, making them less likely to recover from the disaster in the near term (U.S. Census Bureau, 2017a; Kaiser Family Foundation, 2016; Kaiser Family Foundation, 2017). Participants from a focus group also noted that some elderly residents did not want to leave their homes: "I have my grandparents on my mom's side … they get to a certain age and don't want to listen to anyone. I tried to get my grandmother to come home with me but she did not want to at all, she lived in Guaynabo and she [did] not want to leave. So we prepared her house as she wanted and as safe as possible so nothing would happen to her."

Female caregivers

Puerto Rican women have traditionally been the principal caregivers within the family, as well as important sources of income. As such, they may bear a greater burden during times of disaster. However, as a lecturer from the University of Manchester explained, local gender roles and norms must be considered when initiating recovery plans after disasters. For example, administering financial assistance to women within a household—due to their perceived vulnerability—might undermine gender norms and cause strife "if the man is the provider."[61]

[61] Interview with a lecturer from Univeristy of Manchester; March 2018

Children and youth

Young children are another at-risk population. The Census Bureau estimated that more than half (53.7%) of children (under the age of 18) are part of families whose household income is below the poverty level (U.S. Census Bureau, 2016, Table C17001A). Four critical areas of support on which many Puerto Rican children have depended include the following:

- food assistance and security (prior to the hurricanes, Puerto Rico imported 85 percent of its food, making food security tenuous)
- housing (prior to Hurricane Maria, 31 percent of Puerto Rican children lived in households that spent at least one-third of their income on housing)
- health and medical care (as of June 2015, almost half of Puerto Rico's population was enrolled in Medicaid or the Children's Health Insurance Program)
- early education (35,093 young Puerto Ricans were educated in government child care centers, many of which will need to be rebuilt due to the recent hurricanes) (Novoa, 2017).

Prior to Hurricane Maria, vulnerabilities or shortcomings in Puerto Rico's public education system—related to the overarching fiscal crisis—had been cited. As a result, Puerto Rican families with the financial means to do so had begun leaving to seek better educational opportunities for their children elsewhere. This practice was hastened following the hurricane on September 20, 2017 (Strauss, 2017). Details on these factors are available in the Health, Social Services, and Education chapter of this report.

Residents of informal housing

People living in informal housing, or housing built without permits, have constituted a large segment of Puerto Rico's population. Informal housing is particularly susceptible to hurricane damage. According to the Commonwealth government, informal housing accounts for as much as half of Puerto Rico's housing (roughly one million dwellings). Although these houses range in quality and size, most were not constructed in accordance with building codes (Viglucci, 2018). Also, informal housing tends to be established in precarious areas. For example, the municipality of Toa Baja and San Isidro in San Juan, both of which are considered squatter neighborhoods, are within mapped flood zones. Some areas in the mountainous Jayuya, also considered squatter neighborhoods, were known to be vulnerable to mudslides. Despite the well-known risks, government policies and community actions did not focus on reducing potential problems. "Before the emergency, it was something we needed to do; now it's a more ambitious project," said Puerto Rico Housing Secretary Fernando Gil. (Woellert, 2017). More information on informal housing is available in the Housing chapter of this report.

Rural residents

Rural, mountainous areas of the Government of Puerto Ricohave historically faced more economic, demographic, and disaster recovery challenges than have coastal urban areas. For example, a focus group participant from Rio Grande described factors that prevent rural residents

from properly preparing for disasters like Maria: "The requirements of governmental and private agencies do not help those who are vulnerable. Some of these people live far from locations where help is served and agencies lack knowledge of them. The government and agencies lack knowledge of who they are and where these people are found, for which they are not able to provide them with the necessary help, even if they live close to town hall."

Utuado serves as an example of a rural community whose residents faced challenges prior to the storm. Even well before Hurricane Maria, Utuado's main economic activities, agriculture and a fledgling adventure-tourism industry, offered limited employment opportunities. With two-thirds of its population comprised of senior citizens, many youth were fixated on leaving Utuado for the capital, San Juan, which is about 70 miles out of the mountains to the northwest, or for CONUS. Due to such trends, Utuado had already been referred to as a "town in decline" (LaFranchi, 2017b).

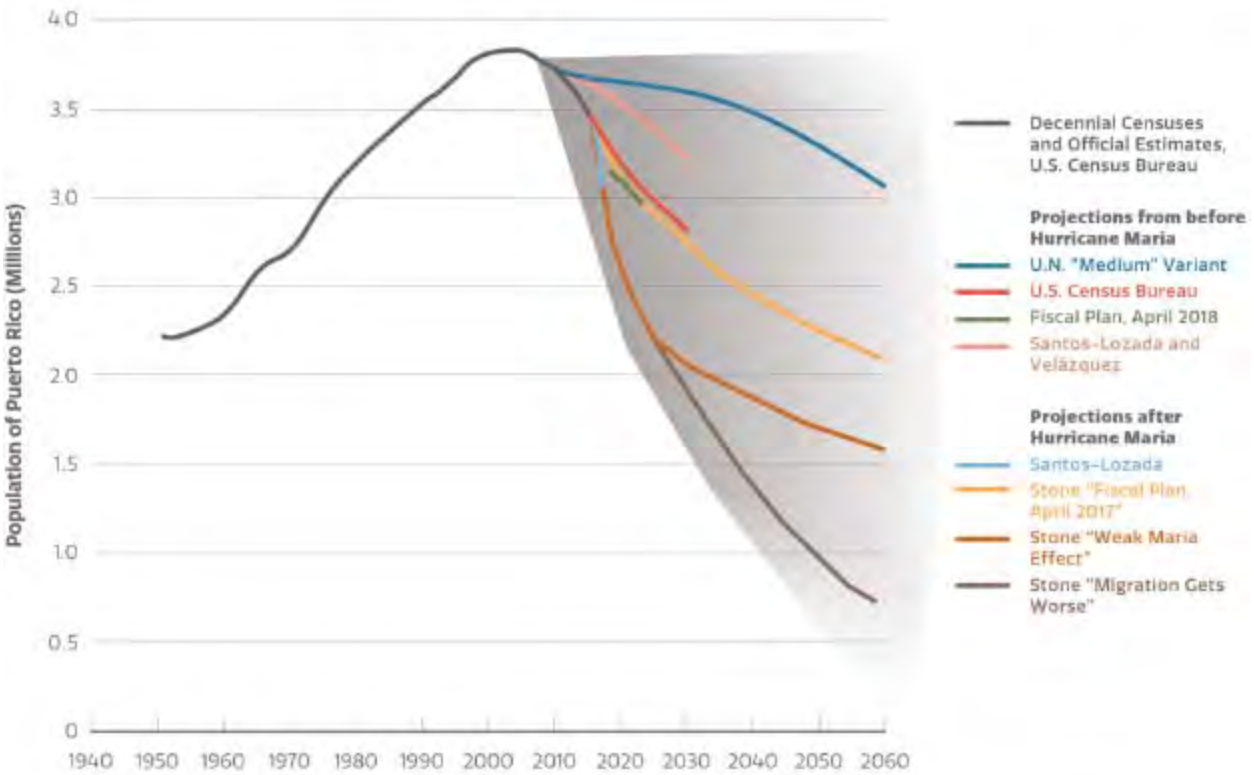
Chronic poverty and unemployment

Unemployment in Puerto Rico has followed similar trends to the mainland U.S. over the last decade since the economic recession (e.g., see Figure 5.6), however the magnitude of unemployment is nearly two times as great. According to the Bureau of Labor Statistics Current Population Survey and a similar monthly household survey for Puerto Rico, unemployment in 2017 was 10.8% in Puerto Rico compared with 4.4% nationally (Bureau of labor Statistics, 2018e). Among other possible factors, high relative levels of unemployment have likely contributed to a high rate of poverty in Puerto Rico. 43.5 percent of residents have incomes below the federal poverty level, and the rates vary from 27.2 percent in Guaynabo to 63.8 percent in Maricao (U.S. Census Bureau, 2016, Table S1701; Instituto Desarrollo Juventud, 2018).

Population loss and population aging

In every decade in which the U.S. Census Bureau has conducted a census in Puerto Rico until 2000, the Government of Puerto Rico experienced population growth. These periods of growth included the period of the "Great Exodus" of migrants from Puerto Rico to the continental U.S. (1945-1960), which until the turn of the 21st century had been the largest previous migration wave (Valeazquez-Estrada, 2015). Figure 6.2 illustrates the historical—and the range of possible projected—population size of Puerto Rico, based on HSOAC analysis of data from a variety of sources.

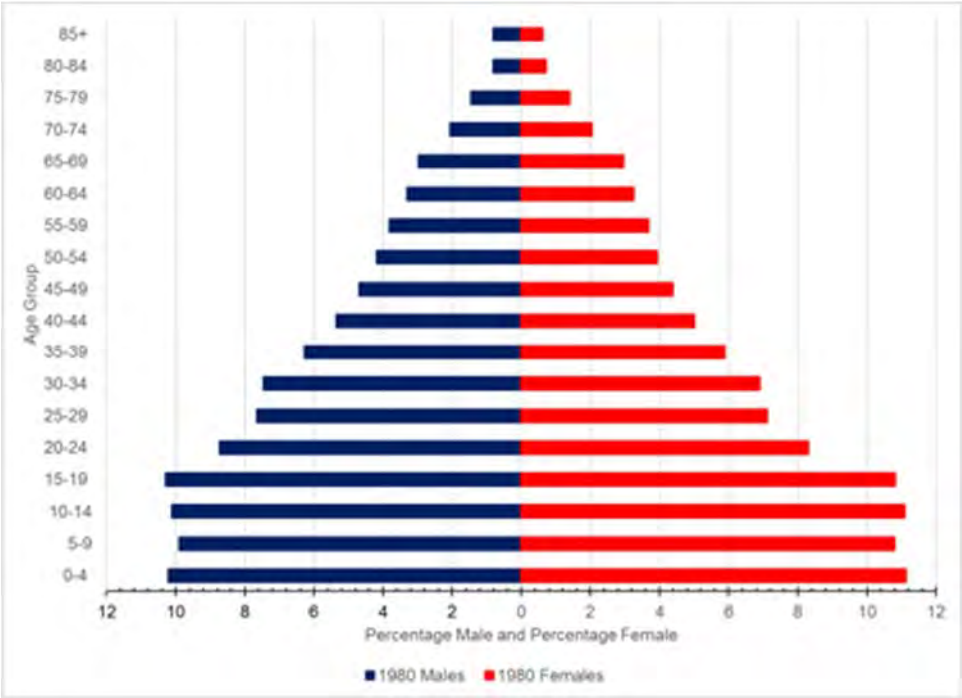
Figure 6.2. Historical and projected population of Puerto Rico (1950-2060)



Sources: U.S. Census Bureau International Database, 2017; U.N. World Population Prospects, 2017; Santos-Lozada and Velasquez, 2015; Santos-Lozada 2018, New Fiscal Plan for Puerto Rico, April 2018; Stone, 2017

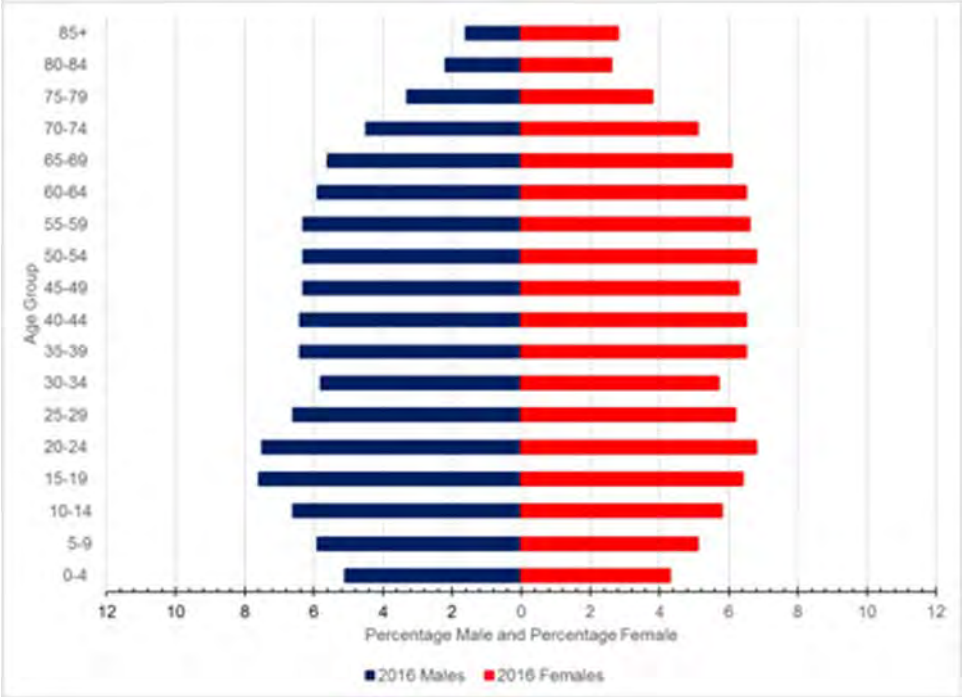
Prior to the economic contraction set in motion in 2006 (e.g, see the discussion of the phase-out of Section 936 of the Internal Revenue Code in 2006 in the Economy chapter), the Census Bureau PEP estimates that Puerto Rico's population peaked in 2004 at an estimated 3.8 million. Between 2004 and 2016, the population dropped to about 3.4 million. Two factors are about equally responsible for this population decline: an increase in the net population outflow to the continental U.S. and a continuing decrease in childbearing below replacement level. For example, between 1981 and 2012, the net outflow to the CONUS increased almost two-fold, from a net migration of -1.5% of the total population in 1981 to -2.8% in 2012. Similarly, between 1980 and 2016, childbearing reduced by about two-fold from 2.6 births per woman in 1980 to 1.3 in 2016 (compared with 1.8 in both years in the U.S. in total) (World Bank). Puerto Rico now ranks as having among the lowest of fertility rates compared to the CONUS and other countries world-wide, with only four other countries reporting lower fertility. Because of these dynamics, the age distribution of men and women has shifted from the pyramid shape of a relatively young and growing population (Figure 6.3), to the rectangular shape of a rapidly aging population (Figure 6.4).

Figure 6.3. Population Pyramid 1980



Source: US Census Bureau, 1980 Census

Figure 6.4. Population Pyramid 2016



Source: US Census Bureau, 2016 American Community Survey

The economic contraction has had a dynamic and mutually reinforcing relationship to the population losses. The continuing loss of people in Puerto Rico, particularly school-aged children and working adults, has added to its economic concerns (Krogstad, 2016). Coupled with the general aging of Puerto Rico's population, Puerto Rico's population, workforce, and, consequently, its tax base are expected to continue to shrink. This shrinkage surpasses existing workforce shortages in many in-demand fields, including health and social services.

Coupled with the general aging of Puerto Rico's population, Puerto Rico's population, workforce, and, consequently, its tax base are expected to continue to shrink. This is beyond existing workforce shortages in many in-demand fields, including health and social services.

Chronic unemployment and other factors have contributed to both outmigration and internal migration. According to one media report, "10 to 15 percent of San Juan's population was looking to 'make the jump' [to the mainland] earlier in 2017, well ahead of Hurricane Maria" (LaFranchi, 2017a). It also noted that rural areas with high unemployment, such as the mountainous municipality of Utuado, often see young residents leave for larger cities and municipalities like San Juan (LaFranchi, 2017a). In outmigrant focus group discussions in Florida, a distinct group of people asserted they had plans to leave the island prior to Hurricane Maria. Within this group, the majority were from rural areas and had family ties to the mainland US. Pre-Maria motivations for wanting to relocate were family health needs, children's educational needs, and economic necessity. Although they were not fully prepared to leave, their plans were expedited by the storm and the damage it caused to Puerto Rico's infrastructure and services.

Hurricane damage

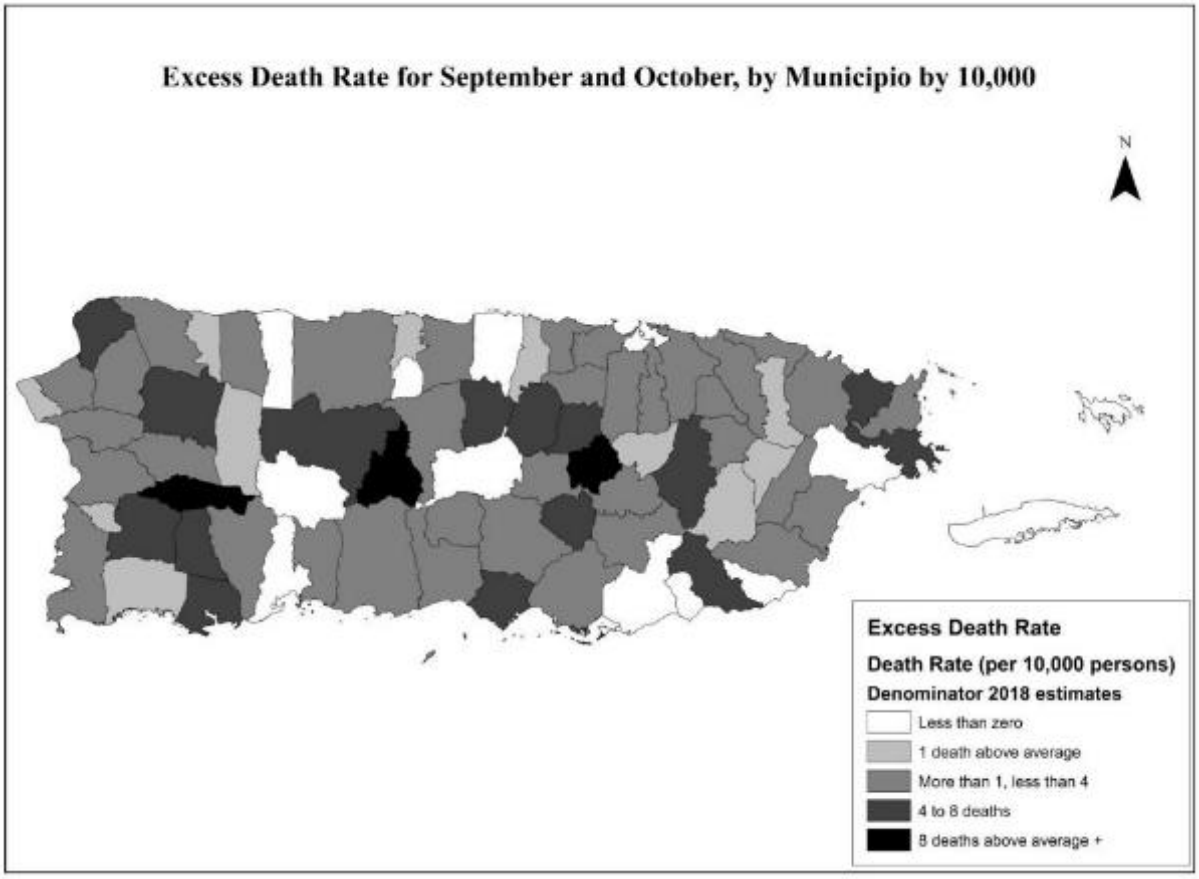
The experiences of Puerto Ricans affected by the recent storms have varied widely. This section provides mostly anecdotal information on the impact of Hurricanes Irma and Maria on local communities and populations. This information is drawn from focus groups and interviews with community members and supplemented with examples taken from Puerto Rican and CONUS English and Spanish-language media sources from October 2017 through March 2018. The examples of damage inflicted on individual members of vulnerable communities are intended to be illustrative and do not present a full picture of post-hurricane conditions for the communities as a whole.

Physical/mental health and hurricane-related deaths

The physical toll of Hurricane Maria on the island's population is only beginning to be documented. The official death count from the Puerto Rico Department of Public Safety has been 64. Subsequent analysis of Vital Statistics data by independent researchers showed about 1,000 more deaths occurred in the two months after the hurricane than expected (Sosa Pascual, 2017; Santos and Howard, 2017; Robles et al., 2017). Two of these studies found an unequal

distribution of these excess deaths across municipalities, even after accounting for the population distribution (Figure 6.5). For example, analysis of excess death rates in September and October 2017 compared with monthly trends of mortality by municipality 2010-2016 show an excess rate of death in more rural municipalities and municipalities along the path of the hurricane (Santos and Howard, 2017).

Figure 6.5. Excess Deaths in Puerto Rico Following Hurricane Maria (September 2017)



Source: Monthly death counts from Puerto Rico Vital Registration System obtained from PRIS for 2015-2017. RAND population denominator 2018 estimates calculated from average USPS active residences December 2017-April 2018.Excess death rate was estimated using approach described elsewhere (Santos and Howard, 2017).

Underestimation of death counts and inappropriate accounting of causes of death in the Vital Statistics have been a historical problem in Puerto Rico (Santos-Lozada, 2018b). For example, long delays in the reporting of deaths by family members or local officials have led to underestimation, and systematic flaws in the classification and recording of deaths by clinicians have produced errors in official reports on the causes of death. The independent government agency, the Puerto Rico Institute of Statistics (PRIS), has advocated for and implemented an automated data entry, classification, and retrieval system for deaths developed by the Centers for Disease Control and Prevention.

In response to concerns about official accounting of Hurricane Maria deaths, the Governor commissioned a study by George Washington University to review and analyze existing records and death certificates and estimate the excess mortality from the time the storm hit on Sept. 20 through February. In the interim, a much-publicized Harvard study estimated that the excess of hurricane deaths in October through December of 2017 versus the previous year ranged from of 793 to 8,498. Like the previous independent studies, this study argued that "excess deaths" caused by the storm should include deaths both directly and indirectly related to the disaster due to the loss and inaccessibility of electricity, safe water, food, and medical care. For example, the mortality survey found that up to one-third of the excess deaths could be attributed to delayed or interrupted health care (Kishore et al. 2018). Because the estimate is based on a relatively small sample of households, the range of possible estimates is wide.

Most recently, on June 13, the Puerto Rico Department of Health revealed 1,427 more deaths in the four months after the hurricanes than under normal circumstances (based on the previous four years), and it will update the official count after the George Washington University study is completed.

With respect to non-fatal health consequences of the hurricane, many interviewees shared the negative impact of the hurricane on their physical and mental health. The information below comes from interviews with individuals and focus groups. More systematic information on health impacts of the hurricane can be found in Chapter 7. Some residents did not have access to adequate medical care or medicine. Some reported that their communities and families had experienced loss of life. One interviewee from a discussion group of people who left Puerto Rico said, "Perhaps 12 hours after the hurricane we go to my grandmother's house. We found my grandmother with her house flooded on the second floor, she was on the ground almost dead with fingernails swollen…so we took her to the emergency room at the hospital because Hurricane Maria caused her to have a stroke. My grandmother died in the hospital." A law enforcement officer in San Juan who was interviewed by HSOAC described a post-Maria surge in suicides and accidental deaths that resulted from inappropriate use of propane gas or candles.

Many interviewees also related the psychological distress they had experienced themselves or observed in others. When asked about the impact of the hurricane, one interviewee from Lares said, "there was emotional and psychological damage and uncertainty of the people, regarding what was going to happen and how they would recover." Some interviewees shared that they had witnessed suicide in their family and neighborhoods. According to one interviewee from Mayaguez, who worked in community mental health, "almost 85% of people [he saw in one neighborhood] wanted to take their lives, very traumatic events for children and families." Describing the mental health assistance needed by students who experienced the recent hurricanes, a professor from Universidad Del Este stated: "I'm not sure if the university as an

institution is conscious of the impact that this hurricane has had on the students. So maybe they need a counselor who has a type of PTSD and other trauma training."[62]

Impact of the hurricane on populations disproportionately affected by disaster

Elderly

Elderly people appear to have suffered greatly from the recent hurricanes. Focus group participants from multiple municipalities (e.g., Naranjito, Loiza, Maunabo) shared that many elders in their communities were depressed and traumatized by the hurricane. Interviewees have also reported challenges with storing medications and powering medical devices, as well as substantial unaddressed housing challenges, with many stating that they have been forced to live with relatives. One interviewee from Naranjito thought that, "the elders were greatly affected because of their special conditions and sometimes the lack of company and attention when finding themselves completely in the dark…depend on neighbors who would give them water. The elders are the first who were affected because they turned into children – helpless."

Female caregivers

The loss of power over a prolonged period due to a massive hurricane has been shown to be a greater burden for women than for men. According to a British researcher conducting a longitudinal study of 19 families in one urban Puerto Rican neighborhood, the lack of refrigeration meant that people (mostly women) had to make daily trips to shops if they wanted to eat fresh food (Sou, 2018). Also, women who ran food-based businesses in their homes were unable to continue earning their own income. Ordinary chores like cooking and doing laundry were much more onerous without regular power. Furthermore, women have had to care for extended family members who have been left temporarily homeless (Sou, 2018). Focus group participants and individual interviewees frequently described the vulnerabilities and challenges experienced by women immediately following the hurricane. When commenting on community members most severely impacted by Hurricane Maria, a community volunteer in Guayama responded, "Women because there are women who live alone and lost their houses completely." Similarly, when asked which segment of the population is the slowest to recover, the interviewee stated, "People in poverty, women who are alone, without any support." An interviewee from the Lares municipality said many have suffered because of the hurricane, but pregnant women and the elderly face particular challenges.[63]

Children and youth

Recent hurricanes have also proven disruptive for Puerto Rico's children and youth population. An attorney working for the Boys and Girls Club of Puerto Rico described difficulties providing

[62] From an interview with a professor from Universidad Del Este (Carolina).

[63] Interview from the Lares municipalit; 23 April 2018

critical resources for children in shelters. He mentioned mothers who were unable to provide milk to their children. As described in more detail in the Health, Social Services, and Education chapter, children were out of school for prolonged periods, and some schools took longer than others to reopen due to varying levels of destruction and the pace of recovery operations. According to media reports, many parents concerned about the school closures after Hurricane Maria decided to leave Puerto Rico and enroll their children in Florida public schools. According to school enrollment data from states that historically have had the largest concentration of Puerto Rican immigrants, in the three to five months after the hurricanes, increases in enrollment have been observed in each of these states: 11,554 Puerto Rican children have enrolled in Florida's school districts, 2,556 in Massachusetts, 2,874 in Pennsylvania, 2,218 in New York, 1,827 in Connecticut, 886 in New Jersey and 607 in Illinois (Hinojosa, Roman and Melendez, 2018).

College students are also reported to have sought opportunities in CONUS. For example, some availed themselves of New York University's (NYU's) Hurricane Maria Assistance Program, which began in November 2017; this program had 400 applicants, 63 of whom were accepted and 57 of whom attended (Gulec, Chinn and Jew, 2018). Recent news reports have described how universities in Puerto Rico have received only about 1/5 of the total emergency relief funds dispersed by the Department of Education (Green and Cochrane, 2018).

Residents of informal housing

Although damage was widespread throughout Puerto Rico after the hurricanes, neighborhoods with a large proportion of informal housing were hit harder. Systematic data are not available on damage to the informal housing sector, but Housing Secretary Fernando Gill stated that the informal housing sector accounted for the majority of the approximately 300,000 dwellings that suffered significant damage from the recent hurricanes (Viglucci, 2018). Assistance for people in these informal housing settlements has reportedly been hamstrung by the fact that many residents do not have a legal title over their houses, and many reports indicate that more attention has been focused on meeting immediate needs for shelter than on long-term solutions to the informal housing problem. Two interviewees spoke about the challenge of informal housing and lack of documentation: "when they live in a farm for many years and it is separated into many small ones – those people are ruined because they do not have their property title either."

Regional differences

Isolated rural areas were severely impacted by the hurricanes. Although half of Puerto Rico's residents had power by mid-January 2018, they were concentrated in the cities. The 50 percent who remained without power were spread over 95 percent of the Commonwealth's land mass (Stoneham, Hasty and Sesin, 2018). This relative urban advantage holds not only for big cities, such as the capital, San Juan, but also for smaller provincial cities, such as Ponce, a municipality with 19 rural neighborhoods and 12 urban neighborhoods on the main island's southern coast.

According to Ponce's mayor, María Meléndez, power had been restored to 92 percent of urban neighborhoods four months after Hurricane Maria, but none of the rural neighborhoods had energy (Echenique, 2018).

One interviewee from Naranjito said: "people who live in suburbs out of town were the most affected by the hurricane, since the mountainous areas were greatly affected due to landslides. Also, in order to receive food and help, they had to find a way to reach the areas close to town." "Across Puerto Rico, officials say, altitude matters" (Bronstein, 2017). Even in Trujillo Alto, a sprawling suburb of San Juan, the lowland coastal parts of the city had clean water and electricity well before the mountainous parts, which are more distant from the power generators along the coasts (Bronstein, 2017).

Economic losses are also reported to have differed by regions. In the coastal community of Humacao, fishing production decreased dramatically. In urban centers, commerce has been stagnant, and even during SanSe festivities in San Juan, traders complained about low sales (Pagan Negron, 2018). In rural regions, damage to the agriculture sector (see Chapter 4) was felt acutely. Finally, transportation challenges (see Chapter 10) were evident in hard-to-reach municipalities. For example, in the mountain town of Utuado, the U.S. military was unable to deliver supplies even 30 to 40 days after the storm (Venes, 2017). In the peripheral islands of Vieques and Culebra, disabled people have found it difficult to travel to the main part of the island for needed services. To address this problem, SER (a Puerto Rican NGO specializing in disabled/vulnerable people) and FEMA have worked together to provide special assistance (Rolon Cintron, 2018).

Post-hurricane conditions

The elderly population, women, young children, residents of informal housing, and rural residents continue to have significant unmet needs with respect to essential services, housing, medical and mental health, physical security, employment, and education. In the aftermath of the hurricanes, the immediate needs of these groups and regions seem to have been addressed mostly through family and local community support, but some indications suggest that they are beginning to receive help—for example, in the form of monetary and temporary housing assistance—from Commonwealth, Federal Government, and non-profit organizations. The departure of many Puerto Rican residents to CONUS has increased the vulnerability of those left behind, particularly the elderly population. Although moving to CONUS has offered the prospect of a temporary or permanent safe haven for many people from vulnerable and less vulnerable regions, the increasing loss of productive citizens threatens Puerto Rico's economic recovery. The numbers of people who have gone to the mainland has left towns with unkempt vacant houses, which lower property values and impede tourism. For their part, those who left because of the hurricanes, both young and old, can face a different set of vulnerabilities as a result of their move to CONUS, especially if they lack a support network there upon which they can depend.

Continuing population needs

Based on community focus groups and interviewees, some residents still needed basic necessities, such as water and electricity, as long as six months after the hurricanes. One interviewee from Maunabo said: "most of the community needs electricity, there are still a lot of people who to this date lack electrical service."

Many interviewees spoke about the need to build a more disaster resistant infrastructure system. Participants from a community focus group in Mayaguez suggested, "re-evaluate areas susceptible to floods, tsunami and storm surges, create a plan for the next 20-25 years, relocate housing and prohibit construction in land maritime zone, and eliminate or demolish existing structures." In another community focus group in Gremios, participants discussed the need to "improve transportation, monitoring, and [collection] of statistics and data and their accessibility by the government."

In addition to investment in infrastructure, interviewees shared that safe and secured housing is another continuing need. An interviewee from Guayama said, "the key is that agencies go house to house and give priority to the people who really need it, so they may recover…try to help him build, try to keep them safe so they do not sleep in fear. This affects health, makes people nervous, they do not feel supported, they are in need of help." Participants from the community focus group in Humacao made the following suggestion: "identify what places are in the community, what houses, that are empty that can be used for people who are homeless. Schools that are closing can be used and qualified for housing projects. In the community of Mariana it is being done."

Assistance to the population

When asked about which groups have provided recovery help, many interviewees named FEMA, the military, and the municipality government. However, a few interviewees were dissatisfied with the government response. One interviewee from Naranjito said: "the principal obstacles in the community is the lack of federal government support to the municipal government. If the federal government supported the other, the resource we need such as bridges, materials, and equipment will help the citizens of Lomas Valles and we would have the resources to move forward."

Interviewees had a lot of suggestions for improvement. For example, participants from the community focus group in Caguas suggested, "rescue the polyculture system for production locally and as a country, to be able to feed and export; promote a country project for the use of renewable energy to reduce dependence on fossil product; and development of solar panel companies that involve design, installation, and maintenance of panels."

Finally, some interviewees discussed the help they received from non-profit organizations and religious institutions. One interviewee from Cayey said, "[a non-profit agency] came and brought food. They also came, [someone] from the Catholic Church which was part of what the

municipality gave. The municipality would give to the church and the church would distribute it. Also other churches came to bring food."

Movement of people between Puerto Rico and CONUS since Hurricane Maria

Since Hurricane Maria, it has been expected that the net loss of the population through a net negative flow of outmigration exceeding inmigration has expanded considerably. However, no official statistics have been released on the number or demographic characteristics of outmigrants, inmigrants or the net migration flow (inmigrants-outmigrants), and the Census Bureau is not scheduled to release data on the resident population of Puerto Rico until December 2018. Absent any official estimates of outmigration or net outflow of the population subsequent to the hurricane, researchers have employed a variety of methods to produce estimates.

One method of estimating post-hurricane outmigration entails analyzing school enrollment data, which is a standard source of migration data in data scarce contexts. Using data on enrollment of Puerto Rican children in schools in the continental U.S. since the disaster, researchers estimate that 135,592 people migrated from Puerto Rico to the United States in the six months after the storm (Hunter CUNY and Center for Puerto Rican Studies, 2018).

Another method of estimating migration patterns involves analyzing port of exit data on passenger flow, which can provide information on exits, entries and the net balance of exits and entries. The net balance of exits and entries have been tracked by the Puerto Rico Institute of Statistics (PRIS) since 2000 and are the preferred source of net migration flow data used by PRIS to produce monthly population projections for the US Bureau of Labor Statistics. Analysis of these data indicates that over 100,000 (between 106,630 and 107,480) more people left Puerto Rico than entered it in September and October 2017, relative to the number that was expected based on net passenger flow during the same months between 2009 and 2016 (Santos-Lozada, 2018a). On the basis of the pre-hurricane relationship between the net passenger flow (i.e., entries-exits) and the estimated outmigration from the ACS, the PRIS rescales this estimate to reflect estimated net migration.

The advantage of using either school enrollment data or port of exit data to estimate outmigration is that the fact that these data can be reweighted to better reflect the total migration flow. This reweighting process helps to address the limitations respectively that the school enrollment data likely captures only a subset of the total number of outmigrants (e.g., it excludes outmigrants without school age children) and the port of exit data likely captures a considerable excess of passenger entries and exits from Puerto Rico that are not from outmigrants or inmigrants (e.g., disaster response workers). Other sources of information on outmigration include the FEMA Individual Assistance (IA) application data and intake data from evacuee service organizations like the New York Disaster Interfaith Services (NYDIS).

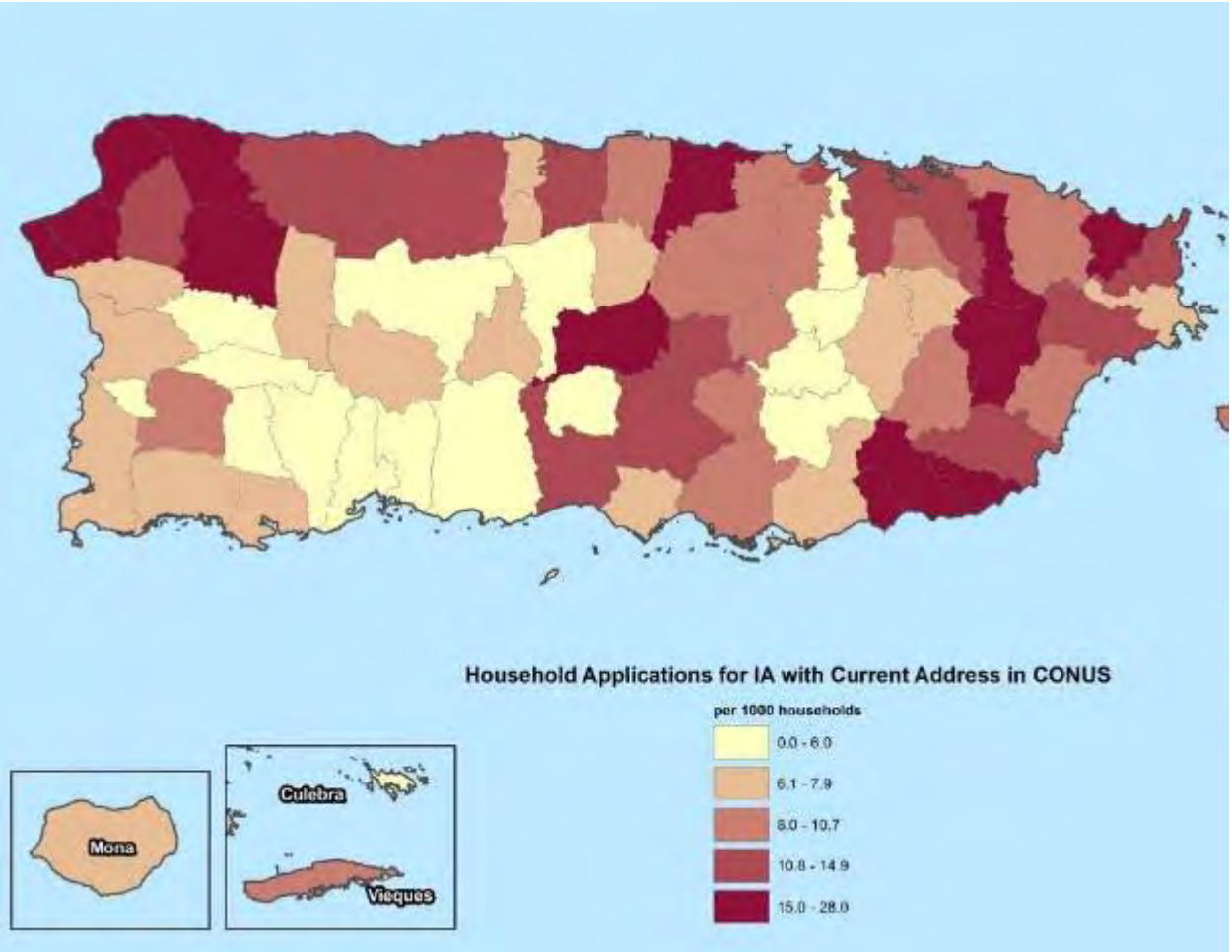
HSOAC obtained from FEMA the IA data through June 1, 2018 for Hurricane Maria by households with a current residence in the CONUS and a damaged residence in Puerto Rico. A total of 21,184 FEMA applications were received from individuals applying for assistance for

their household. HSOAC weighted the municipality-specific counts of applications from households by the average household size (using data from the 2012-2016 ACS) to yield an estimated total of 45,267 outmigrants.

Another method of estimating outmigration draws from data on evacuees who sought services from the NYDIS. HSOAC obtained NYDIS evacuee intake records for the period February through June 2018. Based on exit interviews for households visiting the Hurricane Evacuee Service Center and household rosters completed during the exit interviews, there were a total of 1,216 households representing a total of 2,366 individual outmigrants. However, these data capture only outmigrants from Puerto Rico to New York.

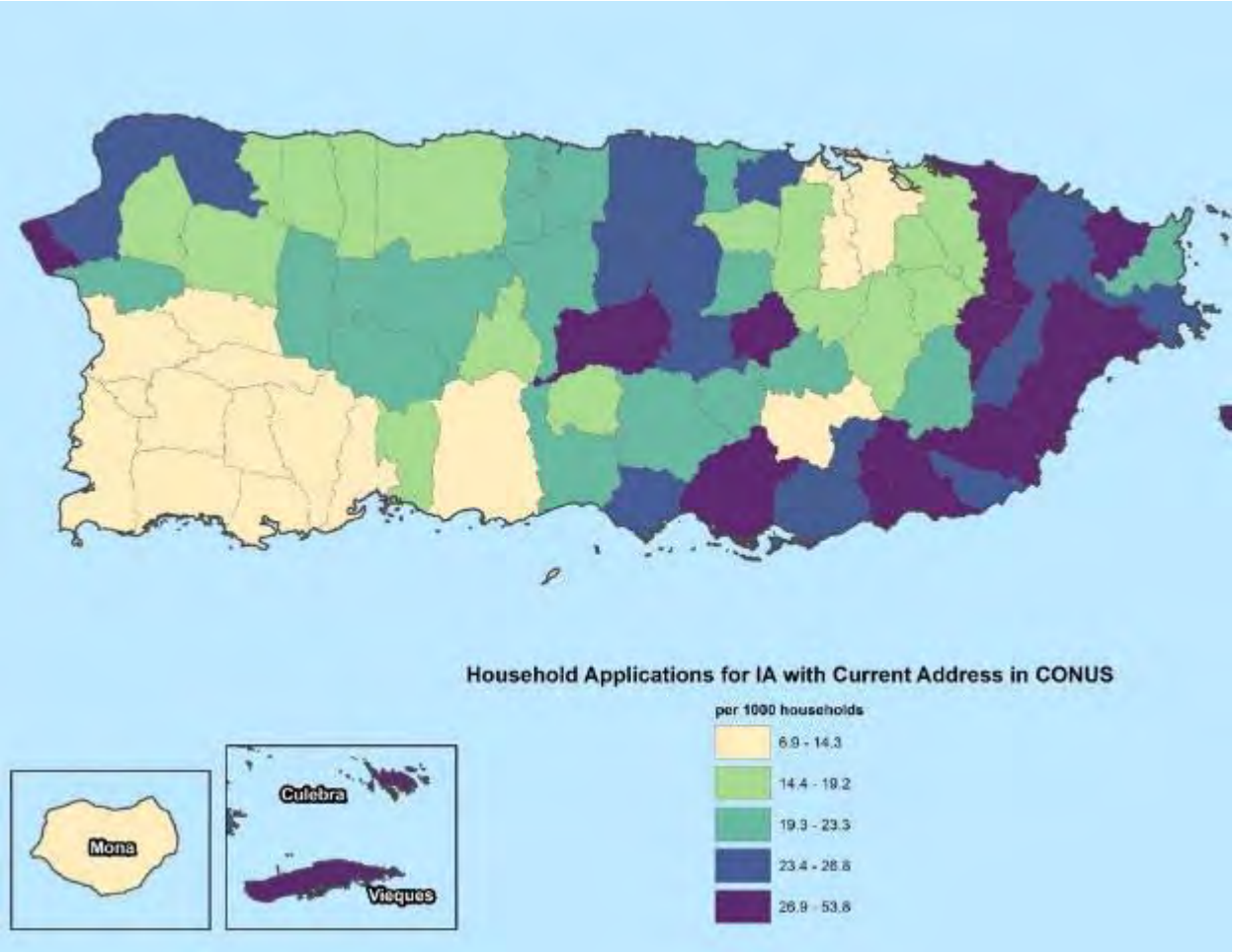
Only two of the above sources of migration data provide information on the zip code of the damaged address distribution of outmigrants by municipality: the FEMA IA data (Figure 6.6) and the NYDIS (Figure 6.7). HSOAC estimated outmigration rates using each of these data sources. Despite the different populations sampled by these data sources, the relative distribution of rates by municipality (i.e., placed on a quantile scale) show a similar geographic distribution. Both data sources show outmigration from outlying western and eastern coastal areas of Puerto Rico as well as a few provinces the central areas of Puerto Rico, with a concentration of high rates in the south eastern coastal municipalities.

Figure 6.6 Estimated Rates of Outmigration to CONUS by Municipality of Puerto Rico, FEMA Individual Assistance Data through June 2018



Source: Rate estimated as the ratio of the counts of exit interviews with household representatives applying to FEMA for Hurricane Maria assistance through June 2018 (i.e., applications with a current address in the CONUS and a damaged address in a respective municipality reported by FEMA at the zip code level) relative to the counts of active residents by municipality reported by USPS at the zip code level in April 2018 for December 2017. The distribution of the outmigration rate by municipality is categorized in quartiles.

Figure 6.7 Estimated Rates of Outmigration to CONUS by Municipality of Puerto Rico, New York Disaster Interfaith Services (NYDIS) Household Applications for Evacuee Services through June 2018



Source: Rate estimated as the ratio of the counts of exit interviews with household representatives visiting the NYDIS Hurricane Evacuee Service Center through June 2018 relative to the counts of active residents reported by the USPS in April 2018 for December 2017. The distribution of the outmigration rate by municipality is categorized in quartiles.

Data on the total household income of outmigrants are available only from the FEMA IA applications. Consistent with recent trends in outmigration from Puerto Rico to the CONUS, reported household income is higher among FEMA IA applicants who outmigrated to the CONUS ($41,667 excluding missing responses and responses of zero income, $35,376 including missing responses and responses of zero income) than applicants who were internally displaced within Puerto Rico ($35,717 excluding missing responses and responses of zero income, $29,374 including missing responses and responses of zero income).[64] Additionally, the incomes of both

[64] Note that the HSOAC team has concerned about the data quality underlying this section, as it draws from self reported data from IA applicants that may be incomplete or misleading.

outmigrants and internal migrants are above the total median household income for Puerto Rico which was $19,606 between 2012 and 2016 (U.S. Census Bureau, 2017b).

Similarly, data on the demographic characteristics of post-Maria outmigrants from Puerto Rico to the CONUS are available only from the NYDIS household exit interviews. Children between the ages of five and 17 constitute the single largest group of outmigrants (23 percent) represented in the NYDIS, followed by adults between the ages of 45 and 64 (19 percent), 30 and 44 (18 percent), 18 and 29 (18 percent), and 65 or older (15 percent); children under the age of five represent only seven percent of these outmigrants. With respect to the distribution of gender by age, although male and female children are equally common, both working age adults (age 18-64) and older adults (age 65 and older) are more likely to be female (working age adults: 64 percent; older adults: 69 percent). Just over half of outmigrant households represented in the NYDIS were single adults without children (56 percent), and more than a quarter of households were single adults with children (29 percent). Couples with children and couples without children made up eight and seven percent, respectively, of outmigrant households in the NYDIS.

Based on FEMA IA applications through June 2018, Florida and New York were the most popular emigration destinations, accounting for 19 percent and 18 percent, respectively, of outmigrant households (CUNY Center for Puerto Rican Studies, undated). The large number of outmigrants to Florida is further indicated by data from the Florida Division of Emergency Management, which reported that more than 200,000 citizens of Puerto Rico had arrived in Florida by November 30, 2017 (Sesin, 2017).

According to HSOAC-sponsored focus group discussions with outmigrants, six factors were primarily responsible for either pushing from people from Puerto Rico after the hurricanes or pulling them to Florida. These factors included:

- Economic problems and disruptions in work
- Physical health
- Mental health
- Higher education
- Lack of food, fuel, and other resources
- Safety.

That said, post-Maria migrants appear to have relocated to nearly every state (Sutter and Hernandez, 2018). Overall, researchers expect that Hurricane Maria will lead to as much emigration from Puerto Rico in the next two years as in the previous decade during the economic and fiscal crisis.[65]

[65] Nearly all outmigration, post-Maria, has been to the mainland U.S., notably Florida, Pennsylvania, and Texas. Previous research on the Mariel Boat Lift and on refugee populations in the U.S. suggest that the economic impacts of outmigration from Puerto Rico on local labor markets in the mainland U.S. will be nil or perhaps positive (Card, 1990; Evans and Fitzgerald, 2017).

Many recent migrants have faced a challenging situation on the mainland. For example, participants in focus group discussions in Florida reported multiple obstacles to accessing stable housing, employment, transportation, and medical and mental health services. Notably, many participants identified lack of English language proficiency as a deficit that affects many aspects of their adaptation (i.e., employment, education, service access), including how others treat them. Multiple discussants said they felt discriminated against and exploited based on English language limitations, particularly in Central Florida. Additional challenges include interfacing with FEMA and advocating for disaster relief benefits and receipt of social services.

Although some declines in outmigration from and increases in return immigration to the Government of Puerto Rico are possible as housing vouchers and other supports from FEMA begin to expire in Spring 2018 and reconstruction progresses in the most populated areas, most estimates predict persistent outmigration for the foreseeable future (Melendez and Hinojosa, 2017). This is especially likely given that the main underlying drivers of emigration—job and family-related issues--remain in place in Puerto Rico (Krogstad, 2016). Moreover, research suggests a strong link between outmigration and extreme weather (including hurricanes) and predicts increasing severity due to changing weather patterns (Acevedo et al., 2017; Carleton and Hsiang, 2016). Thus, extreme weather events like Hurricane Maria could also continue to drive outmigration from Puerto Rico.

Migration within Puerto Rico

While systematic data are not available on migration within Puerto Rico, there is anecdotal evidence that many Puerto Ricans in economically depressed rural areas have decided to relocate to larger cities with more job opportunities. For example, in Utuado, a mountainous municipality with a poor transportation network, the main economic activities of agriculture and adventure tourism offered limited employment opportunities prior to the hurricanes. With two-thirds of Utuado's population comprised of senior citizens, many youth were inclined to seek better employment opportunities in the capital, San Juan.

Future population size and characteristics

No official statistics have been released from the Census Bureau about the impact of the disaster on the number of people residing in the territory, their geographic distribution or social and economic characteristics. Estimates of the population size post-Maria may not be available from the Census Bureau until 2019 since the 1-year estimates to be released in December would normally include a rolling assessment of population over all 12 months of the year (including pre-Maria data). Some evidence indicates that the population will likely not rebound: Over 70 percent of emigrants from Puerto Rico to CONUS in 2015 remained there through 2017 (Krogstad, Starr and Sandstrom, 2017). Similarly, over three-quarters of both participants in the outmigrant focus groups and NYDIS interviews said they did not plan to move back to Puerto Rico permanently. Less than five percent of participants in the outmigrant focus groups had

concrete plans to return to Puerto Rico in the near future.[66] Given deep-seated economic and infrastructure problems in the Commonwealth, incentivized work force development programs may induce more circular migration among younger working-age males than return migration of young families. If so, this has important implications for housing and supporting workers in reconstruction efforts in Puerto Rico.

Estimates of the municipality specific distribution of the population that incorporate outmigration from the hurricane are expected from PRIS by August 2018. In the meantime, the best and most systematic evidence for geographic population distribution comes from the US Postal Service (USPS) active residence database (in which inactive residences are those not collecting mail for at least 90 days). A total of 1.164 million active residences were reported for April 2018, which we estimate as a total population of about 3.26 million people if the most recent municipality specific household size estimates from the American Community Survey (2012-2016) are applied to USPS active residence counts by municipality. Our April 2018 estimate of the relative distribution of the population by municipalities was generally consistent with the ACS 2012-2016 with the largest absolute differences for Toa Alta (-0.56 percentage points smaller proportion in 2018), Mayagüez (+0.56 percentage points), San Juan (3.77 percentage points greater in 2018), Ponce (1.01 percentage points), Carolina (+0.75 percentage points).

Population projections produced before the hurricane displayed above in Figure 6.2 already varied considerably with differences in the magnitude of projected loss determined by how recent the base population data are (i.e., the U.N. used the 2010 Census while the Census Bureau used the 2016 population estimate) and consequently, the number of years of observed population decline subsequent to 2010 the model has used to project the inputs for the projection (i.e., births, migration and deaths).[67] For example, by 2016, the U.N. "Medium" and "Low" were already at least 250,000 over the observed (estimated) population total for Puerto Rico.

The few independent researchers who have forecast population trends subsequent to Hurricane Maria first face the initial obstacle of not yet having reliable data on the short-term impact of the disaster on population inputs (especially migration).[68] A robust accounting of the impact of the short-term impact of the disaster on net migration will have to wait for the release

[66] Outmigrant focus group discussions, southern and central Florida, April 13 and 15, 2018.

[67] With few exceptions, the major domestic and international population projections produced before Hurricane Maria (e.g., by the Planning Board of Puerto Rico, US Census Bureau, United Nations, and World Bank) forecast population losses. These exceptions include the assumption that net migration is zero or that fertility is at replacement levels or higher.

[68] A further dimension of uncertainty in population trends is that population statistics for Puerto Rico have historically had considerable measurement error. For example, the 2010 Census in Puerto Rico had a net error for of 4.5% (overcount of 160,300 persons), which is nearly ten times the magnitude of the average error across U.S. states (0.5%) and over four times the magnitude of the estimated annualized rate of decline between 2010 and 2017.

of the 2017 ACS.[69] In contrast, vital statistics data have been readily available to inform the short-term impact of the disaster on mortality, and this approach could be readily applied to assess childbearing as well.[70]

The more profound obstacle for population projection is to identify evidence that can inform forecasts about the long-term trends in population inputs. To reverse the already well-established trend of depopulation the changes will need to sizeable. For example, comparisons of U.N. projections not depicted here show that the gains in population growth are relatively small if current population losses via migration and childbearing are eliminated.[71] Long-term impacts could even be intergenerational given the observed ill consequences of catastrophic events (e.g., famines, tsunamis, pandemics) on the health of children whose mothers were exposed to the physiological and psychological impact during the child's gestation.

The outmigration of many Puerto Rican residents to CONUS may have also increased the vulnerability of those left behind, particularly the elderly population. Although outmigration has also offered the prospect of a temporary or permanent safe haven for many people from vulnerable and less vulnerable regions, the increasing loss of productive citizens threatens Puerto Rico's economic recovery. In addition, recent outmigrants, who are currently located in every U.S. state, may be in need of additional assistance.

Municipal governance

Background

Local government in Puerto Rico is provided by 78 diverse, independent municipal governments. In contrast to much of the continental United States, Puerto Rico does not have an intermediate layer of government between its local municipal governments and the Government of Puerto Rico, which is responsible for island-wide governance.[72] Municipal governments in the

[69]Furthermore, due to the rolling sample design of the survey, will require special analyses to separate data on individuals surveyed after the hurricane from those who were surveyed before.

[70] Previous research on the impact of hurricanes and other disaster events on childbearing has observed that decreases in fertility arising from poor birth outcomes can be offset or reversed by increases in fertility resulting from more frequent sexual activity and lack of contraceptive supplies.

[71] The difference of the annual projected population growth between the U.N. projection variant "Zero migration" (which sets net migration to zero) and the variant "No change" (which holds all projection inputs constant from the base year conditions) is about a 0.4 percentage-point increase in growth. Similarly, the difference between the "Instant replacement" (which immediately sets childbearing to replacement levels) and the the variant "No change" (which holds all projection inputs constant from the base year conditions) is about a 0.5 percentage-point increase in growth.

[72] For example, in the continental United States, while larger municipalities may not have an intermediary between their government and the state government, smaller municipalities are often part of a county which provides some services and serves as an intermediary with the state government on many issues. However, there is a great deal of variation within the continental United States as well, including some areas where county governments play little to no intermediary function between small municipal governments and the state government. A detailed comparative

continental United States of similar size to jurisdictions in Puerto Rico also use a variety of leadership structures, such as a professional city or county manager; in contrast, all municipalities in Puerto Rico are managed by an elected mayor. There has been significant discussion and consideration in the years prior to Hurricanes Irma and Maria regarding whether some sort of intermediate or regional structure or other structural changes to municipal government should be implemented to take advantage of economies of scale and improve service delivery. The organizational structure of municipal government in Puerto Rico has significant implications for all aspects of response to and recovery from Hurricanes Irma and Maria, and is discussed in more detail below. This section covers how municipal government in Puerto Rico is structured and organized, the powers and authorities of municipal governments, how they raise revenue to pay for their operations, and emerging structures and proposals regarding different collaborative and organizational structures.

Jurisdictional boundaries, population, and political parties

Puerto Rico's 78 municipalities range in size from 12.4 square kilometers (Cataño) to 326.6 square kilometers (Arecibo) (Government of Puerto Rico, 2018c). Municipal populations range from 1,868 inhabitants (Culebra) to 442,447 (San Juan) (Government of Puerto Rico, 2018c). The top three most populated municipalities are San Juan, Bayamón, and Ponce. Figure 6.8. shows the distribution of population density throughout the Commonwealth.

Figure 6.8. Population Density by Municipality, (population per square mile)

SOURCE: U.S. Census, 2010.

analysis of municipal government in Puerto Rico and the continental United States was outside the scope of this assessment, although we do attempt to draw some high-level comparisons where we believe they provide useful context.

Puerto Rico's topography and geographic characteristics vary substantially across the Island and as a result across municipalities. These underlying geographic differences have significant implications for a variety of aspects relevant to municipal life. For example, municipalities in coastal regions tend to be more densely populated, have direct exposure to storm surge flooding, and feature more diverse economies. Municipalities located in mountainous areas are generally less densely populated, more difficult to access, and experience less economic development.

There are two primary political parties in Puerto Rico: Partido Nuevo Progresista (PNP) and the Partido Popular Democrático (PPD). Each municipality in Puerto Rico is headed by a mayor and a municipal assembly elected every four years. The last mayoral election was held in November 2016 in conjunction with the U.S. general election. The election saw the PNP gain control of the executive branch, with the election of Governor Ricardo Rosello, as well as both legislative branches. Municipal governments are split between the parties, with 33 municipalities whose mayors belong to the PNP and 45 municipalities whose mayors belong to the PPD.

One of the first recognized forms of association between municipalities was the Association of Mayors of Puerto Rico[73]. The Association was created in 1949 by the PPD. whose mayors governed all of Puerto Rico's municipalities at the time. The mayors of the New Progressive Party (PNP) founded the Federation of Municipalities of Puerto Rico (now Federation of Mayors of Puerto Rico) in 1968. Both are non-profit organizations whose purpose is to train municipal officials and offer technical and managerial support to municipal government employees.[74] In the past, the two organizations have seldom agreed on a common agenda and have tended to keep their interests and lobbying activities separate. However, mayors of both parties worked together in 1991 to successfully obtain more political and financial autonomy for municipalities (Cordero Nieves, 2018).

As a result, there is no single group representing municipal governments such as the U.S. Conference of Mayors, which represents mayors of both parties in CONUS. The lack of one unified organization to represent mayors in Puerto Rico, has impacted mayors' ability to speak with one voice on issues that affect all municipalities.[75]

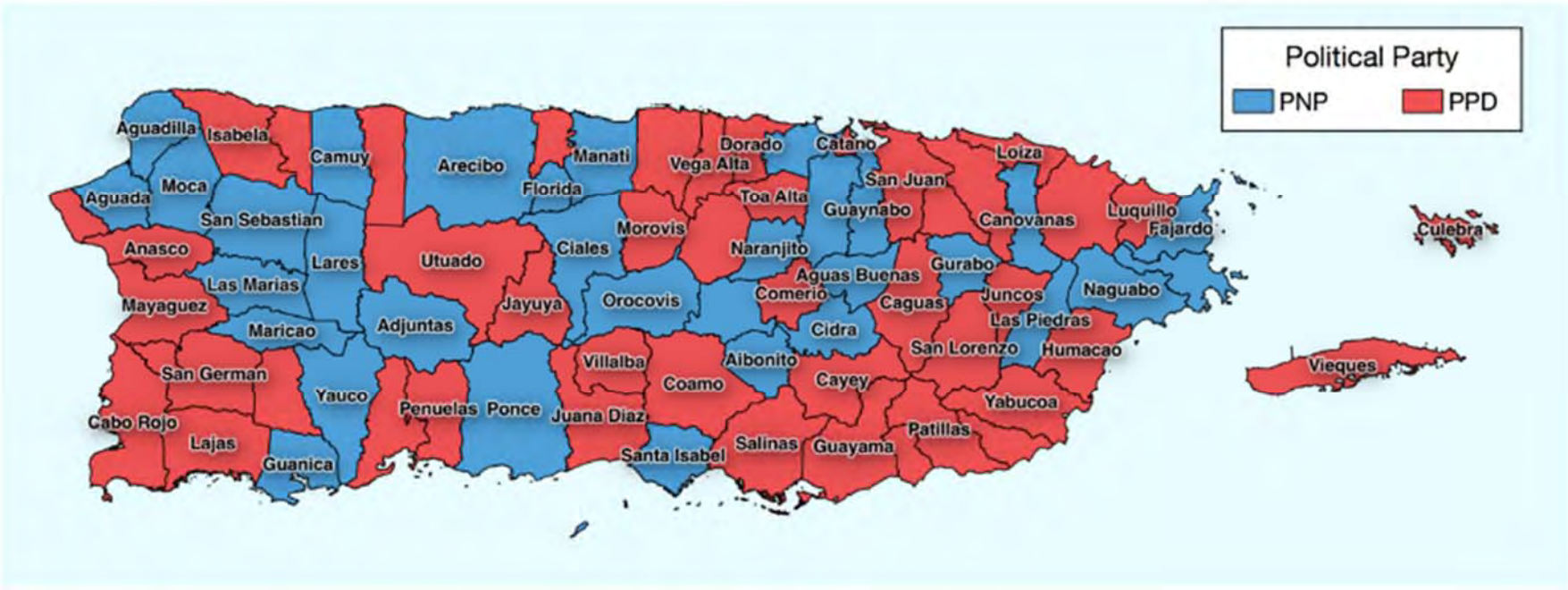
Figure 6.9 shows a map of municipal borders in Puerto Rico, labeled with the political affiliation of the current mayor.

[73] The goal of the Association when founded in 1949 was to unite efforts among municipal governments that were in better financial shape to assist those with fewer resources.

[74] From their 2014 websites. In 2018, none of them have an active webpage or portal. Both have presence in social networks, which has been a trend among municipal governments.

[75] Based on comments from mayors of both parties at HSOAC led roundtables.

Figure 6.9. Municipalities of Puerto Rico, 2018



SOURCE: HSOAC, data extracted from Official Municipalities Directory on Puerto Rico Online Government Portal

Structure and functions of the municipalities

The current form of municipal government in Puerto Rico has been in place since 1991. Historically, Puerto Rico featured a highly centralized system in which the municipalities depended on the Government of Puerto Rico to provide most services for citizens.[76] The Autonomous Municipalities Act of 1991 (formally Law No. 81 of 1991) in principle bestowed considerable autonomy on municipalities to:

> elect municipal authorities through a direct vote of its inhabitants;
> administer municipally-owned assets and issues in its jurisdiction; and,
> collect, invest, and spend municipal income ("Autonomous Municipalities Act of 1991," 1991).

In practice, the act gave municipalities greater fiscal autonomy, and along with this gave mayors the authority to provide services such as school transportation, waste collection, and cemetery operation.[77]

The act empowered municipalities to fund, own, and manage programs and assets to meet municipality needs—regardless of whether these municipal programs and assets overlapped with efforts undertaken by the Government of Puerto Rico. Over time, this has led to considerable overlap service delivery in some areas, including law enforcement, firefighting, maintaining roads and bridges, and emergency response.

The act also granted municipal legislatures the right to approve key municipal positions of authority, approve the purchase, disposal, or sale of municipal assets, and authorize budget readjustments and other budgetary decisions. The act required that all municipalities have a minimum organizational structure in place by codifying the need to establish certain offices.

The act also established OCAM (the Office of the Commission for Municipal Matters) to serve as the main advisor to municipal governments, and it gave OCAM regulatory oversight over municipal accounting. OCAM was intended to function as a fiscal support structure for municipalities—a parallel to the state Office of Management and Budget—as well as provide legal, technical, and training assistance. However, over time, OCAM's primary function became disbursing federal funds rather than providing institutional support. OCAM's top-down approach was also unpopular with municipal authorities and some considered it to be ineffective in carrying out its key support role.[78] As part of Governor Ricardo Rosselló's efforts to streamline the Government of Puerto Rico, OCAM was dissolved in July 2017, and its main functions were divided into two different organizations: ODSC (Office of Community Socioeconomic

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[76] Interview with University of Puerto Rico professors Carmen Concepción, William Vazquez, and Yolanda Cordero, May 8, 2018.

[77] These are services described explicitly in the Law No. 81 of 1991 document, however are not an exhaustive list of possible municipal services

[78] Based on interviews with UPR Professors from the Schools of Planning, Public Administration, and Law.

Development)—which now handles disbursement of funds for the Community Development Block Grant Program and the federal Juvenile Justice grants—and the OGM (Office of Municipal Management)—which takes on the main functions of assistance to municipalities (Alvarez, 2017).[79]

Municipal finances

Municipalities have five main sources of income: sales tax from products sold within their jurisdiction; real estate taxes on sales of properties; fees charged for business licenses; construction permits; and transfers or subsidies from the Government of Puerto Rico. These sources of income have been under different forms of pressure in recent years, and are sensitive to different factors, which has implications for the municipal-level recovery efforts.

Sales and use tax

On May 13, 2006, Puerto Rico enacted legislation approving a sales and use tax (IVU by its Spanish acronym) for products sold within the Commonwealth, with an overall rate of 7 percent. Of this, 5.5 percent went to the central government and 1.5 percent went to the municipalities—though .5 percent of the municipal rate was collected by the Government of Puerto Ricoto secure municipal bonds. On May 29, 2015, Puerto Rico enacted new legislation that raised the total IVU to 11.5 percent, but reduced the municipal contribution to 1 percent.

Property tax

The Municipal Revenue Collection Center (Centro de Recaudación de Ingresos Municipales, or CRIM in Spanish) is responsible for assessing property values and collecting real estate taxes in Puerto Rico. The legislature and municipal governments play a role in setting local property tax rates, and the first $15,000 of assessed value on owner-occupied residences is exempt from taxation ("H.B. 2752," 2010). Property values had been decreasing substantially in Puerto Rico even before Hurricanes Irma and Maria, impacting revenue for municipalities and the Commonwealth. For example, the median price for homes listed for sale in Puerto Rico declined from $307,000 in May, 2010 to $118,000 in April, 2018 (Zillow, 2018). More detail on housing issues is described in the Housing chapter of this report. In addition, a number of special real estate tax exemptions, meant to spur job creation, are granted to commercial properties by the Government of Puerto Rico through Puerto Rico Industrial Development Company (PRIDCO) tax-free zones. Lastly, property values in Puerto Rico have not been formally assessed for more than 60 years (since 1957) and the rate of compliance with the payment of owed property taxes is estimated to be only 68 percent (Financial Oversight and Mangement Board for Puerto Rico, 2018). We were unable to put this into context with municipalities in the continental US, but it is common in many areas for properties to be formally reassessed every three to five years, and in general revenue from property tax is an important component of municipal finance.

Business license fees

As a general rule, businesses operating within a municipality must pay an annual business license fee or tax directly to the municipal government. This fee varies by municipality but generally ranges from 0.2 percent to 0.5 percent of gross income for non-financial businesses, and from 1 percent to 1.5 percent for financial-related businesses. Over time the Government of Puerto Rico has created a number of exemptions to this requirement. Businesses operated by the government, for example, are fully exempt (e.g., the Puerto Rico Tourism Company ("See Puerto Rico,," 2018)). Some other key entities receiving exemptions include small businesses with income less than $5,000, international banks and insurance companies, businesses operating in PRIDCO tax-free zones, and businesses selling oil or derivative products to the Puerto Rico Electric Power Authority (PREPA) (Puerto Rico Department of Economic Development and Commerce, undated).

Construction permits

A key source of revenue for municipal governments are fees associated with construction permits, levied on companies undertaking construction within the territorial limits of the municipality. The cost for construction permits varies, but typically ranges from 4 percent to 5 percent of the cost of the project (Puerto Rico Department of Economic Development and Commerce, undated). There are exemptions to this requirement for non-profit organizations engaged in building low-cost housing for certain PDADs, for projects overseen by Government of Puerto Rico agencies, and for the construction of medical facilities.

Financial transfers from the commonwealth

The Legislature of Puerto Rico authorized the central government to make a number of transfers to the municipalities each year, in part to compensate for various exemptions that limit their ability to collect taxes at the local level ("Municipal Property Tax Act of 1991," 1991). These transfers include: 2.50 percent of the net internal revenues of the General Fund for each fiscal year; 35 percent of the annual net revenues derived from the operation of the lottery system; an annual amount from the General Fund to compensate the municipalities for real estate and property tax exemptions; and an annual amount from the General Fund to compensate for the exemption related to the assessed valuation of all taxable property within the municipalities.

These transfers were reduced by $150 million in 2017 from previous years, to approximately $220 million a year. The Fiscal Oversight Management Board (FOMB) certified a fiscal plan on April 19, 2018 that will further reduce these transfers by 20 percent each year through 2022, and fully eliminate them by 2024 (Financial Oversight and Management Board for Puerto Rico, undated). In May Governor Ricardo Rosello came to an agreement with the FOMB on a path forward that did not affect these specific requirements (Reuters, 2018).[80]

[80] Also information communicated in a meeting with the Governor's Office of Municipal Affairs.

Emerging alternative structures and proposals for governance

In an effort to reduce costs and operate more efficiently some municipalities in Puerto Rico have begun to collaborate with neighboring jurisdictions to deliver services regionally. The Association of Mayors and the Federation of Mayors recently convened a working group to examine the issue and make recommendations.[81] To date regional service delivery efforts have largely been limited in scope; examples include two joint permitting offices and consortiums to remove solid waste and provide transportation services.[82]

Governor Rosselló and FOMB have both proposed expanding and formalizing this type of regional collaboration. As part of its plan to phase out of transfers from the Government of Puerto Rico to the municipal governments, the FOMB also requested the consolidation of municipal services and the creation of new structures at the regional level. The stated goal in the certified fiscal plan is to "reduce cost by leveraging scale, especially in areas of services provided directly to citizens, including public works and infrastructure, public safety, family services, education, and housing" (Financial Oversight and Management Board for Puerto Rico, undated) The FOMB also recommended that remaining transfers be tied to municipal and local administrations' performance; that municipal performance metrics be developed and published in order to benchmark municipalities against each other; and that the Government of Puerto Rico streamline laws in order to remove barriers to regional collaboration.

Governor Rosselló has proposed consolidating municipalities into a county structure that could lead to a "regionalization of services," a reduction in the number of municipalities, and the creation of fiscally independent and self-sufficient autonomous municipalities. The governor's new fiscal plan also acknowledges there is considerable duplication of effort between the Government of Puerto Rico and municipal government, and supports a "shared-services approach at the county level."

Puerto Rico has seen similar proposals before. In 2013, then-governor Alejandro Garcia Padilla created a Commission on Decentralization and Regionalization that studied the issue in depth. This commission concluded that some authorities could be delegated directly to municipal governments, but others would be better delegated to autonomous regional entities based on local capacity, the complexity of the activity in question, and the need to generate economies of scale. These autonomous regions would be managed by a committee of mayors, Government of Puerto Rico officials, and members of the public. The 2013 commission also pointed out that the Government of Puerto Rico itself had forty agencies with different regional structures, and more than 255 regional offices across Puerto Rico. The large number and variety of regional maps and regional offices was confusing to the general public and made it difficult to access services (Governor of Puerto Rico, 2014), something noted by several mayors that HSOAC engaged.

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[81] From HSOAC discussions with municipal officials at roundtables.

[82] From HSOAC discussions with municipal officials at roundtables.

Estudios Tecnicos, a non-profit think tank in Puerto Rico, produced a report in 2016 that studied municipal governance in Puerto Rico (Estudios Tecnicos Inc, 2016). Among other things, Estudios Tecnicos called on Puerto Rico's municipalities to greatly expand the use of municipal consortiums to consolidate administrative offices—and it recommended making these consortiums mandatory for municipalities that are vulnerable due to population, social, fiscal, or economic reasons. The study also recommended greatly expanding the use of municipal corporations to deliver municipal services such as human resources, transportation, and federal funds management (Estudios Tecnicos Inc, 2016).

We were not able to assess for this version of the report why previous efforts at regional service delivery had not been more effective. Following is a brief discussion of some other emerging arrangements related to shared provision of services.

Municipal land use and planning arrangements

The Autonomous Municipalities Act provided a mechanism for transferring powers related to planning and land use from the Government of Puerto Rico to the municipalities, and it established five levels of autonomy, with level V being full autonomy to issue land use permits and plans. The goal of this system was to incentivize municipalities to reach full financial and fiscal autonomy and drive their own development, but in practice only larger and wealthier municipalities have pursued full autonomy.

To be delegated these powers, municipalities must develop an approved local land use master plan. The approval process is supervised by Puerto Rico's Planning Board (the Board) and requires submission and approval of three types of plans: a territorial plan, an extension plan, and an area plan. The territorial plan is considered the main requirement, however, and must be reviewed every eight years and must address land classification, infrastructure for urban development, and an action plan for execution of the territorial plan.

Once the plans are approved by the Board, the municipality can request that the governor transfer certain powers of the Board and the permits office related to land planning, including complaints, authorizations, and permits. An agreement is signed between the municipality and the Board, which can limit the delegated powers based on the municipality's capabilities.

To date, only ten municipalities have reached level V—mainly the largest. Of the 53 municipalities with an approved territorial plan in 2015, those who reached level V had an average population of 158,546, while those in level I-IV had an average population of 36,635. Municipalities without an approved plan had an average population of 30,593.[83]

One potential explanation or why large municipalities tend to be the only ones to reach the highest level of autonomy may be budget related: to provide the delegated services, municipalities must establish permitting and planning offices and hire personnel but do not

[83] From meetings and white papers produced by University of Puerto Rico professors Carmen Concepción, William Vazquez, and Yolanda Cordero.

receive funding. This means that the law creates an incentive for smaller municipalities to allow the Government of Puerto Rico to continue to carry out these functions.[84]

There are a few examples, however, of smaller municipalities joining together to submit joint territorial plans. Barranquitas, Comerío, and Aibonito were the first municipalities to adopt this strategy; Cayey, Coamo, Villalba, and Salinas signed a second similar agreement. The Autonomous Municipalities Act specifically provides for these kind of agreements, and it stipulates that they must be approved by the Board and the governor ("Autonomous Municipalities Act of 1991," 1991).[85]

Municipal consortiums

The Autonomous Municipalities Act also includes a general grant of authority to municipalities to create consortiums. The act authorizes creating "intermunicipal bodies that will allow two (2) or more municipalities to identify common problems and to plan and develop joint activities or services in benefit of the inhabitants" ("Autonomous Municipalities Act of 1991," 1991). The act also allows municipalities to form consortiums among municipalities that are not geographically contiguous to provide administrative services such as human resources administration, revenue collections, solid waste recovery and disposal, medical emergency systems, and federal programs and tourist development offices ("Autonomous Municipalities Act of 1991," 1991). Consortiums are considered a distinct legal entity and must establish their own system for personnel management.

Historically, this authority has mainly been used as the framework for administering federal funds related to the Workforce Investment Act of 1998 (WIA). While municipalities with more than 500,000 residents may receive funding directly under WIA, smaller jurisdictions can form groups and be designated to receive funding by the governor of a given state. In Puerto Rico, this led to the creation of twelve municipal consortiums to receive and manage WIA funding.

The historical experience with these WIA consortiums has been mixed. In some cases rivalries surfaced between municipalities over control of the administrative process, budget, and the selection of personnel in WIA local areas. This may explain the historical lack of interest in pursuing consortiums to deliver other services (Cordero Nieves, 2018).

Pre-hurricane conditions

Municipal finances

Municipalities in Puerto Rico faced complicated fiscal challenges even before Hurricanes Irma and Maria made landfall. The most recent data available regarding municipal financial

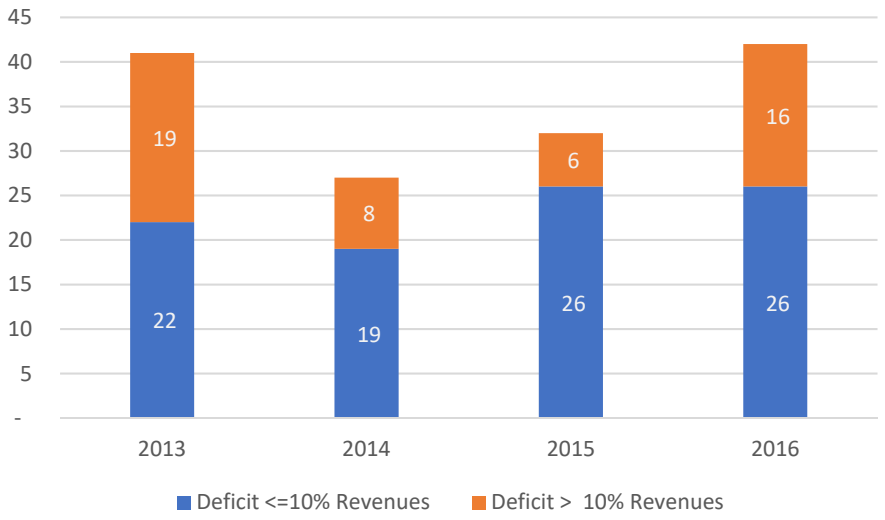
[84] From meetings and white papers produced by University of Puerto Rico professors Carmen Concepción, William Vazquez, and Yolanda Cordero.

[85] Also from a white paper submitted by UPR Professor Yolanda Cordero.

statements are from fiscal year (FY) 2016. Unfortunately, data are only available for 68 municipalities for FY2016 because ten municipal governments did not submit their financial statements in a timely manner to the Government of Puerto Rico. This may be indicative of other issues, including a lack of capacity or fiscal transparency.[86]

Figure 6.10 shows that 62 percent of municipalities for which data are available had deficits in their General Fund in FY2016. Sixteen of these municipalities had operating deficits greater than 10 percent of their revenue. This fact potentially had direct consequences on Puerto Rico's ability to prepare for the hurricanes, because municipal governments with a budget surplus are allowed to place funds in a special emergency fund intended for events such as Hurricanes Irma and Maria.[87] Although data were not available at the time of this assessment regarding how many municipalities had emergency funds in place prior to the hurricanes, but given that most municipalities ran budget deficits in FY2016 the majority would not have been eligible to do so. None of the municipal staff we interacted with referenced having had such a fund in place, while many identified it as a need.

Figure 6.10. Number of municipalities with a deficit in their General Fund (out of 68, FY2016)



Source: HSOAC analysis of municipal financial statement data provided by the Foundation For Puerto Rico. NOTE: The data exclude the municipalities of Canónavas, Ceiba, Cidra, Guánica, Lajas, Loíza, Santa Isabel, Toa Baja, Villalba y Yauco

[86] The FY2016 data excludes the municipalities of Canónavas, Ceiba, Cidra, Guánica, Lajas, Loíza, Santa Isabel, Toa Baja, Villalba y Yauco, because their financial statems were not submitted on time to the Office of the Controller (Oficina del Contralor) and to the Office of the Commissioner of Municipal Affairs (Oficina del Comisionado de Asuntos Municipales).

[87] Art. 7.002(b)(6) of the Autonomous Municipalities Act of 1991 authorizes municipalities to create an Emergency Fund when they have a budget surplus, using up to 30% of that surplus for this purpose.

To shed some light on the specific components of municipal revenue sources, we analyzed the budget submissions for municipalities in Puerto Rico which include a detailed breakdown of forecasted revenue. Figure 6.11 shows that 77 percent of the budgeted revenue in the General Fund (in FY2016) came from municipally-derived sources. The main own source of revenues for municipalities are property taxes. The combined revenues from exempt and non-exempt properties made up 29 percent of total municipal revenues in the General Fund.[88] Business license fees are also an important source of income representing 23 percent of total revenues in FY2016,[89] while revenues from sales taxes (IVU) represented about 9 percent of total municipal revenues.

The composition of revenues for municipalities in Puerto Rico appears to be broadly in line with the composition of revenues for the average municipal government in the continental United States in 2012, the most recent year for which comparable data are available. According to the 2012 Census of Governments, 74 percent of the general revenues for U.S. municipal governments came from tax receipts, with property taxes accounting for 24 percent, followed by taxes on sales and gross receipts at 13 percent. One key difference between municipalities in Puerto Rico and the mainland was the role that business license fees play in Puerto Rico, where they represent more than one-fifth of municipal general revenues. In municipalities in the continental United States, on the other hand, income tax only represents about 6 percent of the general revenues for municipal governments (4 percent from individual income tax and 2 percent from corporate income tax).

Although revenues from own-sources make up the largest share of revenues, intergovernmental transfers are also an important component. As Figure 6.11 shows, transfers from the Government of Puerto Rico[90] (including State compensations for Christmas Bonus) accounted for 14 percent of the projected revenues in the General Fund, while contributions from

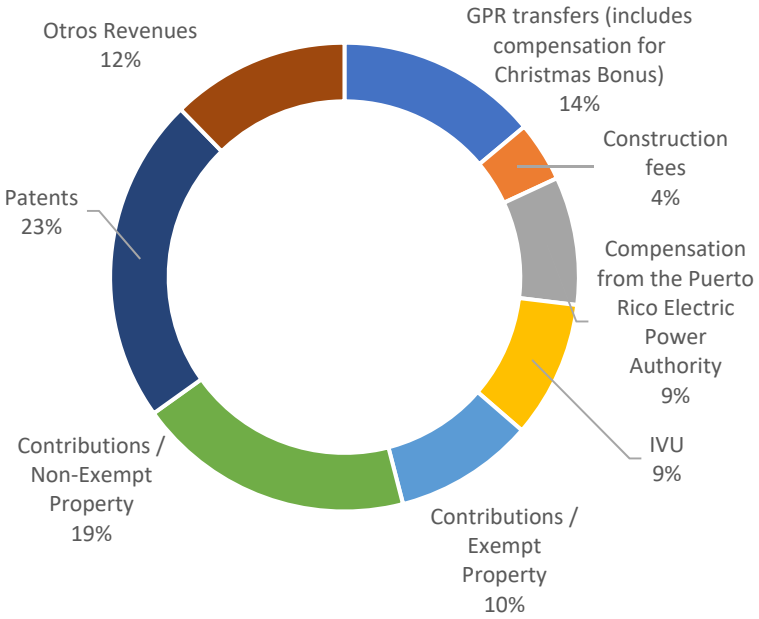
[88] The Municipal Revenue Collection Center (Centro de Recaudación de Ingresos Municipales, or CRIM in Spanish) is the entity charged with assessing property values and collecting real estate taxes in Puerto Rico. Both the legislature and the municipal governments play a role in setting local property tax rates, and the first $15,000 of assessed value on owner-occupied residences is exempt.

[89] As noted earlier in the background section, businesses operating within a municipality must pay an annual business license fee or tax directly to the municipal government. This fee varies by municipality but generally ranges from 0.2% to 0.5% of gross income for non-financial businesses, and from 1% to 1.5% for financial-related businesses.

[90] Act No. 83 and Act No. 80 of the Legislature of Puerto Rico authorized the central government to make a number of transfers to the municipalities each year, including: 2.50% of the net internal revenues of the General Fund for each fiscal year; 35% of the annual net revenues derived from the operation of the additional lottery system; an annual amount from the central government's General Fund to compensate the municipalities for the $15,000 Real Property Exemption and the $50,000 Personal Property Exemption; and an annual amount from the Commonwealth's General Fund to compensate the municipalities for the exemption of 0.20% of the assessed valuation of all taxable property within the municipalities.

the Puerto Rico Electric Power Authority[91] (PREPA) represented and additional 9 percent. Nevertheless, municipalities in Puerto Rico appear to rely slightly less on intergovernmental transfers than their counterparts in the continental United States. According to the 2012 Census of Governments, transfers from other governments accounted for 26 percent of the general revenues of municipal governments in the U.S.

Figure 6.11. Revenues in the General Fund – Budget FY2016



SOURCE: HSOAC analysis of Office of the Commissioner of Municipal Affairs data.

A substantial number of municipalities in Puerto Rico are extremely dependent on the transfers that the FOMB recommended, and the Governor announced, will be eliminated by FY2024. According to information from the FY2016 financial statements, the average value of all intergovernmental transfers (including PREPA) over revenues in the General Fund was 21 percent.[92] However, intergovernmental transfers accounted for more than half of the revenues in the General Fund for 25 out of the 68 municipalities in Puerto Rico for which we have financial statement information. There are some clear geographic disparities. Coastal municipalities in the

[91] PREPA has power plants and offices in every municipality. Instead of paying business license fees or municipal taxes, PREPA pays a contribution. This is known as a Contribution Instead of a Tax (Contribución en Lugar de Impuesto, or CELI in Spanish).

[92] This indicator of intergovernmental transfers over revenues in the General Fund was constructed, for each of the 68 municipalities on which we have data, by the Foundation for Puerto Rico. We acknowledge their contribution to this study.

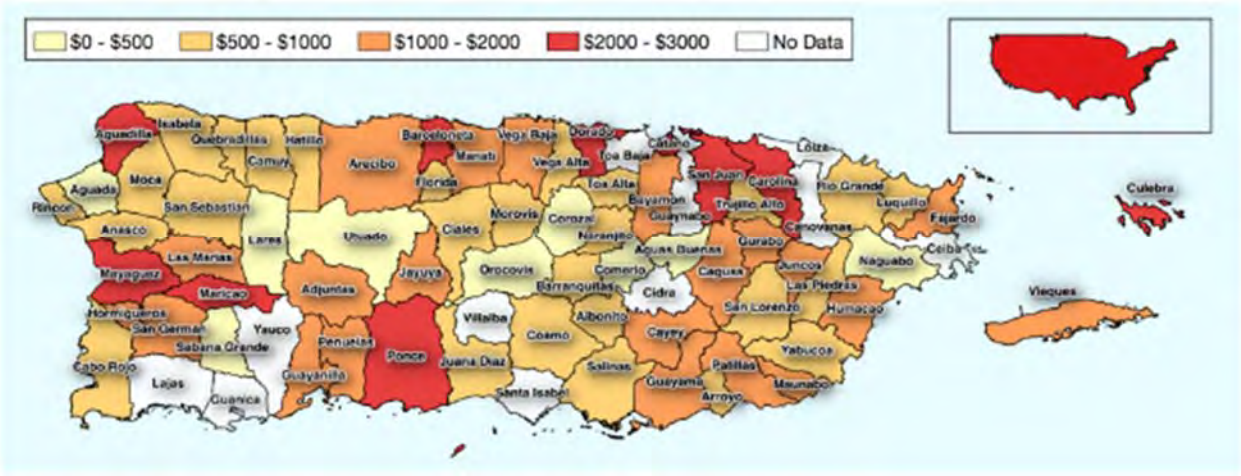
relatively wealthy metropolitan area of San Juan depended much less on intergovernmental transfers in FY2016 than municipalities in the generally poorer mountainous central region.

The data shows that municipalities that relied less on intergovernmental transfers were not necessarily in a better financial situation, however, as many of them they were likely to go into debt to balance their budgets. Total municipal debt has increased by more than 50 percent over the past decade, rising from roughly $2.5 billion in 2007 to $3.9 billion in 2016, and the average municipal debt per capita was $1,505.[93] This represents about 6 percent of Puerto Rico's outstanding debt (Government of Puerto Rico and Government Development Bank of Puerto Rico, 2018). However, the overall municipal debt load masks substantial variation between municipalities. Figure 6.12 shows that municipalities in the metropolitan area of San Juan had debt per capita values that were considerably higher than the average, while the municipalities in the central mountain region had values well below it.

The average debt per capita for municipalities in Puerto Rico appears to be substantially less than the corresponding value for municipal governments in CONUS, which was around $2,000 in 2012. In other words, the average municipality in Puerto Rico relies less on transfers and carries less debt than the average municipality in the United States as a whole.

[93] Notably, these figures exclude the large amount of debt associated with pension and retirement health obligations to government employees.

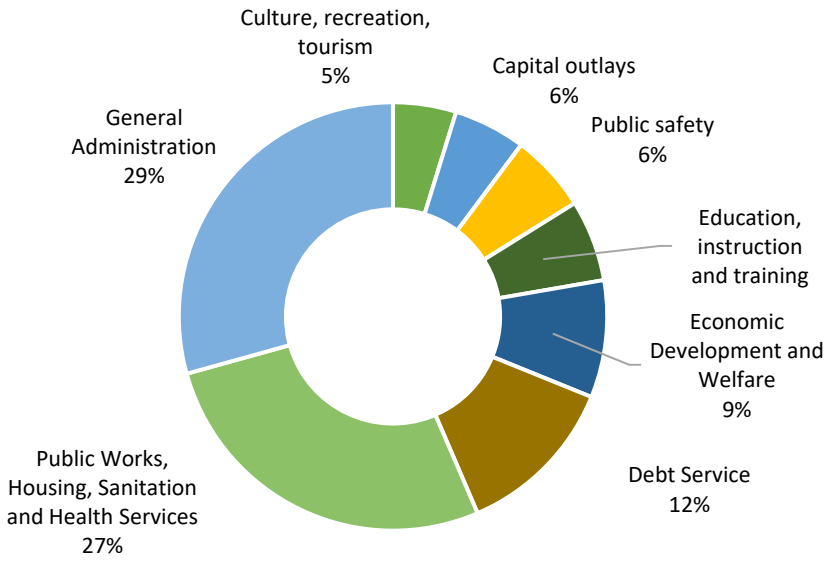
Figure 6.12. Long-Term Debt Per Capita (FY2016, in dollars)



Source: HSOAC analysis of data provided by the Foundation for Puerto Rico and 2012 Census of Governments
Note 1: Debt values excludes future pension liabilities.
Note 2: The data excludes the municipalities of Canónavas, Ceiba, Cidra, Guánica, Lajas, Loíza, Santa Isabel, Toa Baja, Villalba y Yauco
Note 3: Municipal Governments in CONUS average: $2,000 (2012).

However, municipalities in Puerto Rico allocate more of their budget to paying for debt than their counterparts in the continental United States. Figure 6.13 shows that 12 percent of municipal expenditures in Puerto Rico went to the repayment of debt principal and interest. As a comparison, large cities in the US had a ratio of debt service to expenditures of 9.6% in 2010 ("Debt Service Expenditure Ratio in Large Cities," 2012).

Figure 6.13. Expenditures composition – General and other funds (FY2016)

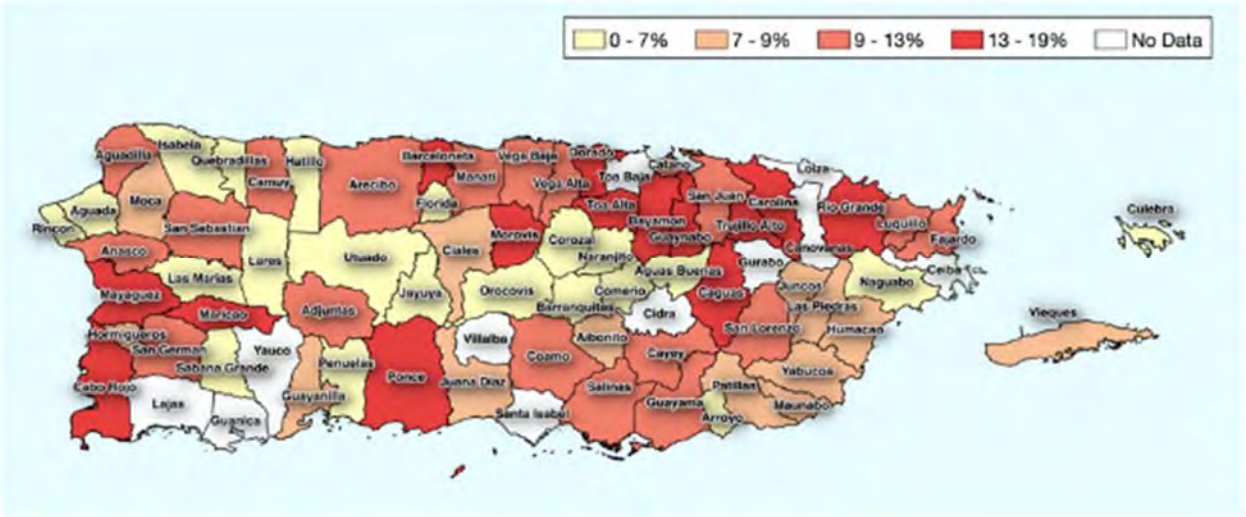


Source: HSOAC analysis of data provided by the Foundation for Puerto Rico. Note: The data excludes the municipalities of Canónavas, Ceiba, Cidra, Guánica, Lajas, Loíza, Santa Isabel, Toa Baja, Villalba y Yauco

Figure 6.14 shows that the average burden of debt service varied significantly across municipalities in Puerto Rico with a substantial number of municipalities allocating almost 20 percent of their total expenditures to paying debts in FY2016—or more than double the average in the United States.[94] Municipalities that carry more debt per capita in Puerto Rico tend to be concentrated on the coasts and have larger populations and higher revenues than those that do not.

[94] In Morovis, Bayamón, Carolina and Gurabo, total debt service represented between 18%-19% of the total expenditures in FY2016.

Figure 6.14. Debt Service/Total Expenditures (FY2016)



Source: HSOAC analysis of data provided by the Foundation for Puerto Rico. Note: The data excludes the municipalities of Canónavas, Ceiba, Cidra, Guánica, Lajas, Loíza, Santa Isabel, Toa Baja, Villalba.

The data presented in this section show that in some respects municipalities in Puerto Rico are comparable financially to their counterparts in the United States. However, by some key metrics municipalities in Puerto Rico fare worse—including the high levels of debt service they carry and the high number that run operating deficits each year. This is particularly true for some key indicators that bond rating firms use municipalities, including their general fund balance as a percent of their revenues and the 2-year ratio of their revenue to their expenditures.

In fact, it is also possible the financial condition of municipalities in Puerto Rico may appear better than it is. We were not able to collect detailed data on what resources municipalities own or their condition (for example, vehicles and equipment), the number of staff in specific units, or the nature and quality of services provided. Municipalities could appear reasonably financially health by some measures as a result of providing fewer services or lower quality services than they had in the past or relative to their mainland counterparts, or having limited inventories of resources relative to comparably-sized communities in the continental US.

The growing municipal debt load meant that municipalities were confronted with the need to cut costs and raise revenue collections even before the FOMB required reducing transfers from the Government of Puerto Ricoto municipalities by 20 percent each year through 2022, with a goal of fully eliminating them by 2024 (Financial Oversight and Management Board for Puerto Rico, undated).

However, municipalities face significant challenges in their efforts to reduce costs and increase revenues. Many have already begun to tighten their belts, as overall municipal budgets declined by 3.5 percent from FY2013 to FY2017. Figure 6.15 shows that 23 municipalities had reduced their budgets by at least 10 percent, while 4 had made cuts of at least 20 percent.

Moreover, adverse economic conditions, tax exemptions, and recent changes to tax laws in Puerto Rico all negatively affect the ability of municipalities to increase revenues. In the case of property taxes, property tax collections have been affected by the reduction in property values. According to open source information on real estate websites, the median price for homes listed for sale in Puerto Rico has declined from $307,000 in May, 2010 to $118,000 in April, 2018 (Zillow, 2018). There are also the special real estate tax exemptions granted to commercial properties by the Government of Puerto Rico through PRIDCO tax-free zones. [95,96] As previously noted, business license fees account for 23 percent of municipal revenue, but over time the Government of Puerto Rico has created a number of exemptions to this requirement.[97] Sales taxes are also an important component of municipal budgets, but the municipal component of the IVU was reduced from 1.5 percent to 1 percent in 2015. It is also important to note that the future of PREPA—parts of which will be privatized by the Government of Puerto Rico[98]—may call into question its contributions to municipal budgets, which currently account for 9 percent of overall revenues. The FOMB recommends the elimination of these contributions in order to pass the fiscal gap to customers.

[95] http://www.pridco.com/why-puerto-rico/incentives/Pages/default.aspx.

[96] A number of mayors at HSOAC led roundtables stated that they are not consulted when PRIDCO designates these tax free zones, which they believe negatively impact their budgets because they are required to provide services to these areas but are prohibited from collecting taxes or business licenses from the companies operating there.

[97] For example, the 51 public corporations operated by the government are fully exempt. Some other key entities receiving exemptions include small businesses with income less than $5,000, international banks and insurance companies, businesses operating in PRIDCO-designated tax-free zones, and businesses selling oil or derivative products to PREPA. See http://www.gdb.pr.gov/documents/AGuidetoDoingBusinessinPR-ll.pdf

[98] "Puerto Rico governor signs bill for partial privatization of PREPA", by Robert Slavin, The Bond Buyer, June 20, 2018, available at: https://www.bondbuyer.com/news/puerto-rico-governor-signs-prepa-partial-privatization

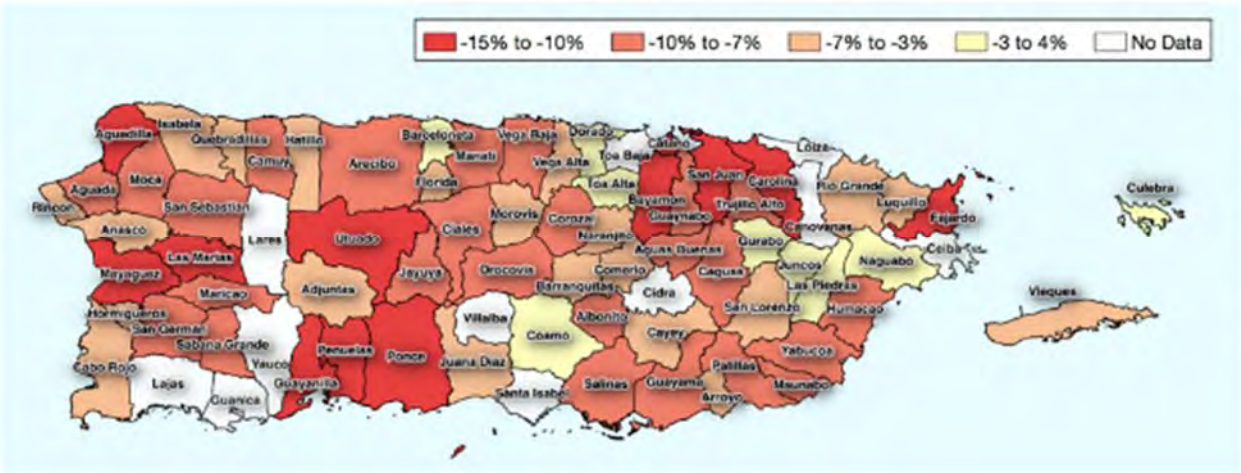
Figure 6.15. Change in the General Fund budget FY2013-FY2017

Source: HSOAC analysis of Office of the Commissioner of Municipal Affairs data.

Population loss and unemployment by municipality

As described in the previous section, population loss has been a significant pre-storm issue. Figure 6.16 shows that eleven municipalities lost between 10 and 15 percent of their populations between 2010 and 2016—including key metropolitan areas across the Island such as San Juan, Ponce, and Mayaguez.

Figure 6.16 Population change 2010-2016, by municipality



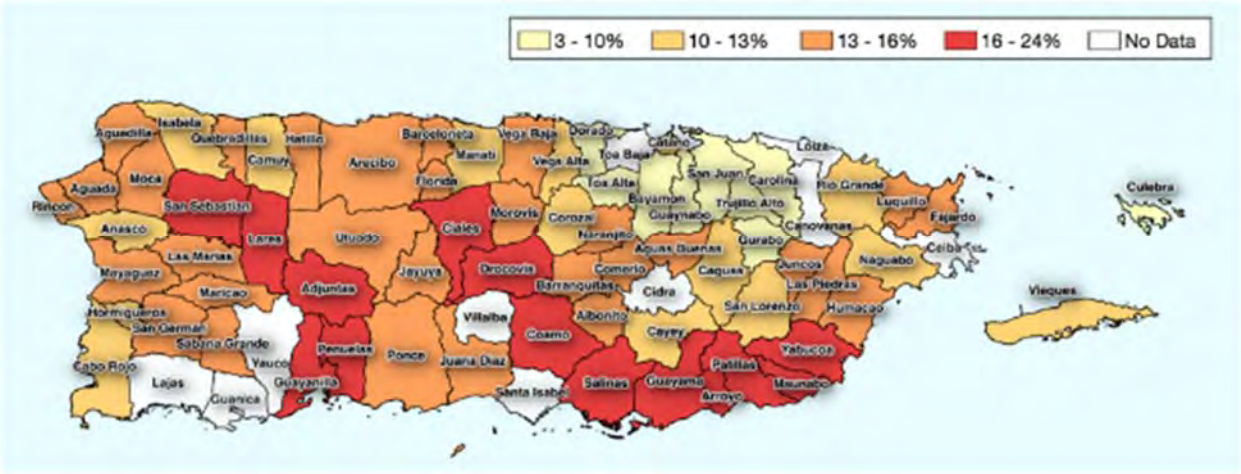
Source: HSOAC analysis of data provided by the Foundation for Puerto Rico. Note: The data excludes the municipalities of Canónavas, Ceiba, Cidra, Guánica, Lajas, Loíza, Santa Isabel, Toa Baja, Villalba y Yauco.

Puerto Rico also faced high levels of unemployment prior to Irma and Maria. Figure 6.17 shows that unemployment exceeded ten percent in 60 of the 68 municipalities for which data are

available in 2016, and was between 16 and 24 percent in fourteen of those municipalities. The municipalities with the highest levels of unemployment were largely concentrated in the mountain region and the southeast coast —the two geographic areas that were among the hardest hit by the hurricanes.

HSOAC did not have access to detailed demographic data on the characteristics of individuals who had left Puerto Rico, but the general perception among mayors and subject matter experts we spoke with was that the Island was experiencing a "brain drain" in which the individuals who left were often younger or those who were most able to do so by having financial resources or capabilities which were in demand by employers elsewhere. Generally speaking, these types of individuals would require fewer forms of government service and assistance, could contribute to Puerto Rico's economy, and had skillsets which would be valuable to the island. In contrast, residents who were unable to leave were more likely to be elderly, in need of more assistance from their government, and have fewer employment opportunities elsewhere. Similarly, individuals who were unemployed were more likely to require government assistance, and less likely to be able to contribute to the economy.

Figure 6.17. Unemployment rate by municipality (2016)



Source: HSOAC analysis of data provided by the Foundation for Puerto Rico. Note: The data excludes the municipalities of Canónavas, Ceiba, Cidra, Guánica, Lajas, Loíza, Santa Isabel, Toa Baja, Villalba y Yauco.

Municipal government capacity and services

Human resources

Municipalities had been reducing their staff in the years prior the hurricanes. In 2016 there were 53,987 municipal employees, which represented a decrease of 1.9 percent from 2014 staffing levels. Over the same period, the population of Puerto Rico declined by 3.8 percent, suggesting that some of these loses could have been related to overall population loss from the Island. However, there is evidence that financial pressures also played a role, as during this period,

municipalities were replacing government workers with contractors—that is, the number of civil service positions declined by 6.4 percent during this period while the number of employees in contract or other transitory positions increased by 2.9 percent. In all the regional roundtables HSOAC conducted, participants indicated that declining budgets in the years before the hurricanes had undesirable economic consequences such as cutting workforce hours and reducing staff via attrition to avoid mass layoffs. Mayors expressed concerns that this had resulted in a loss of institutional memory in the municipal staff. However, without having baseline performance indicators for municipal governments it is difficult to assess whether this shift from permanent to contract staff has had a direct impact on municipal government capacity.

The average number of municipal employees per capita in Puerto Rico was 17.5 in 2016—very close to the overall average for United States municipalities of 18.2 according to the 2012 census of state and local governments. This average masks substantial variation across Puerto Rico's municipalities, however. Some municipalities, including Toa Alta, San Lorenzo, and Barranquitas, had 5 to 7 municipal employees per 1,000 residents. Other municipalities had almost 10 times as many employees per capita, including Vieques (40 per 1,000 residents), Maricao (41 per 1,000 residents), Barceloneta (53 per 1,000 residents) and Culebra (86 per 1,000 residents).

Services provided by municipalities

This section analyzes service delivery at the municipal level in order to show what services have been provided by municipalities, what services have been provided by other government entities (the government of Puerto Rico (GPR)), and what services have not been provided in the community. The information here is based on the data recorded in the ICMA instrument during site visits to municipalities.

Figure 6.18 covers services related to public safety and shows municipal staff reported high levels of overlap between municipal governments and the Government of Puerto Rico. For example, municipal staff reported that a number of public safety services were being delivered by municipal governments and by the Government of Puerto Rico, including: crime prevention in 90 percent of municipalities, public safety dispatch in 74 percent, emergency medical care in 69 percent, and emergency medical transport in 69 percent. In fact, municipal staff reported that both the municipal government and other forms of government provide the same service for half of the public safety services we asked about.

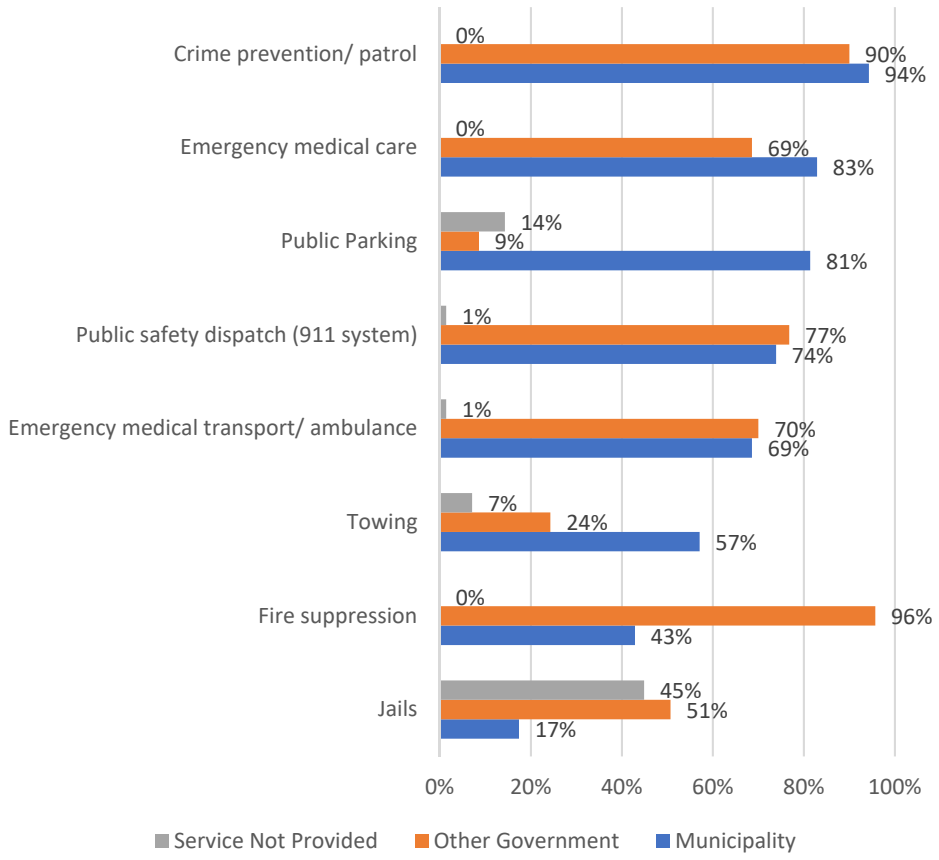
The high levels of overlap in this arena may be partly due to Law No. 19 of 1977,[99] which granted municipalities the authority to form municipal police forces that operate independently, with the mayor serving as commander-in-chief. Given the deteriorating financial situation that municipalities face, in recent years many of them have significantly downsized their municipal

[99] Municipal Police Act, Section 3. Link (in Spanish): http://www2.pr.gov/ogp/BVirtual/LeyesOrganicas/pdf/19-1977.pdf [

police force. In two roundtables participants stated that they wanted the Government of Puerto Rico to take over policing, and that their municipalities would likely eliminate their municipal police forces if the Government did not absorb them.

It is important to note here, however, that this kind of overlap in public safety services is not necessarily uncommon in the United States. Policing, for example, is often carried out by state, county, and local governments. However, in other cases, such as fire and EMS, these services are typically provided by one level of government. In all cases, what is most relevant is whether services are duplicative, whether there are gaps in services, what the quality of services is, and whether services might be more efficiently and effectively provided under a different organizational arrangement. We were not able to collect detailed information on most of these issues for this assessment, but focused our collection on municipal official's views regarding whether services might be duplicative.

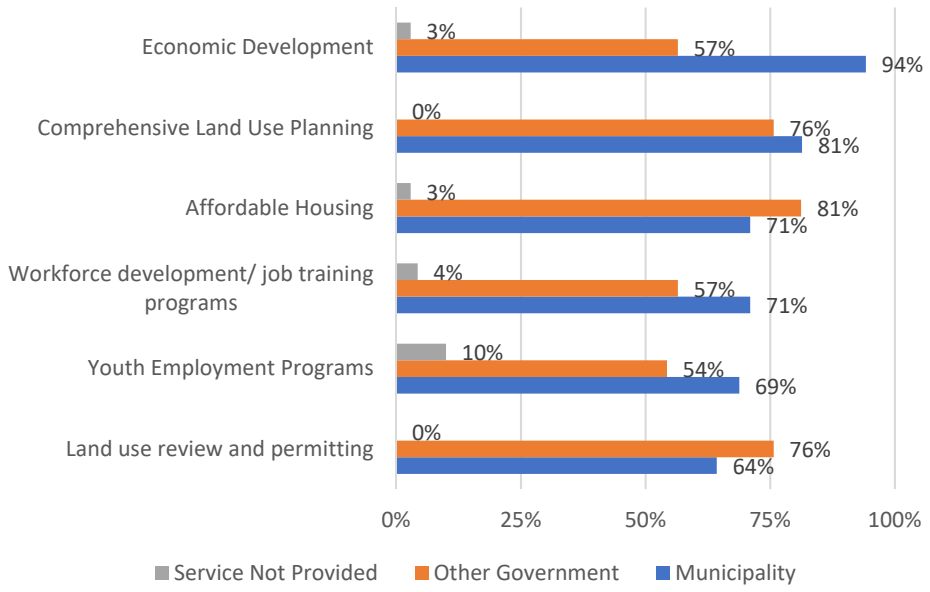
Figure 6.18. Municipality services related to public safety



Source: HSOAC analysis of ICMA municipal survey data. Note: Based on interactions with municipal staff from 70 municipalities. Services may be provided by more than one level of government so do not sum to one hundred percent.

Figure 6.19 presents information on services related to economic development and planning. Despite the powers conferred to municipalities by the Autonomous Municipalities Act, in practice, many municipalities in our sample reported the involvement of other government organizations (usually the Government of Puerto Rico) in the provision of services related to economic development and the preparation of land for construction, improvement, and repair. These overlaps can create economic inefficiencies and problems of jurisdiction between the municipalities and the Commonwealth—an issue that emerged as a recurrent topic across all the regional roundtables with the mayors or their representatives.

Figure 6.19. Municipality services related to economic development and planning



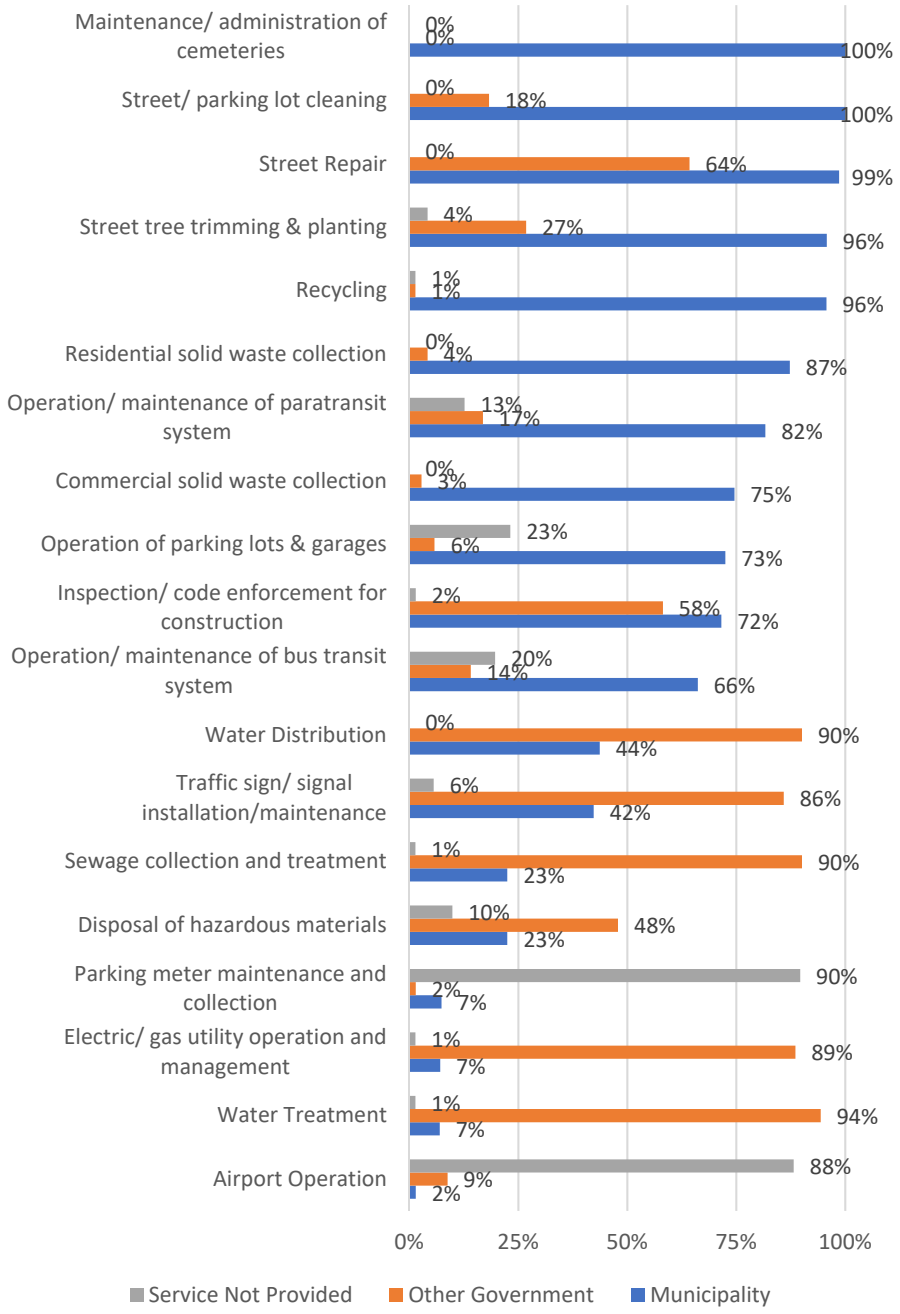
Source: HSOAC analysis of ICMA municipal survey data. Note: Based on meetings with municipal staff from 70 municipalities. Services may be provided by more than one level of government so do not sum to one hundred percent.

Figure 6.20 presents information on public works services. The figure shows a clear divide between services that are mostly offered by municipal government and services that are mostly offered by the GPR. For example, street and parking cleaning, solid waste removal, recycling, and public transport operation and maintenance are mostly managed by the municipalities. By contrast, services related to water, electricity and gas supply and management are mostly provided by the GPR.

Figure 6.20 also indicates that there could be an important overlap between the municipal government and the GPR in the provision of services related to street repair and maintenance. During seven roundtables, participants noted that this was an area with significant overlap between their governments and the GPR. This is not unexpected since two-thirds of the rural

roads and almost three-quarters of the urban roads in Puerto Rico are owned by the municipalities. However, in the majority of roundtables participants noted that municipalities provide maintenance to roads they do not own or have jurisdiction over. Participants stated that this is the case even when they do not receive timely compensation from GPR, which adds to the fiscal pressure on their budgets. Roundtable participants also explained that while their citizens do not know or care who owns specific roads, they expect roads to be maintained and repaired in a timely manner. As a result, some municipalities have felt obligated to maintain roads they do not technically have responsibility for maintaining.

Figure 6.20. Municipality services related to public works



SOURCE: HSOAC analysis of ICMA municipal survey data. Note: Based on meetings with municipal staff from 71 municipalities. Services may be provided by more than one level of government so do not sum to one hundred percent.

Municipalities also share responsibilities for health and human services with other government entities; some of the key services being provided by most municipal governments include transportation to medical appointments and operation of nursing homes/ senior care

centers. The GPR is more likely to be in charge of sanitary inspections and programs related to addiction and mental health issues. Municipal staff report substantial overlap in the provision of a number of key services, including operation of daycare facilities, support to people with disabilities, nutrition programs, and child welfare programs. Additionally, 34 percent of the municipalities assessed report not having mental health centers—something that is concerning because many municipalities identified mental health services as a key concern after the hurricanes. Also, 34 percent of municipalities report not having electric power centers for medical equipment. This is also a source of concern given that after the storms many patients that require medical equipment could not use them due to lack of electricity. More information on health and human services is available in the Health, Social Services, and Education chapter of this report.

Assets

The Government of Puerto Rico is required by law ("Autonomous Municipalities Act of 1991," 1991,Section 8.010) to coordinate with municipalities and provide counsel on their accounting systems and methods in order to maintain uniform municipal accounting. The law calls on the Government of Puerto Rico to “have an effective control and accounting of all funds, properties, and assets belonging to the municipality.” As part of this requirement, municipalities can develop and maintain their own asset control systems and procedures so long as they meet certain standards. Data collected by HSOAC show that different methods and systems of accounting do indeed exist, creating possible inefficiencies in the way the 78 municipalities interact with the Government of Puerto Rico in this critical area. For example, only 60 percent of municipalities assessed reported having a dedicated office for this asset management activity, and their methods ranged from keeping an Excel spreadsheet to having an automated system for inventory.

Every municipality we met with reported owning land, vehicles, and buildings. However, detailed information concerning these assets and their conditions were generally not provided, or when it was provided was paper-based. There is no electronic repository of information about the ownership and status of municipal assets.

As one example, identifying the ownership of core infrastructure such as roads can be problematic since defining where ownership precisely begins and ends can be difficult. Even so, roundtable participants noted that the day-to-day care of Government of Puerto Rico roads within their municipalities largely falls on them because residents have come to expect that the municipality will provide the service—and also because residents do not generally know which government entity owns which road. Table 6.3 shows that more than 70 percent of the municipalities report owning more than half of the roads within their jurisdictions.

Table 6.3. Road ownership by municipalities

Percentage Owned	Percentage of Municipalities
50-75%	37%
More than 75%	34%
25-49%	20%
Less than 25%	6%
Unknown/No Response	3%

Source: HSOAC analysis of ICMA municipal survey data.
Note: Based on meetings with 68 municipalities

Governance

As described previously, the need for some kind of regional governance structure to provide services in Puerto Rico has been studied and debated for years. In the past five years alone, there have been two major studies on this topic, including one produced by a bipartisan commission under the previous Governor's administration. This debate in Puerto Rico has largely focused on three alternative visions:

1. **Counties**: Governor Rosselló and the FOMB have agreed on a certified fiscal plan that will require regional service delivery, potentially by instituting a county structure. This could include merging or consolidating municipalities that are deemed too small to be economically viable.
2. **Autonomous regions**: The 2014 Commission on Decentralization and Regionalization proposed a middle-ground solution that would have ceded some authorities directly to municipalities, but also created autonomous regions to handle services where economies of scale come into play.
3. **Consortiums or ad hoc regions**: Many municipalities are already working on creating small consortiums or other kinds of regional collaborations with neighboring municipalities.

During our visits to municipalities, we asked municipal staff who expressed a willingness to explore regional collaboration to identify services that they believed most lent themselves to being shared. Three key activities and services—purchasing, human resources, and public safety—were emphasized by 19 percent of municipalities who reported a willingness to explore collaboration and sharing. Municipal leadership and staff said that being able to leverage consortiums of municipalities to buy goods in bulk could deliver economies of scale that would allow them to save money. They also said that human resource functions can be centralized, and that hiring can be done in a standardized way based on education and experience—something that also emerged as a theme in many of the roundtables HSOAC conducted.

Concerning public safety, municipal leadership and staff expressed that there should be more collaboration not only between the municipalities but also with the Government of Puerto Rico police. Participants in two roundtables noted that they wanted the Government of Puerto Rico to

take over policing in general and absorb the current municipal police forces that many municipalities manage.

While single service category emerged as a priority for consolidation, about two thirds of municipalities reported during site visits that they had engaged in sharing services. Municipalities seemed to generally favor sharing services, but may not have considered options thoroughly. We did not hear any explicit opposition to regionalizing or consolidating service deliver, but only a relatively small number of mayors seem to have specific options in mind. Many of those who did were those that were part of a consortium or service-sharing already, such as Caguas (INTECO) and Mayaguez (shared permit office). The distribution of responses may reflect differing priorities or needs among the municipalities.

Government communication with residents, transparency, and management

HSOAC attempted to determine how municipal governments make services accessible to community members, provide transparency regarding how their governments operate, and manage government operations. An increasingly common way of providing access to a country's government services is through technology, such as online portals where citizens can obtain information, requests services, or conduct certain types of transactions with their governments, and phone- or internet-based "311" systems, which provide a central point for routing and tracking citizen service requests. During visits to individual municipalities, HSOAC asked municipalities about a variety of resources and services that might be provided online.

Almost three-quarters (73 percent) of municipalities reported having an official government website with a list of services provided. More than half reported using electronic systems for emergency alerts (56 percent) and for online citizen engagement and receiving comments from residents (61 percent).

However, while these services were available in more than half of municipalities, many other online services were available in a quarter or fewer municipalities. Only 27 percent of municipalities reported having a centralized 311-type customer service system. Most municipalities do not offer an electronic means of making payments to the government for taxes (23 percent), utility bills (7 percent), or fines and fees (10 percent). They also generally do not have electronic portals to facilitate common business interactions with government, for example, for completing and submitting permits (27 percent) or for business license applications or renewals (10 percent). Only a little more than a third (37 percent) reported posting budgets, financial statements, and other public documents for search or download. Few reported making legislative meetings available online for viewing (18 percent).

Municipal governments did report using a variety of non-electronic means for sharing information with the community. The single most common venue for sharing information were religious institutions, with 79 percent of municipalities reporting that they relied on religious institutions in this way. Almost equally commonly cited were schools (73 percent),

neighborhood groups (73 percent), non-profit groups (67 percent), and city information and referral services (78 percent).

To better understand the extent to which municipalities engage the community, HSOAC asked municipal governments whether they sought to involve citizens in certain types of decisions and processes. More than two-third of municipalities reported that they involved citizens either individually, in groups, or as a whole in planning services (70 percent), designing services (70 percent), delivering services (73 percent), and assessing services (63 percent).

There is also a lack of integration between the online presence of GPR and municipalities. For example, the Government of Puerto Rico's online portal (http://pr.gov) provides basic information about each municipality, including land area, population, the name of the mayor, and contact information for the municipal government. However, only 31 of the 78 municipalities (40 percent) have a link to an official website on the portal, and only 18 percent of municipalities have a working link to their official web portals.

HSOAC's analysis of municipal web presence showed that 32 municipalities (41 percent) have official websites, 73 have active facebook pages (93 percent), and 33 use twitter to disseminate information (42 percent).[100] The fact that most municipalities do not appear to have websites, and that many of those that do have websites are not linked to correctly in the Government of Puerto Rico's web portal, illustrates how difficult it can be to access public information for the municipalities. Social media is clearly the preferred method of communication used by municipalities, which suggests that disseminating information online is a bigger priority than providing services online.

Emergency preparedness

Municipal governments play a critical role in emergency operations because they are typically the first responders. Puerto Rico's State Agency for Emergency Management and Disaster Administration (AEMEAD) developed and adopted an operational plan for emergencies in September 2016 that spells out the roles and responsibilities of municipal governments and state agencies during an emergency (Departamento de Justicia, 2016). The plan calls for state and local agencies, as well as NGOs and private organizations, to coordinate with AEMEAD leadership in preparation for such an event and to harness their capacities towards a more effective response.

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[100] HSOAC analysis of Government of Puerto Rico and municipal web sites, as of June 14, 2018.

Further, it establishes fifteen "Emergency Support Functions" (ESF), describes the functions each of these entail, and designates the government office or department responsible for carrying out or coordinating that function. At the municipal level, municipalities are expected to provide resources and support to the Municipal Office of Emergency Management (OMME) director in the creation and implementation of a Municipal Operational Plan for Emergency Management, and to update this plan regularly and train relevant personnel to implement it. Specific functions to be undertaken by municipalities include carrying out the following: public advisories, search and rescue, public safety tasks, medical emergency assistance, evacuations, refuge set-up, provision of food and water, and damage assessment.[101]

The operational plan for emergencies establishes that municipal governments have the primary responsibility to respond and implement all emergency statutes and ordinances and declare a local state of emergency that may mobilize local or regional resources.[102] If these measures are insufficient, municipalities are authorized to request support through their corresponding AEMEAD regional zone (there are 12 regional zones based on geographical groupings of municipalities; Figure 6.21). If emergencies are too large to be handled regionally, the AEMEAD zones can request assistance through the State Center of Emergency Operations (COE), which may then recommend that the governor authorize state resources and relief efforts or if necessary, to declare a general state of emergency and activate the Operational Plan of Emergencies.

The activation of the COE follows five staggered levels, depending on the severity of the event and the level of response required:

Level 5 – day-to-day operations
Level 4 – local response local COE activation
Level 3 – zone activation: zone(s) COE activation
Level 2 – partial COE activation: COE with FEMA representation activated, but without presidential declaration
Level 1 – total activation with presidential declaration.

[101] Ibid.

[102] Ibid. Page. 34-35, *Assignment of responsibilities, Local Government section, point 7:* "The Mayor or official designated by the mayor, as head of government of that jurisdiction, is responsible for the safety and public well-being of the population of that jurisdiction. Thus, the local government: […] depending on local or state laws, has the extraordinary powers to suspend local laws and ordinances such as: establishing curfews, directing evacuations, and, in coordination with the local health administration, ordering quarantines."

Figure 6.21. Emergency Management and Disaster Administration Zones

SOURCE: Puerto Rico Emergency Management Agency, Office of Technology

Through their respective OMMEs, municipalities maintain a close relation with regional AEMEAD offices, and are entrusted with exchanging information on ongoing emergency status and needs. Municipalities are responsible for coordinating local resources during an incident response, collaborating with Government of Puerto Rico authorities, and maintaining and carrying out disaster prevention and response plans. These response plans are critical components of the overall effort in that they describe how municipalities provide: warnings; search and rescue efforts; emergency medical assistance; and emergency shelter and food. They also describe how municipalities are expected to undertake damage assessments.

According to the operational plan for emergencies, in times of disaster, the municipalities also have "extraordinary powers" to suspend laws and local ordinances. For example, the municipalities have the power to establish quarantines in coordination with local health

authorities, or to implement a curfew, among other actions.[103] In addition, the municipalities must establish mutual aid agreements with leaders in the private sector, volunteer organizations, and other community groups to support incident response and management.

Almost 90 percent (60 out of 70) of the municipalities surveyed by HSOAC reported having disaster preparedness plans—or plans that guide how a locality will respond to a disaster—in place before 2017 hurricane season, and 72 percent of municipalities reported conducting emergency preparedness exercises at least once a year. Only 37 percent reported that the plans worked adequately after the hurricanes. Of those with disaster preparedness plans in place, 57 percent specifically addressed how to protect children, seniors, and individuals with disabilities. Lastly, according to a FEMA Community Conditions Assessment from May 2018, 19 of the 78 municipalities had hazard mitigation plans—which aim to reduce the ultimate damage caused by a disaster—that were expired.

Despite most municipalities having emergency response plans in place, and several of them taking extraordinary measures to prepare for the hurricanes, Mayors claimed that the scale and intensity of the damage caused by Hurricane Maria was far too overwhelming and emergency plans had to be modified as recovery progressed. Moreover, communication and power interruptions throughout the island made coordination with state and federal authorities sluggish and challenging. Thus, at least in the initial stages, municipalities were left with little option but to rely on their own personnel only and respond using municipal offices or with staff and material support from neighboring municipalities.

At HSOAC's mayoral roundtables, respondents described pre-storm emergency preparedness planning as ineffective in the face of a hurricane as devastating as Maria. More detail on emergency operations in the aftermath of the storm, which revealed deficiencies in pre-storm planning, are described in the next section on hurricane damage.

Hurricane damage

This section focuses on the hurricanes' impact on municipal operations and services. In general terms, Hurricanes Irma and Maria exacerbated underlying problems that existed before the hurricanes—including placing additional stress on local economies and municipal finances—while also creating new issues. The fiscal situation of municipal governments is likely to deteriorate substantially in 2018 due to expected sharp declines in fee, license, and tax collections. In visits to municipalities and during roundtables, mayors and municipal staff a reported that—even a full 8 months after the hurricanes—portions of their populations continue to lack access to adequate water services, telephone and internet service, and specialized health care. While some of these issues may have predated the hurricanes, we found substantial levels

[103] Ibid. Page 20, *Response protocol*, *section a*: "When a disaster is imminent or has occurred, local governments have the primary responsibility of responding and preserving life and property. Local officials must implement statutes of emergency and ordinances, and declare a local state of emergency that allows the mobilization and commitment of its local resources."

of need for basic services across most of Puerto Rico's municipalities. Details on the damage to these sectors are available in other chapters of this report. As such, this section will focus on the experience of municipal leaders and the impact of damage across sectors on capacity to govern. However, problems in sectors that are not owned by municipal governments had significant impacts on municipal capacity to govern by creating new demands on those governments; for example, widespread and prolonged power loss meant that police had to be diverted from normal duties to patrol darkened areas which would have otherwise not required their attention. Data summarized in this section were collected between 7 to 9 months after Hurricane Maria and represent the perceptions and experiences of municipal leaders as of June 2018.

Municipal governments also reported that their capacity to provide services to citizens had been diminished, in part because significant numbers of public employees left municipal government in key sectors such as public health and public safety. This section concludes with a description of the first days after the storm, when Puerto Rico's mayors were the face of the response, to illustrate the impacts the hurricanes had on communities across the commonwealth.

Conditions in municipalities as a result of the hurricanes

Participants in every roundtable reported that the situation immediately after the hurricane had passed was dire. Roundtable participants described the immense challenges they faced immediately after the hurricanes: people in their communities had no shelter, food and water became scarce, the electric grid collapsed, and fuel shortages became commonplace. Entire communities were cut off due to road blocks, bridge collapses, or flooding. Communication was impossible due to the failure of telecommunications systems.

Ambulance and 911 services were not responding and hospitals were overwhelmed or closed. Mayors and their staffs shared grim stories about the impact these conditions had on their citizens during roundtables. Mayors talked about the "mental health crisis" resulting from the storm--how they have had to deal with suicidal constituents and are still concerned about latent effects on worsening mental health once the immediate emergency had passed and citizens faced the reality of how they were still unemployed or without a roof over their heads eighth months after. In another of many examples, a mayor noted that three dialysis patients in their municipality died because they were not able to get dialysis in time due to delays in receiving medical supplies and assistance.

Supporting the findings summarized in other chapters of this report, HSOAC's roundtable and municipal site visits found that gaps in critical lifeline services remained eight months after the storm in large numbers of municipalities. For instance, a mayor from the mountainous central region reported that mainland US and international volunteer health care personnel were still providing physical and mental health services --including vaccination clinics, psychological therapy, and other vital services-- as the municipality has not yet received health care services from the Government of Puerto Rico. Critical communications infrastructure, such as phone and internet access, were lost or significantly degraded, impacting municipal government's ability to

provide critical services, including emergency assistance or for citizens to contact them and request assistance.

These service issues are likely to have cascading effects on municipal governments, diminishing their own ability to provide services and increasing citizen demand for assistance from their municipal governments. Here, we focus on several bellwether indicators of community well-being such as municipal finances, staffing, public safety, sewage, healthcare, and the ability to communicate by telephone or internet. In each case municipalities were severely impacted by the hurricanes, with many reporting on-going issues long after the hurricanes. One key caveat here is that, because limited data are available about the extent of access to these services prior to the hurricanes, some of these issues may predate the hurricanes. However, for most of the indicators which follow, services should be ideally be available in all American municipalities and for every U.S. citizen. Our site visits and roundtables show substantial levels of need for these basic services across Puerto Rico.

Municipal finances

Hurricanes Irma and Maria severely disrupted economic activity in the commonwealth. Damage to property, prolonged periods of power loss, flooding, and other direct and indirect impacts of the hurricanes have had major consequences for Puerto Rico's economy, as described in the Economy chapter of this report. Although detailed data are not yet available, the impact of the hurricanes on economic activity in Puerto Rico has almost certainly had significant negative effects on municipalities' ability to raise revenues from property taxes, business license fees, and IVU (sales and use taxes), their primary source of revenues. These impacts are likely to be prolonged, and not limited to the immediate period following the hurricanes.

Municipalities confirmed during roundtables that they were seeing substantial declines in revenue because of small businesses having to close, lower than expected IVU collections, and real estate transactions being essentially frozen. About 80 percent of municipalities identified the restaurant, agriculture, and retail sectors as being "hardest hit" in terms of employees lost. Each of these industries plays a significant role in the Island's economy and is in turn a critical source of revenue generation for municipal governments.[104]

While the hurricanes adversely impacted municipal revenues, they also increased municipal expenses. Many roundtable participants indicated they had incurred significant expenditures for response operations during the hurricanes and repairs after the hurricanes, but had yet to be reimbursed for these expenses by FEMA or insurance companies. Municipal officials reported that the lack of timely reimbursements for these eligible expenses has resulted in their being unable to pay contractors who have already performed work. In some cases, municipalities reported they have been unable to pay their own employees. Participants were concerned that

[104] HSOAC analysis of ICMA municipal survey data

this unfortunate situation could have cascading impacts on economic activity, their ability to provide needed services, and ultimately municipal revenues.

Mayors reported they had not received payouts from insurance companies for damage to insured properties. One mayor noted that the insurance company the municipality had been paying monthly premiums to for years had proposed to pay only thirty cents on the dollar on the municipality's insurance policy. These mayors pointed out that the lack of insurance payouts further complicated reimbursements because many FEMA programs in particular only cover shortfalls after municipal insurance policies have paid out.

Lastly, a number of mayors noted that the Government of Puerto Rico government and FEMA did not notify local governments when contractors were hired to work in a municipality. This made it difficult for municipalities to collect the fees that construction companies were supposed to pay, and which are an important part of municipal revenue and budgets.

More than half of municipalities for which data were available were in deficit prior to the hurricanes. Increased expenditures from the hurricanes, only some of which are reimbursable, and negative impacts on the primary revenue sources municipalities rely on will only exacerbate these conditions. Discussions with municipal personnel suggest these stressors are likely to persist for some time.

Population loss and unemployment

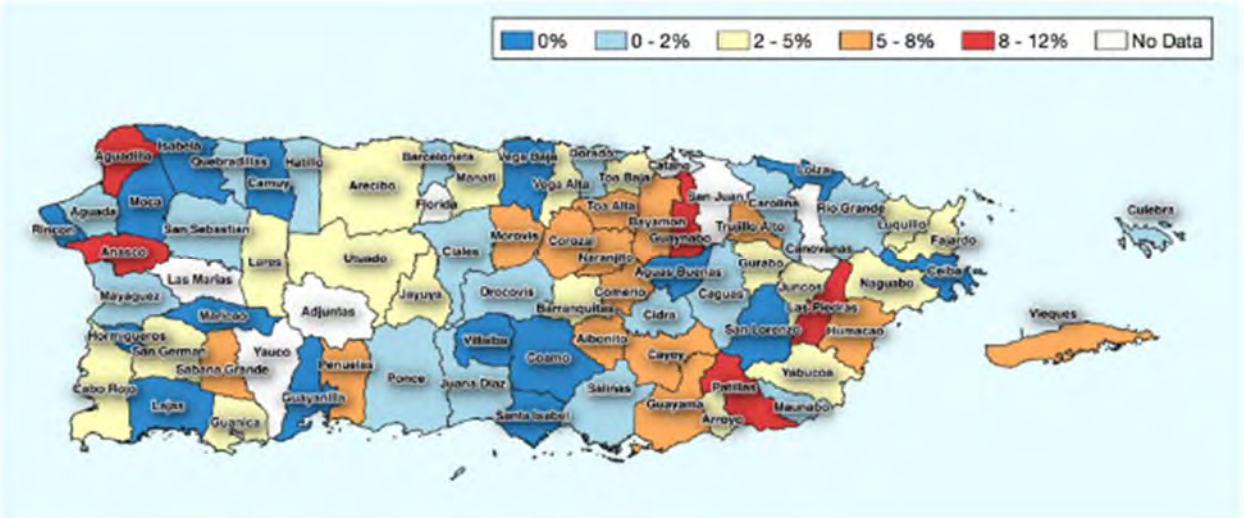
The previous section of this chapter includes an analysis of outmigration and the Economy chapter of this report describes employment losses related to the hurricanes. The results are mixed when examined through the lens of municipal governance. One the one hand, preliminary population data suggest a slight acceleration of the pre-hurricane decline in overall population. This will contribute to stress on municipal revenues by negatively impacting income from sales and use taxes. On the other hand, the impact of the hurricanes on employment may be mitigated as federal funding related to the recovery effort flows to the commonwealth. For example, total employment declined substantially in October 2017 in the immediate weeks after the hurricanes, but had rebounded to pre-hurricane levels by December 2017. It appears likely that this is primarily related to the recovery effort, as described in the Economy chapter.

Municipal staffing

Municipal staff reported losing municipal employees due to the hurricanes and that this has negatively impacted their ability to provide services. Most municipalities (56 of 72) for which onsite assessments have been conducted to date report personnel leaving as a result of hurricanes Irma and Maria, with 19 municipalities reporting that at least 5 percent of their employees departed, and .Aguadilla, Ańasco, Guaynabo, Las Piedras, and Patillas reporting between 8 and 12 percent of their employees departed.

On average, 23 percent of lost employees occupied key positions, and many municipalities expressed concern that policing, emergency response, and nursing were among the hardest hit. Figure 6.22 below shows the percent loss by municipality.

Figure 6.22. Percent of municipal employees leaving after hurricanes



Source: HSOAC analysis of ICMA municipal survey data.

Municipal services

Municipal governments reported that their ability to provide services to their citizens had been negatively impacted as a result of the hurricanes, even as the disaster created the need for additional services and assistance from municipal government. As described in other chapters of this report, the energy, telecommunication, and water networks throughout Puerto Rico collapsed or were severely damaged. All of the municipalities that we met with reported extended power outages, some that continued to persist through the time of the assessment. Many reported lack of access to safe drinking water and widespread communication outages in the days after the storm and, in most cases, for extended periods afterwards. Access to these key services continued to be a challenge for some at the time of the assessment. While municipalities do not provide many of these critical lifeline services, such as power, deficiencies in these services create strain on municipal governments by increasing demand for services and creating health and public safety hazards and other needs which municipalities must respond to. HSOAC's assessment shows that the hurricanes' impact on citizens and municipal governments continues to be felt a full 8 months after the hurricanes.

Participants across the twelve roundtables reported having to divert municipal resources from regular service delivery to support response efforts for very prolonged periods following the storm, including in some cases through the time of our assessment. Municipalities report having to provide emergency food and water in the first days and weeks after the hurricanes. In fact, in

some cases mayors reported breaking the locks of school cafeterias to use the food stored there to make rationed meals for constituents. Municipal resources were used to move citizens to urban centers to make it easier to provide services and to remove them from vulnerable or dangerous areas. Municipalities provided materials, such as tarps to families whose homes had been damaged. Municipalities also assisted efforts to rebuild or strengthen damaged structures to allow businesses to re-open.

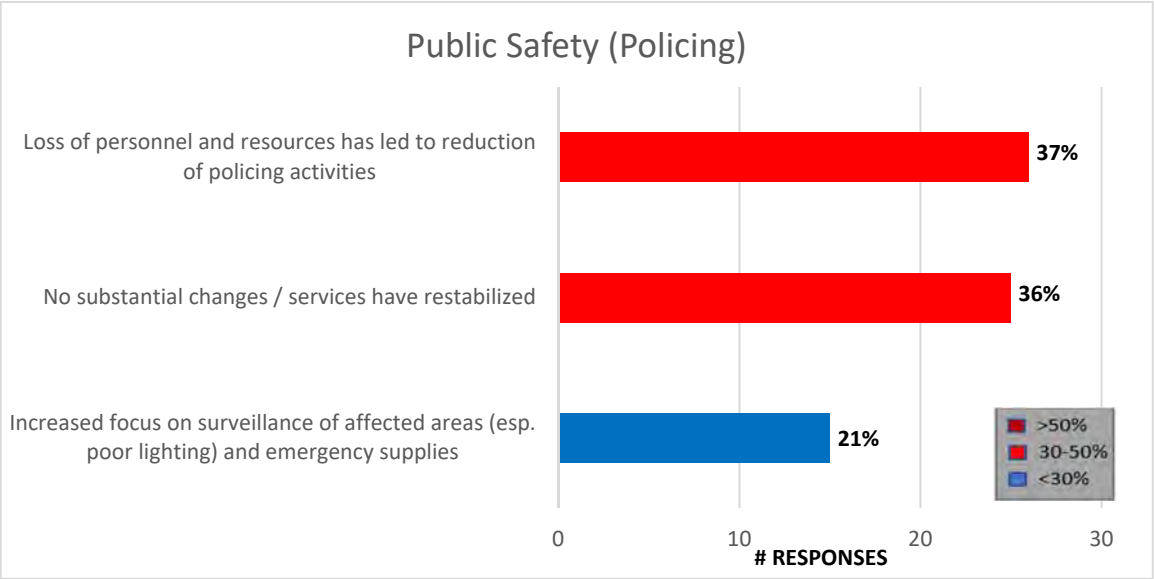
About a third of municipalities reported that their ability to provide services was the same as before the hurricane or had recovered to that level by or before the time of the assessment. However, many of these municipalities noted that it took months to reestablish service and that their ability to enhance services had stalled. Roughly a quarter stated that administrative services had deteriorated, were delayed, or had become more inefficient due to problems with communication and infrastructure. A quarter also stated that intermittent power and communication continued to cause disruptions, albeit not in the same frequency as in the months following the storms, and impaired their ability to deliver services.

Public safety

As shown in Figure 6.23, 37 percent of municipalities reported a significant reduction in police services due to loss of personnel and resources since the hurricanes. Personnel losses after the hurricanes were attributed by municipalities to police officers leaving or retiring, in many cases to go work in the continental United States where law enforcement pay and resources are perceived to be substantially higher. However, a comparable number—36 percent—noted that policing services had stabilized since the hurricanes.

The hurricanes also created new public safety needs in municipalities and altered the duties of municipal police. All of Puerto Rico suffered power loss, often for prolonged periods of time. The lack of lighting created new safety issues which required police to divert resources from more proactive policing to patrolling poorly lit areas. Similarly, police were often needed to respond to other emergencies resulting from the storm. 21 percent of the survey respondents noted that since the hurricane police work included more preventative surveillance of affected areas with low lighting or emergency resources such as generators.

Figure 6.23. Changes in police services after Hurricane Maria



Source: HSOAC analysis of ICMA municipal survey free text data.
Note: Sample size for this graphic is 70 municipalities.

Debris removal

One of the main challenges municipalities faced as they responded to and began trying to recover from the hurricanes was the collection and disposal of the immense amounts of debris and solid waste that the hurricanes generated. These efforts may be complicated by the fact that 17 percent of municipalities report having access to a landfill.[105]

Among those municipalities which reported that they did have access to a landfill, seven noted that the landfill they had access to was not licensed or authorized. This problem predates the hurricanes, but has been complicated by the amount and nature of the debris generated as a result of damage caused by the hurricanes. For example, more than half of municipalities noted that the biggest threat or challenge in environmental planning was the disposal of solid waste and debris and the creation of clandestine landfills. More information on the issue of solid waste is discussed in the Natural Resources section of this report.

Critical infrastructure: Water, sewer, telecommunications, housing

Damage to critical infrastructure systems is summarized in the other chapters of this report. Data from roundtables and municipal site visits confirms the extent of the damage to critical infrastructure within municipalities, and underscores the long-lasting impacts of damage on municipal services and quality of life in Puerto Rico's municipalities. Because information about the pre-storm status of many of this infrastructure and these services does not exist, some of

[105] HSOAC analysis of ICMA municipal survey data

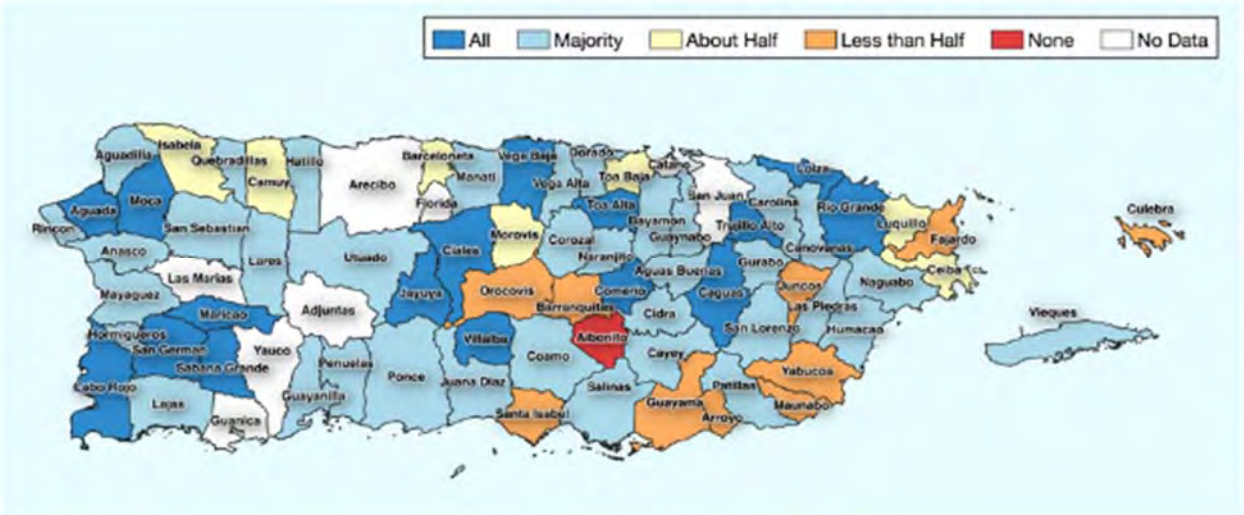
these results could be attributed to pre-existing needs. As a snapshot of the conditions reported by municipalities as of June 2018:

- Only 9 out of 71 municipalities for which data are available reported that the entire community was served by a public sewer system. Eighteen municipalities reported that little to no-one in their community was served by a public sewer system. Figure 6.24 shows that many of these municipalities are concentrated in the center and west of the Island.
- One municipality reported that eight months after the hurricanes, no one in the municipality had access to landline or cellular service. Seventeen municipalities reported that half or less of their community had landline or cellular service. Figure 6.25 shows that pockets of the Island—particularly in the center and south east—continue to lack adequate communications.
- 38 percent of municipalities reported that half or less of their constituents had access to internet services. Figure 6.26 shows that the center and north of the Island are generally less likely to have adequate internet services.
- 35 percent of municipalities reported that residents are still living in temporary housing.

Figure 6.24. Access to Adequate Stormwater Sewers and Drains

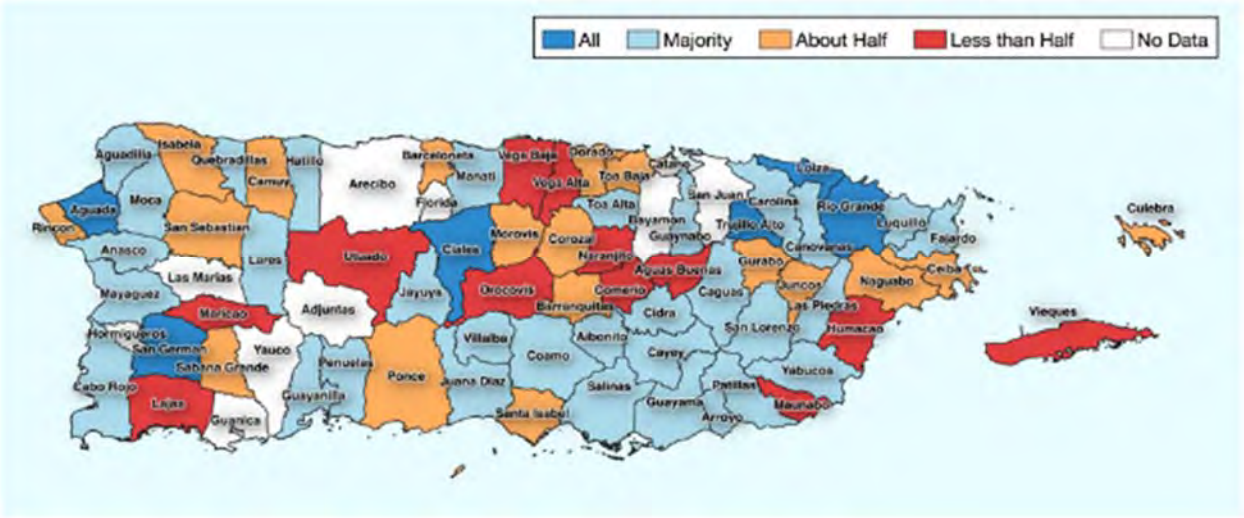
Source: HSOAC analysis of ICMA municipal survey data.

Figure 6.25. Access to Landline or Cellular Service



Source: HSOAC analysis of ICMA municipal survey data.

Figure 6.26. Access to Internet Services



Source: HSOAC analysis of ICMA municipal survey data.

Damage to municipally-owned assets

Participants in every roundtable reported heavy damage to a wide range of municipally-owned assets, including roads and highways, buildings and other structures. Participants reported damage to government buildings, schools, emergency shelters, local businesses, historic buildings, parks, theaters, and sports facilities. The damage incurred by these kinds of infrastructure are covered in other chapters of this report.

Some municipalities reported that rural communities were hit hardest. Municipalities along the coast reported heavy damage from storm surge, with significant damage to local beaches, wharfs, and ports. Municipalities with communities located near riverways experienced extensive flooding and damaged or collapsed bridges, while municipalities in the mountainous region described how difficult it was to access many of their communities because of washed out roads.

Post-hurricane conditions

Emergency response

Participants in every roundtable reported that immediately following the hurricanes, municipal authorities undertook various activities to provide emergency relief to their communities and to begin the recovery process. Across the twelve roundtables, participants reported that their first priority in the initial recovery effort was to restore the power and water supply as quickly as possible and to clear blocked roadways and remove debris to facilitate access to the municipality and to those in need. Participants also described addressing short-term needs such as distributing food, water, medicines, and tarps, as well as identifying community members at risk (e.g., the elderly who lived alone, those with critical health care needs, and those who were frail or bedridden) and moving them to emergency shelters.

In several cases, participants reported that how quickly and effectively they were able to respond seemed to be related to the municipality's proximity to San Juan and other large urban areas. For example, one participant explained that power and water were restored earlier for those closer to San Juan. Municipalities with resources to implement recovery projects at their disposal to were able to respond more quickly, with poorer communities facing more challenges. Mayors also mentioned that geographic accessibility, particularly for mountainous regions and communities in the smaller islands, was a very important barrier. These are factors which should be considered in recovery efforts and efforts to improve the resilience of municipalities.

Municipalities recognized that the hurricanes' impact forced them to work together to respond effectively. A number of roundtable participants described ad hoc efforts to collaborate with their neighboring municipalities in the immediate days after the storm. Some examples included municipalities sharing gasoline, equipment, and supplies with each other to facilitate response efforts, working together to clear roads, and sharing communication equipment. Several mayors in the mountainous region described working together to reach communities that were more accessible by jurisdictions other than those where the community was physically located. A number of participants noted that the hurricanes had led them to think about the ways that they could collaborate regionally.

Another key factor in how quickly municipalities have been able to engage in recovery seems to be related to municipal-level emergency preparedness and mitigation efforts prior to the

hurricanes. One mayor described reviewing each service they provided and putting it through a re-engineering process aimed at identifying opportunities for improvement (e.g., re-paving roads with concrete to make them more resilient). This municipality had also created a database that contained information on each household, such as whether there had been recurrent flooding in the home and whether a resident needed special medical supplies or attention. The municipality also had an inventory of water pumps and generators and had trained staff on how to fix basic mechanical problems—something the mayor noted allowed them to restore power more quickly than would otherwise have been possible. These sorts of pre-event mitigation efforts could potentially be undertaken in all municipalities to improve preparedness.

Barriers to response

A lack of adequate preparedness was a universally noted barrier. Participants across all twelve regional roundtables emphasized that the emergency preparedness plans that were in place prior to the hurricanes did not envision a disaster as extreme as hurricane Maria. No plans were in place for the total collapse of the energy grid or for the extent of the landslides and debris that cut off entire municipalities. Participants also believed that the implementation of existing plans was ineffective. All the mayors we met with that had been given satellite phones as a contingency stated they did not work. There were long delays in distributing emergency supplies and assistance, and hospitals and emergency services were overwhelmed. In addition, participants reported that many agencies and services were largely unable to respond or inaccessible immediately after the hurricane. A recurrent theme in all of the 12 regional roundtables was that the assistance they received from FEMA and the Government of Puerto Rico government was insufficient given the magnitude of the damage their municipalities incurred

Another recurring theme across all roundtables was that communication with GPR and regional authorities immediately after the hurricane was extremely challenging. This was compounded by the fact that regional representatives for government agencies were also unable to communicate with the GPR, and in some cases participants reported that their representatives felt that they did not have the authority to act without guidance from their chain of command — something they cited as having slowed the immediate response. Many participants noted that it had been extremely difficult to obtain information on relief and recovery efforts, either because Federal and State agencies did not respond or because municipalities did not know who to go to for information and assistance.

Problems coordinating relief efforts and receiving assistance from Federal and State agencies were also reported in all regional roundtables. Participants from all but one of the roundtables stated that the administrative processes and paperwork for requesting or receiving assistance was overly burdensome, unclear, and caused bottlenecks in the delivery of aid. In all roundtables participants expressed frustration at the business processes in place at the convention center during the first weeks of the response, noting that decisions taken there that were never

communicated to local governments and that they were being asked to submit forms online when they did not have electricity.

Participants also reported that different FEMA teams would request the same information multiple times, were not familiar with the situation on the ground, did not understand processes for delivering aid in Puerto Rico, would schedule delivery of supplies without coordinating with the authorities, and in some cases were unable to communicate with municipal authorities and staff because of a language barrier. Finally, many municipalities noted that FEMA rotated key staff frequently, making coordination with local staff difficult and forcing municipal staff to spend valuable time getting new people up to speed.

A common observation was that the complex governance and ownership of infrastructure in Puerto Rico also had slowed the response to the hurricanes. A common example related to efforts to clear Government of Puerto Rico-owned roads of debris, with participants noting that that the Department of Transportation did not clear some roads for a considerable amount of time but also did not authorize municipal governments to clear them. Some noted that they had taken it upon themselves to clear debris from Government owned roads to facilitate access to their municipalities but were never reimbursed for these efforts. Participants identified this as a governance issue that complicated the response to the hurricanes and adversely impacted the ability to access communities. Another participant reported a similar issue regarding Government of Puerto Rico owned water pumps that needed to be turned to mitigate flooding, but the Government was unable to provide fuel in time and did not allow the municipality to provide the fuel.

Many participants suggested that reconstruction efforts are hampered by existing building codes and regulations. Participants explained that codes designed to protect buildings designated as historic (including some municipal government buildings) make reconstruction projects expensive and impede their efforts to reinforce damaged buildings. Some participants suggested that construction regulations should be tightened to prevent or discourage people from building or rebuilding in low-lying or flood-prone areas, to require people to build vertical structures, and to prohibit the use of wood in construction.

Municipal officials are deeply concerned that the hurricanes' impact on local economies is putting additional pressure on their already precarious fiscal condition, and that this will hinder and delay recovery and rebuilding. Almost all the municipalities represented in the roundtables reported having to cut municipal staff hours significantly, leave vacant positions unfilled, and, in at least one case, implement layoffs. All of the participants expressed concern about the financial forecast for their municipalities and their ability to maintain services and operations. Many indicated they were pessimistic about the future because of this.

Roundtable participants universally agreed that delays in receiving financial assistance had adversely impacted their efforts to re-establish services, recover from the hurricanes, and rebuild their economies. Almost all of the mayors and municipal staff we met with expressed a great deal of frustration with this sort of disconnect between municipalities and resource providers,

noting that they had been telling people about their needs for months but had not received the assistance that they have been asking for. Almost every participant noted that they had spent a significant amount to undertake cleanup efforts in their municipality—sometime running into the millions of dollars—and that they had only been reimbursed for a small fraction of these expenses. They also expressed concern that assistance to date was not targeted towards particularly PDADs such as the elderly, those living in extreme poverty, those in mountainous and rural areas, and those who do not own their own homes. Although anecdotal, the comments reported in this section are illustrative of the sentiments we heard from mayors and their staff and are included here due to the lack of more definitive data.

Remaining needs and recovery priorities

Overall, the municipalities HSOAC met with generally noted that revitalizing Puerto Rico's urban centers should be a key focus of economic recovery efforts. Participants argued that this would allow the Government of Puerto Rico and municipal governments to reduce expenditures and take advantage of economies of scale by concentrating delivery of key services, provide employment opportunities to residents, keep tax revenues within the municipality, reduce social isolation for the poor, the elderly, and those with special needs, and improve resilience and facilitate more effective emergency response and recovery in the event of another natural disaster.

The overlap in service delivery between municipalities and the Government of Puerto Rico, combined with the lack of effective regional coordination and planning, is a key challenge that likely complicated the response to the hurricanes. There is broad consensus about the need to rethink service delivery—including creating regional structures—to make it more efficient, reduce costs, and improve outcomes for citizens. There is also broad opposition to doing so without including the municipalities in the process. It is also clear from our assessment that regardless of what form service delivery ultimately takes, a more systematic method to collect and store data—perhaps managed by the Government of Puerto Rico—regarding municipal governments and the assets they own and the services which they provide would be useful to a large number of stakeholders and circumstances.

Economic Development

HSOAC asked roundtable participants to share their visions for recovery and economic development in their municipality. Although responses varied substantially across roundtables, a number of broadly shared objectives emerged:

- Invest in rebuilding and upgrading key infrastructure, including electric power, water and wastewater, communications, and transportation;
- Incentivize large manufacturers to stay on the island;

- Reduce labor shortages by incentivizing workers to stay on the island and allow businesses (particularly agribusinesses) to bring in foreign workers on temporary visas;
- Involve municipal authorities in identifying priorities for their region;
- Adjudicate the authority for planning and implementation of development projects to municipal authorities; and
- Expand investment in projects related to the visitor economy and tourism to all municipalities in Puerto Rico—not just the traditional hotspots.

Visions for economic recovery varied across roundtables, generally reflecting the distinct priorities of each region. Urbanized municipalities with strong manufacturing sectors prioritized investments to expand this strength, while municipalities in the more vulnerable and highly impacted regions prioritized reconstruction, restoration, and updating of key infrastructure including the electrical grid, water systems, roads and bridges. These more vulnerable municipalities also prioritized mitigation projects, particularly those related to flood control, and policies and projects designed to repopulate and restore urban centers and revive economic activity in urban centers. All regions expressed the desire for tourism to be a key component in their economic development, and many participants believed that Puerto Rico needed to expand its tourism offerings beyond the traditional focus on San Juan and the beaches in order to provide economic development across the entire Island.

Short and Longer-Term Needs

Short- and longer-term needs for Puerto Rico's people and communities are covered in many of the remaining sections of this report. However, there are a number of key issues to address related to understanding the needs of Puerto Rico's communities (and in particular those at highest risk as Puerto Rico enters its next hurricane season), as well as long-term functioning of Puerto Rico's municipal governance structure.

Short term

Over the next one to 12 months, priorities include:

- *Emergency preparedness across Puerto Rico's communities.* Puerto Rico was not adequately prepared during the last hurricane season, which led to a very severe level of community damage. While some of the factors impacting the level of damage sustained were the pre-existing financial strain and aging infrastructure, essential preparation and disaster response capabilities were not in place. Additionally, it will be critically important to continue to monitor recovery progress in Puerto Rico's communities, particularly those at highest risk from storm impacts.

- *Impact of the hurricane in reshaping Puerto Rico's population trends.* Currently there is very little quantitative evidence about how the hurricane has impacted the population's rate of growth, social and economic characteristics and geographic distribution. Of particular importance will be understanding whether the hurricane has simply increased

the magnitude of outmigration flows to the CONUS or if the disaster changed their demographic composition.

- *Hazards of Puerto Rico's highest-risk communities.* Increasing community disaster preparedness should be accompanied by targeted hazard mitigation activities. Knowing that not all communities are exposed to the same levels of risk, it is critical to monitor and mitigate hazards faced by communities, including social and economic; institutional; infrastructure; and environmental factors.

- *Community resilience to disasters.* Communities that could not be reached quickly in the aftermath of Hurricanes Maria and Irma had to find ways to survive without outside help. Being self-reliant was especially challenging given the lack of information about when essential services would be reinstated. Puerto Rico is still at risk of prolonged periods without essential services in the aftermath of disaster, given the continued fragility of infrastructure systems as Puerto Rico moves into a new hurricane season. Therefore, it is critical to help communities better withstand disasters in the future.

- *Ways that infrastructure decisions may exacerbate or relieve vulnerability.* There is also limited information specific to Puerto Rico on how investment decisions made during recovery will impact overall vulnerability and affect the wellbeing and resilience of all Puerto Ricans and impact economic development and recovery at the municipal level.

- *Communication with GPR's constituents about recovery.* Based on discussions with government stakeholders, it is challenging for Government of Puerto Ricoand US agencies working on the recovery process to communicate consistently with the public about progress in recovery. Communication is an essential component to engage residents in the transformation of Puerto Rico. Research shows that effective communication has a great impact on members' participation in community development, and this involvement improves the likelihood that residents will support and believe in the changes in their communities (Gil-Rivas and Kilmer, 2016; Pearce, 2003).

- *Duplication of efforts.* There are a number of services that are currently delivered by both the Government of Puerto Rico and Municipalities. Some examples include policing, road maintenance, emergency response services, and debris removal. According to interviews undertaken by HSOAC, this duplication of efforts leads to less effective service outcomes for citizens, increases costs, and is generally inefficient. Future research may examine the services currently being undertaken by the Government of Puerto Ricothat might best be delivered by municipalities, and vice versa.

- *Ambiguity in municipal asset ownership:* No centralized record-keeping system exists that identifies what assets municipalities own, or what the conditions of those assets are. When information is available, it is not collected in a standardized manner. HSOAC was generally able to obtain some form of hard copy list of assets from each municipality, but it was unclear how accurate, current, or complete this information was, and it was not electronically accessible. This makes simple, core activities such as property sales and transfers, damage and needs identification, and effective and efficient deployment of

recovery and other outside assistance extremely difficult. As noted above, in some cases there is ambiguity regarding asset ownership, which further exacerbates these difficulties.

Longer term

Over the next one to ten years, Puerto Rico will need to consider undertaking public reforms to address some of the challenges that hinder municipal functions on a daily basis, and significantly limit capacity to respond in an emergency.

- *Financial challenges' impact on municipal functions.* Strains on municipal budgets from years of mounting debt and stunted economic growth have likely deteriorated the municipalities' capacity to respond adequately to disasters, particularly in terms of personnel and equipment. Municipalities have responded to these fiscal challenges by reducing their workforce through attrition, and cutting back the hours worked by personnel—in some cases losing emergency response personnel. Municipalities are exploring ways to raise revenue, including more systematically collecting fees on contractors, and creating municipally owned corporations or entering into public private partnerships to generate economic development.

- *Barriers to economic development.* Economic development is essential for the viability of municipalities and their communities, but far too many municipalities do not currently have economic development plans. There are geographic variations that limit or enhance the suitability of different industries by region. Business requires an available and appropriately trained workforce, as well as other infrastructure, which is often lacking. Bureaucratic requirements may also impede economic development and business creation. These include requirements for permits from multiple levels of government. Municipalities themselves face barriers to productive business activity, including requirements for gubernatorial approval before creating consortiums to jointly deliver services.

- *Transparency in data and decision-making*. Information about what is happening at the municipal level is difficult to come by, in part because many of the records are paper based and stored locally, and municipalities' online presence for use by citizens, private sector businesses, visitors, and other stakeholders is a mix of official websites and social media accounts. Some do not have not have an official website at all. Those that do rarely include important publicly available information or means for requesting government services. This represents a major lost opportunity for the municipal governments of Puerto Rico. Online portals can be used to facilitate fee and debt collection, provide basic information to citizens and businesses, automate and reduce costs of certain processes, increase the speed and efficiency with which some services are delivered, obtain information on citizen needs, and, in general, increase access to and transparency of government.

- *Delivery of basic services and municipal planning.* A small number of municipalities have created consortiums to explore sharing services. As municipal budgets decline from falling tax receipts, outmigration, and declining Government of Puerto Ricosubsidies, municipalities will need to find efficiencies in their operating budgets in order to continue delivering basic services. Some mayors have expressed at HSOAC roundtables their view

that regionalization needs to start from the bottom-up—that is, that local groups of mayors should decide what services can be shared most effectively between their municipalities. Some mayors have also indicated a need for more regional approaches to emergency planning, land use planning, and economic development planning.

- *Knowledge-sharing across municipalities.* A more unified municipal perspective and a forum for sharing information and expertise amongst municipalities is also needed. Municipalities are currently divided by political party in the two existing representative bodies, the Association of Mayors and the Federation of Mayors, but it is clear there is much that the municipalities of Puerto Rico have in common with one another regardless of party. Participants in two of the roundtables explicitly referred to an emerging "Liga de Alcaldes" that would represent and potentially unite the mayors' association and the mayors' federation. Mayors reported they always collaborated both informally and formally with one another, regardless of political affiliation, and expressed interest in finding opportunities to share resources.

7. Health, Social Services, and Education

Overview

This chapter covers the impact of Hurricanes Irma and Maria on the Health and Social Services (HSS) sector. HSS comprises several mission areas: public health, health care services, behavioral health, environmental health, food safety and regulated medical products, long-term responder health issues, social services, disaster case management/referral to social services, and children and youth in disasters. Hurricane impact on education is also included in the chapter. Taken together, these mission areas seek to ensure a sufficient "human recovery," along with recovery of the economy and of physical infrastructure. Indeed, much of the ultimate value of infrastructure lies in the extent to which it supports individuals and communities in living healthy, productive lives, which, in turn, is essential for ensuring a robust economic recovery. For clarity, we have aggregated those mission areas into the following subsections: (a) health, (b) social services, and (c) education. Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Health and Social Services" and "Education" Sector Reports. The storms exacerbated pre-existing problems in each of the sub-sectors. We summarize some of the most important of these problems below and connect them, where possible, to metrics that can provide a systematic basis for understanding gaps and (later) evaluating potential courses of action.

A significant number of clinics and public health laboratories, social service centers, and schools were damaged by the hurricanes, especially on the east side of the main island. This created interruptions in services, including lack of access to chronic care management, schools that were either closed or operating on reduced schedules, and more.

Many public buildings and surrounding areas incurred water damage, resulting in environmental conditions that may be hazardous to human health, including the development of mold, an increase in rodents and pests, and potential dislodging of hazardous chemicals (e.g., exposure to asbestos and lead) and waste. In the immediate aftermath of the hurricane, much of Puerto Rico's power grid was offline, and sewage wastewater treatment plants, including those upstream of drinking water supplies, were out of service, allowing raw sewage to enter rivers and reservoirs. Damage to Puerto Rico's public buildings, e , and water sectors are described in their respective chapters of this report.

Data sources and methods

Data sources were identified based primarily from literature reviews and discussions with subject-matter experts and stakeholders. In addition, we requested and received relevant data from the HSS Recovery Support Function team and the FEMA HSS Sector team. Data were

screened for relevance and combined/summarized as needed. Specific data sources are provided in footnotes in the text, but include:

- over 120 data files in various formats shared by RSF staff, maps and reports from site visits, facility lists, demographic data, and others
- review of SitReps and sector updates
- review of documents, including academic literature, white papers/grey literature, and newsprint, with focus on data that may be used to compare Puerto Rico rates where relevant, epidemiology of disaster recovery, and review of local strategies to address health and social services
- stakeholder input via focus groups, key informant interviews, and solution oriented sessions.

Where relevant, we used data from Census, Bureau of Labor Statistics, and other federal sources to provide context or comparison data. The team then reviewed and integrated information, sorting through key issues and themes that emerged from more than one data source. The team also worked to link quantitative and qualitative information where possible in order to triangulate priority findings.

Data gaps, assumptions, and uncertainties

Given the decentralized nature of most HSS services, many data gaps remain around post-storm status and functioning. Many of these gaps should be addressed through additional site visits planned by RSF and Sector staff. However, the following gaps remain at the time of writing:

- *Chronic disease and health care outcomes.* Capturing more nuanced data (e.g., insurance claims) to assess metrics such as preventable hospitalizations, disease burden, and related health care quality challenges is important and to date is not part of this analysis.
- *Water quality.* Post-storm surveillance is needed on water quality and the burden of water-borne illness (pre- and post-storm). Additionally, up-to-date information is needed on the status of public health laboratories and the capacity for long-term monitoring and surveillance.
- *Air quality.* Air quality monitoring networks were inoperable after the storm, so no data are available to understand the health ramifications of consistent and widespread use of diesel generators as a power source. However, in areas with high generator use, noxious fumes, noise complaints, and respiratory symptoms were reported.
- *Mental health.* Post-storm surveillance is needed to assess the burden of mental illness in the Commonwealth. This surveillance must also include children and adolescents. Additionally, better information is needed about the capacity of Federally Qualified Health Centers (FQHCs, also known as "330s") to provide high-quality mental health services and the community groups who are currently providing mental health services. Information is also needed on the quality of community care and the types of services they offer.
- *Social services.* Service provision is reportedly fragmented, with a patchwork of public and private nonprofit entities being involved. As a result, it is difficult to assess with

precision which services are provided at the local level and how, and the size of the workforce.

- *Educational operations and performance*. While data exist on numbers of open schools, less information is available on the extent to which schools are operating at full capacity. Student achievement tests, typically administered in April or May, will provide additional information on any learning loss due to the storm. Further, more precise estimates are needed of the decline in student enrollment as a result of the hurricane and whether or how this decline is resulting in the under-utilization of school facilities.

Health

Background

History and Structure

The health subsector includes public health, environmental health (a key component of public health), health care, and mental and behavioral health. The purpose of **public health** is to ensure the health of entire populations, including attempts to improve access to resources needed to sustain healthy living, prevent diseases and accidents, and respond to outbreaks and other large-scale threats to human health. The Department of Health, or Departmento de Salud, is a Cabinet-level agency set forth by Article 4, Section 6 of the 1952 Constitution of Puerto Rico. According to the agency's 2011-2018 Strategic Plan, it is responsible for several strategic objectives in the plan that cover the various divisions within the department (Table 7.1), including but not limited to establishing food and nutritional surveillance systems, public policies related to mental health and suicide prevention, epidemiological services, health communication, and chronic disease management. Public health efforts are conducted via the Departmento de Salud with an annual budget of about $848 million (2017) across its agencies, inclusive of the Medical Services Administration (ASEM), the Administration of Mental Health Services and Against Addiction (ASSMCA), and the Health Insurance Administration (ASES).

The goal of **environmental health** is to identify, monitor, and control threats to human health related to the natural and built environments. This includes air, water, soil, buildings, industrial facilities, and so on. The Commonwealth established protection of the environment as a governmental function in 1970 with the passage of the Public Policy Environmental Act of 1970 (Act No. 9). Modeled after the National Environmental Policy Act of 1970, the act established an executive-level Puerto Rico Environmental Quality Board (PR-EQB) and an environmental review requirement. PR-EQB's main function is to protect and conserve the environment, and maintain a balance between economic development and the environment (Table 7.1).

Table 7.1. Parties responsible for public and environmental health

Department of Health	Role
Auxiliary Secretariat for Family and Health Integrated Services	Focused on communicable diseases, including HIV/AIDS, vaccination/immunization services, maternal and child health services, and issues for children with special health care needs; includes the WIC program
Auxiliary Secretariat for the Promotion of Health	Includes programs and activities aimed at the full well-being of the individual; to promote citizen participation in community health promotion. Focused on chronic disease prevention (e.g., asthma and diabetes) and health education
Assistant Secretary of Environmental Health and Public Health Laboratories	Responsible for environmental health at the central, regional and local levels, including technical advice and evaluation and field inspections/closures; involves monitoring of drinking water, radiological health, and food safety and security
Assistant Secretary for Planning and Development	Operates mostly as the evaluation and strategic planning arm for the Departmento de Salud, focused on systematizing planning processes, evaluating health services, and summarizing data needs
Auxiliary Secretariat for the Regulation and Accreditation of Health Care Facilities	Maintains standards for health care facilities (e.g., hospitals, diagnostic and treatment centers, psychosocial rehabilitation centers, mental health centers, rehabilitation centers, units of prolonged care, hospices, and home health agencies)
Office of Epidemiology and Research	Lead on health surveillance systems; provides capacity to respond to outbreaks, share information to address existing diseases, and provide technical assistance on the control of diseases
Office of Public Health Response Preparation and Coordination (OPCRS)	Ensures capacity to manage epidemics, natural disasters, terrorist attacks, and other public health emergencies; follows the standards outlined in the National Incident Management System, or NIMS
Auxiliary Secretariat for Medical and Nursing Services	Ensures health service coordination and integration; has oversight over the adult and pediatric elements of the University and Regional Hospitals of Bayamon and the diagnostic and treatment centers that are part of the Department.
Other Agencies	**Role**
Commission on the Implementation of Public Policy on the Prevention of Suicide	Raises awareness about suicide, mental health interventions and treatment, and training of service providers on signs, symptoms and response to suicidal behavior
Puerto Rico Food and Nutrition Commission	Advises on public policy on food and nutrition; coordinates with other agencies and private organizations on food and nutrition issues.
Puerto Rico Environmental Quality Board (PR-EQB)	Protects and conserves the environment, maintaining a balance between economic development and the environment.
Puerto Rico Aqueduct and Sewer Authority (PRASA)	Monitors drinking water quality
U.S. EPA (Region 2, based in New York City; Caribbean Environmental Protection Division (CEPD) office in San Juan)	Enforces all federal environmental statutes and regulations and has regulatory oversight of drinking water, wastewater treatment, and discharges of pollutants into waterways. Shares responsibility with the PR EQB for Clean Air Act permitting in Puerto Rico. Issues and implements the Prevention of Significant Deterioration (PSD) permits. Operates a Revolving Fund Program
Puerto Rico Department of Natural and Environmental Resources	Responsible for environmental protection and natural resources management as well as the design, construction, and maintenance of flood-control works
Vector Control Unit in Puerto Rico (PRVCU)	Tasked with oversight and implementation of comprehensive mosquito control activities to help prevent and manage diseases spread by mosquitoes. Combines surveillance and the monitoring of mosquitoes with community participation, education, and mobilization

Whereas public health focuses on prevention and health promotion at the population level, **health care** focuses on the delivery of health care services to prevent disease as well as treating acute disease and managing chronic illness at the individual and family levels. Before the 1970s, the Commonwealth of Puerto Rico had a strong publicly-funded health system. However, since the 1970s, the system weakened as a result of decentralization, with funding streams that were increasingly fragmented, and growth in the private sector ensued. By the 1990s, as part of *La Reforma de Salud*, a plan initiated in 1993 that led to a shift to privatization, public hospitals had converted to for-profit and not-for-profit hospitals (similar to the rest of the United States). The municipal diagnostic centers were mostly dismantled and replaced with FQHCs. Since 1994, Puerto Rico has mandated enrollment of most Medicaid beneficiaries, other income-eligible populations, and some government employees in a managed care plan.[106] The formal government health care plan, Mi Salud, emerged from *Reforma* in 2010.

Mi Salud provides acute, primary, and specialty benefits; behavioral health is carved out (described below). The Medicaid program does not cover home health services, hospice care, medical equipment and supplies, or nursing facility services; thus, these services are not available through managed care.

ASES, the state agency responsible for overseeing all aspects of Medicaid, has a cooperative agreement with the health department to administer insurance via each of the health care programs: Mi Salud, the Children's Health Insurance Program (CHIP), Medicare Platino (for those beneficiaries eligible for both Medicaid and Medicare), and programs for medically indigent persons funded by the Government of Puerto Rico only. Public employees are covered by Mi Salud. The Health Department and ASES services are organized by geographic region (East, Northeast, Southeast/Southwest, Northwest, Southwest, North/San Juan), but municipalities within the Health Department and ASES regions may not match.

The Commonwealth of Puerto Rico contracts with eight managed care organizations. Mi Salud is offered through one local, for profit plan (Triple S) and is available throughout Puerto Rico. Medicare Platino is offered through seven for-profit plans, including four local plans (First Medical/First Plus, MCS, MMM Healthcare, PMC Medicare Choice) and three national plans (Humana and two Blue Cross/Blue Shield affiliates - American Health Medicare and Triple S). The Commonwealth also contracts with two pharmacy benefit management companies to provide prescription drugs to Mi Salud participants. Managed care organizations are reimbursed through a combination of capitated and fee-for-service payments, which cover primary and specialty care respectively. Single capitation rates are developed for each contractor using actuarial methods that account for regional variation.

[106] Managed care enrollment requirements for Medicaid beneficiaries differ by state, with no other states requiring it for all Medicaid beneficiaries and ten states requiring it only for Medicaid enrollees who also receive Temporary Assistance for Needy Families (TANF) benefits.

Mental and behavioral health is an important part of well-being. It affects not only an individual's subjective happiness, but also his or her ability to participate fully in the society and economy. Since 1994[107], mental and substance use disorder care have been part of the larger health care system (Alegria et al., 2001). Mi Salud (described above) carves out behavioral health, which is provided through a separate behavioral health managed care organization (MCO) available throughout the Commonwealth, administered by afor-profit plan, Adult Protective Services (APS).

Mental health services are regulated throughout Puerto Rico by the Administration for Mental Health and Addiction Services Administration (ASSMCA, the Spanish acronym), which is a division of the Department of Health legally authorized in 1993.[108] ASSMCA is responsible for overseeing quality metrics for mental health and substance use care in Puerto Rico, including access, acceptability, appropriateness, continuity of care, professional competence, cultural sensitivity, effectiveness, efficiency, and promptness, among others.

Key assets

Assets in the health subsector include facilities, a trained workforce, and, in some cases, equipment and supplies (e.g., pharmaceuticals).

Facilities

Public and environmental health subsectors primarily operate laboratories, which are responsible for coordinating and evaluating environmental health activities. The Puerto Rico Environmental Quality Board operates the Environmental Investigation Laboratory of Puerto Rico, which is responsible for testing samples of environmental media, including water quality from beaches and lakes, as well as air and land resources. This laboratory also supports the Department of Natural and Environmental Resources.

Table 7.2 summarizes the types of health care facilities currently in Puerto Rico (FEMA briefing, 2018). A health facility typically means "any government facility currently operated by the Health Facilities Administration of Puerto Rico" inclusive of mental health facilities, psychosocial rehabilitation centers, chronic disease hospitals, and long-term care facilities. FQHCs refer to all health centers that receive federal funds as authorized by Section 330 of the Public Health Service. FQHCs provide a range of integrated services, including primary care, mental health, oral health, and pharmacy.

[107] Established with Act No. 67 and in 2000, as amended by Act No. 408. Known as the Puerto Rico Mental Health Law, the act contained a bill of rights of those receiving mental health services.

[108] Also authorized by the Puerto Rico Mental Health Law.

Table 7.2. Number of Health Care Centers by Type

Type of Facility	Number
Hospitals	68
Private clinics	4
Pediatric centers	7
Behavioral health clinics	3
Corporate for the Fund of State Insurance (supports workers compensation, government owned)	4
Transitional service centers	7
ASSMCA mental health[109]	1
Centers for the prevention and treatment of sexually transmitted diseases	8
Centers for diagnostics and treatments	171
Federally Qualified Health Centers (FQHC-330)*	50
Stand-alone emergency rooms	3
Dialysis centers	71
Residential treatment facilities	1

*Note another set of briefing slides cite that there are 92 FQHC sites and 10 of those are considered mobile clinics
Source: From a FEMA Briefing, 2018

Figure 7.1 shows the locations of the hospitals in Puerto Rico. Many hospitals are clustered near San Juan.

Figure 7.1. Hospitals in Puerto Rico

[109] This is a federally funded facility; there are 449 behavioral health facilities overall.

A 2011 report states that 449 licensed facilities provide mental health care in Puerto Rico, most of which are nonprofit organizations (Rodreguez, Greeman and Pesante, 2012). HHS reports that the 50 "FQHC-330" clinics also provide mental health services (Rodreguez, Greeman and Pesante, 2012), but it is difficult to determine whether those services are comprehensive across all facilities. It is unknown whether these 50 centers are included in the count of 449 facilities. Three mental health community care facilities are reported to have closed. In addition to these facilities, many volunteer efforts are reported to have started after Hurricane Maria. It is unknown how widespread these efforts are currently.

Workforce

Estimates of the number of health care providers in Puerto Rico vary. Some reports cite significant concerns about the rapid emigration of physicians and other health care professionals, and other analyses cite an adequate supply but note important concerns about the distribution of providers, including shortfalls and provider shortage areas across Puerto Rico.

As of a 2016 AAMC report, 9,874 active physicians were practicing in Puerto Rico, including 3,580 primary care doctors, and 227 general surgeons. On the mental health side, the Bureau of Labor Statistics identified 40 substance abuse and behavioral disorder counselors; 270 mental health and substance abuse social workers; 350 clinical, counseling and school psychologists; 60 psychiatric aides; 120 psychiatric technicians; and 100 psychologists, "all other" in the Commonwealth.

Other assets

Public and environmental health includes a range of assets beyond workforce and facilities, which are provided primarily through the Department of Health operational units described earlier; these include:

- *Surveillance systems.* The Office of Epidemiology and Research measures the impact of conditions and diseases in Puerto Rico and trains community health workers in conducting surveillance.
- *Public health education.* Public information about health and more comprehensive health education are offered through various operational units.
- *Laboratories*. The Assistant Secretary of Environmental Health and Public Health Laboratories, an operational unit within the Department of Health, is responsible for environmental health activities and public health laboratories. The PR-EQB operates the Environmental Investigation Laboratory of Puerto Rico, which is responsible for testing samples of environmental media, including water quality from beaches and lakes, as well as air and land resources. This laboratory also supports the Department of Natural and Environmental Resources.
- *Surveillance networks*. PR-EQB monitors air quality; the Department of Health and PRASA monitor drinking water quality.
- *Vector control*. In September 2016, the CDC awarded $13 million to the private non-profit Puerto Rico Science, Technology, and Research Trust to establish the first Vector

Control Unit in Puerto Rico (PRVCU). The PRVCU is tasked with oversight and implementation of comprehensive mosquito control activities to help prevent and manage diseases spread by mosquitoes. The PRVCU also engages in community participation, education, and mobilization.

- *Federal and Commonwealth revolving funds*. The U.S. Environmental Protection Agency (EPA) operates a large Revolving Fund Program and Puerto Rico operates two state revolving funds: the Clean Water State Revolving Fund (CWSRF) and the Drinking Water State Revolving Fund (DWSRF). Revolving funds function like "environmental infrastructure banks," providing low-interest loans to eligible recipients for water and wastewater infrastructure projects.

Pre-hurricane conditions

Burden of chronic disease

Leading causes of death are heart disease, cancer, and diabetes. Before the storms, overall rates of chronic disease (heart disease, diabetes, etc.) were similar to those in CONUS, but may surpass those of the CONUS with continued aging of the overall population. (Natural Resources Defense Council, 2017; Puerto Rico Department of Health)

In response to these chronic disease burden issues, the Department of Health, along with the Puerto Rico Chronic Disease Control Alliance, introduced a 2014-2020 plan (Puerto Rico Department of Health, undated) to address a set of specific goals organized into four key domains: (1) epidemiology, (2) clinical and community linkages, (3) health systems, and (4) strategies to support healthy behaviors. Goals for the first domain focused on timely data collection and analysis to examine disease burden across various population segments and to ensure that different sectors are supporting chronic disease surveillance. Goals for the second domain focused on reducing risk factors in community settings, such as schools and businesses, as well as promoting the use of community health workers. Goals for the third domain emphasized promoting communication and coordination across the health system regarding clinical and preventive services and using technology to facilitate decision support (e.g., electronic health records). Finally, goals for the fourth domain emphasized implementing policies that support population access to healthy foods, physical activity, and wellness programs.

Health risks differ significantly by age, gender, and economic status. Not unlike other demographic analyses of chronic disease, significant age, gender, and economic differences in health risk exist among the population in Puerto Rico. In Puerto Rico, no significant gender difference has been seen in heart attack prevalence, but women who suffered a myocardial infarction were more likely to die than men with the same condition. The same trends existed for Type 2 diabetes. In Puerto Rico, one out of every three adults age 65 years or older had diabetes, and those at the lower end of the socioeconomic spectrum are at greater risk. Diabetes was also more prevalent among women than men (14 percent compared to 12.7 percent, respectively, on average). Asthma was prevalent among young people, with a higher lifetime asthma prevalence

in the younger age groups. Lifetime asthma prevalence was also higher among women than among men (22 percent compared to l2 percent, on average).

Behavioral/environmental factors affect health. According to data excerpted from the 2014-2020 Puerto Rico Chronic Disease Action Plan put forth by the Departamento de Salud (which uses data from the 2011 BRFSS, which estimates the prevalence of risk factors among adults 18 years or older), the main behavioral and environmental drivers of chronic disease appeared to have been physical inactivity (66 percent), overweight (40 percent), high cholesterol (38 percent), hypertension (37 percent), obesity (26 percent), and smoking (15 percent). These rates were not dissimilar from those in some states, though rates of physical inactivity and overweight were somewhat higher in Puerto Rico. Efforts to address chronic disease prevention and management have included improved surveillance, stronger clinical-community linkages, and strategies to support healthy behaviors particularly with respect to healthy eating and physical activity.

Prevalence of mental health problems

Overall burden of psychiatric illness is comparable to the CONUS. The overall rates of psychiatric disorders in Puerto Rico prior to the storm were similar to those of the CONUS (23.7 percent and 26.2 percent, respectively, in 2015),despite the level of poverty in Puerto Rico and the link between mental health and poverty.

Distribution of psychiatric disorders differs geographically and demographically. To explain the comparability of rates of psychiatric illness, researchers cite the strong family support system in the Commonwealth. The recurrence of economic and social instability in Puerto Rico has also been posited to have led to long-term coping mechanisms (Canino et al., 2016). Women ages 18-64 had a lower probability of being diagnosed with a substance use disorder than did men, and adults in the 26 to 45 year age group had the highest 12-month prevalence rate for having a substance use disorder (5.1 percent) of any age group. However, the prevalence of psychiatric illness was not evenly distributed across demographic groups or geographic areas of Puerto Rico. Overall, 10.5 percent of women in Puerto Rico met diagnostic criteria for a past year psychiatric disorder compared to 8.2 percent of men. Compared to those in other health regions, residents from the San Juan health region had the highest 12-month prevalence rate for alcohol use disorder (8.9 percent), alcohol abuse (8.2 percent), and alcohol dependence (2.5 percent) (Canino et al., 2016).

Prior to Hurricane Maria, suicide rates were declining. As noted earlier, concern about high rates of suicide and suicidal thoughts in the late 1990s led the Department of Health to establish a Commission on the issue of suicide. Prior to Hurricane Maria, as late as 2016, the suicide rate had appreciably dropped. Gender differences in suicide were stark, with far more men than women committing suicide.

Population changes creating new vulnerabilities

Puerto Rico also faced some population-level challenges. While the overall population had been declining, the elderly population was increasing at a higher rate than expected, with 37.2 percent of the population projected to be age 60 or older by 2050 (Puerto Rico Office of the Ombudsman for Elderly, 2015). Because the risk for chronic health conditions increases with aging, , demand for health services and other support services will increase as the population ages. Further, as described in more detail below, emigration from Puerto Rico has posed challenges, including a decrease in the school-age population and in the health care workforce.

Exposure to environmental hazards

Puerto Rico has had longstanding challenges with water-and air pollution, and waste management, as discussed further in the Energy, Natural Resources, and Water chapters of this report. Prior to the storms, poor drinking water quality was a widespread problem, with Puerto Rico having the highest rate of violations of the Safe Drinking Water Act (SDWA) health standards (reported in May 2017) of any state or territory in the nation (Natural Resources Defense Council, 2017). Violations included high levels of volatile organic compounds, total coliform bacteria, and disinfection byproducts. Puerto Rico struggled with limited landfill capacity and low recycling rates. According to an EPA report (U.S. Environmental Protection Agency, 2016a), of the approximately 29 operating landfills in Puerto Rico, the majority are beyond capacity. Moreover, recycling rates were estimated to be about 10 percent, compared to approximately 35 percent in CONUS (Autoridad de Desperdicios Solidos, 2010). Limited disposal options and low recycling rates have created a waste management crisis.

Puerto Rico also had many toxic waste sites: 18 Superfund (hazardous waste) sites on the National Priorities List, or about 3.4 per 1000 square miles, compared to an average of 1.4 per 1,000 square miles in the United States overall.[110]

The energy system has contributed to the waste problem in Puerto Rico. The Commonwealth has relied largely on petroleum derivatives and coal for power. Byproducts from coal energy generation include coal ash, which contains toxic metals such as lead and arsenic. Coal ash waste sites tend to be concentrated in communities along the southeastern coast of the main island (near the associated power plants), areas with high rates of poverty and unemployment, reinforcing concerns that those in the lowest socioeconomic groups are the most susceptible to these dangerous exposures). Additionally, some communities have been exposed to harmful sulfur dioxide from oil-based power generation (Federal Register, 2018).

These environmental hazards have been associated with adverse health outcomes, including a higher prevalence of childhood asthma and risk of asthma attacks in areas near air pollution

[110] Calculation based on the number of Superfund Sites as reported by EPA's National Priorities List at https://www.epa.gov/superfund/national-priorities-list-npl-sites-state and the total geographic area reported by the U.S. Census Bureau at https://www.census.gov/geo/reference/state-area.html#n5.

sources (pollution from heavy industry, burning low-quality fuel oil for energy, and transportation), one known risk factor for asthma exacerbation,(Loyo-Berrios et al., 2007), as well as a high prevalence of preterm births in Puerto Rico (11.39 percent compared to 9.63 percent in CONUS, excluding territories) (Hamilton et al., 2017). Because of the high rates of pre-term birth and the extent of hazardous waste contamination in Puerto Rico, the NIEHS Superfund Research Program funds the Puerto Rico Testsite for Exploring Contamination Threats (PROTECT) Program. The multi-university PROTECT Center studies exposure to environmental contamination in Puerto Rico and its contribution to pre-term birth ("Puerto Rico Testsite for Exporing Contamination Threats (PROTECT)," 2013). Puerto Rico also may face waterborne disease outbreaks (Hlavsa et al., 2015). While the number of reported outbreaks is low or nonexistent, other sources have reported a high prevalence (21 percent per year) of diarrheal disease, which is known to be associated with contaminated water, in Puerto Rico (Sheffield et al., 2014). Vector-borne disease (e.g., Zika virus) outbreaks also impact the health of Puerto Ricans. In 2016, Zika virus disease became a nationally notifiable condition. In 2016, there were 5,168 symptomatic cases reported in U.S. states and 36,512 symptomatic cases reported in U.S. territories; Puerto Rico reported 35,395 symptomatic cases. Provisional data from 2017 (as of April 4, 2018), report 432 symptomatic cases in U.S. states and 653 symptomatic cases in territories; 607 cases were reported in Puerto Rico (U.S. Centers for Disease Control and Prevention, 2018). Other mosquito-borne diseases are also of concern, including dengue, which is endemic in Puerto Rico. Between 2002 and 2010, more than 61,000 suspected dengue cases were reported in Puerto Rico, of which 22,648 were confirmed (Halasa, Shepard and Zeng, 2012).

Healthcare workforce and access to services

Provider shortages and access issues pose functional challenges for the health care system. Historical workforce data are available from the Urban Institute or Perreira (2017), HRSA, Kaiser, AAMC, and the Puerto Rico Health Department, though estimates can vary. The latter has one study that forecasts health workforce into 2019 based on pre-storm provider availability, medical school enrollment and population trends. The issue of shortage and emigration to CONUS are the two greatest concerns for provider retention.

Currently, there are 88 health provider shortage areas (HPSAs) according to HRSA (Health Services Research Administration (HSRA), undated). Seventy-two of Puerto Rico's 78 municipalities have been designated as medically underserved areas, while 32 primary care HPSAs have a population-to-primary care provider ratio of 3,500 to 1 or higher. According to the Urban Institute analysis (Perreira et al., 2017), the number of general providers seems adequate, with 0.4 dentists, 7 nurses, 0.7 pharmacists, and 2.5 physicians per 1,000 people. A 2016 estimate from AAMC noted there were 9,874 active physicians, 3,580 primary care doctors, and 227 general surgeons. The report notes that 23 percent of municipalities had a

shortage of pediatricians, 68 percent had a shortage of OBGYNs, and 64 percent had a shortage of psychiatrists.

The issues of provider emigration is a challenge as well. AAMC estimates that 2,132 health professionals emigrated to CONUS in 2014, of which 361 were physicians. This was one of the largest waves in emigration of educated professionals at the time. If accounting for health care technicians, the total loss is estimated to be 51,740 that year alone. Since 2014, some estimates have indicated that there is a net emigration of 138 physicians from Puerto Rico each year. A shortage of physicians in CONUS has been cited as part of the motivation for migration Some also note that the loss of health providers includes advanced clinical practitioners (e.g., physician assistants (PAs)and nurse practitioners (NPs) who face resistance from the medical community in Puerto Rico because physicians view NPs as competitors.

At the same time, the number of people who used ASSMCA mental health services jumped significantly. ASSMCA served 43,145 residents in 2012, up from 23,560 patients in 2011. Even in 2011, the penetration rate for mental health service providers was 5.99 per 1,000 residents (Rodreguez, Greeman and Pesante, 2012), which is below the national average of 23.07 (Substance Abuse and Mental Health Services Administration (SAMHSA), 2015). Evidence suggests that the low penetration rate has decreased access to care. For instance, approximately 36 percent of adults with serious mental illness (SMI) had not received mental health services in the previous year.

Health care finance challenges

To pay for public services, including Medicaid, Puerto Rico borrowed money through municipal bonds. This action resulted in more financial problems in 2014 when ASES withheld Medicaid payments, creating even more uncertainty. Further, because financing was mostly earmarked for Medicaid/Medicare managed care, virtually no health care providers employed a fee-for-service model, except in some specialty care areas (e.g., psychiatric care).

Overall, Mi Salud reimbursement rates were not high. Puerto Rico received federal matching funds for Medicaid up to the federal statutory cap. Although the nominal federal matching rate (called the Federal Medical Assistance Percentage, or FMAP), was set at 50 percent in 1968 for Puerto Rico and other U.S. territories, the federal statutory cap has resulted in a significantly lower effective matching rate (Sebelius 2013). A one-time grant through the Affordable Care Act in 2012 relieved some of the shortfall in funding, but the solution was temporary (Merling and Johnston, 2017) and some estimates have calculated that federal funds covered only about 23 percent of the cost of Puerto Rico's Medicaid population. This limited access to care for low-income Puerto Ricans (Perreira et al., 2017). The FMAPs for the 50 U.S. states and DC are determined based on a formula that allots a higher FMAP to states with lower average per capita incomes. However, FMAP in Puerto Rico and other U.S. territories had no relation to per capita income. If it did, some analysts have estimated that this coverage would increase to nearly 83 percent (Mach, 2016). Medicaid reimbursement rates put a downward pressure on mental health

care providers. Reports conflict on how this downward pressure has impacted provider salaries, but there was a clear shortage of providers.

To address this set of financing challenges, in December 2015, Public Health Law 235-2015 established a Multisectoral Council, and its first report in 2016 laid the groundwork for the potential paths to single payer models, future roles for public-private coordination, and ways to integrate rights-based language in the future health care system.

Hurricane damage

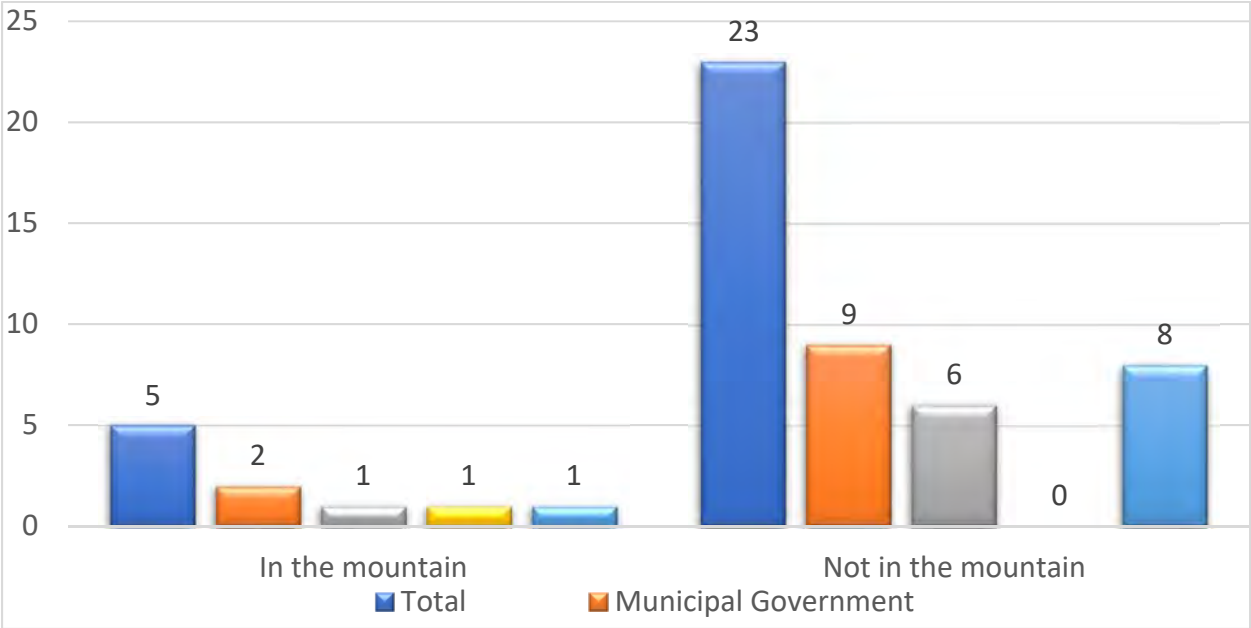
Infrastructure damage

In October 2017, the FEMA assessment of health care infrastructure damage showed that the extent of damage was not evenly distributed. Most of the western part of Puerto Rico—the Mayaguez and part of the Bayamon health care region—was classified as having low damage (on a scale of 0-14, with 1 being lowest). In contrast, parts of the northern, southern, and eastern regions were more significantly impacted; these are other parts of the Bayamon, Caguas, Fajardo, Metro, and Ponce regions.

In February 2018, the HSS RSF team was asked "to provide a clear picture of the status of health care facilities in Puerto Rico damaged during Hurricanes Irma and Maria to inform the development of short- and long-term strategies for the future of health care throughout the Commonwealth. Facilities include Department of Health, public corporations, as well as not-for-profit and private for-profit owned/managed health care providers. In short, given the response and recovery operations, HSS was asked to identify federally funded health care service providers on the island, including roles and responsibilities, geographic location, resource limitations and priority for restoration of services. This information would then be folded into facility assessments conducted by FEMA and HHS, proposed remediation plans, and estimated timelines for completion and return to service of any affected centers.

Figure 7.2, excerpted from the FEMA sector briefing deck, shows the locations of damage for the clinical and diagnostic centers. The severity of damage was most acute for non-mountainous regions.

Figure 7.2. Damage to clinical and diagnostic centers



FQHCs also sustained damage, split evenly between mountainous and non-mountainous regions of the commonwealth. Of the 92 FQHCs in Puerto Rico, 20 reported being damaged, and 10 of those 20 were located in the mountain region.

In the aftermath of Hurricane Maria, the CDC used syndromic surveillance to monitor for disease outbreaks, including waterborne illness, and transporting clinical specimens to Atlanta because much of the Commonwealth's laboratory infrastructure was destroyed (Ravi, 2017). As of January 25, 2018, 556 (55 percent) of the 1,003 public health laboratories in Puerto Rico remained closed (FEMA, 2018).

Health impacts

In the immediate aftermath of the hurricane, much of Puerto Rico's power grid was offline, and sewage wastewater treatment plants, including those upstream of drinking water supplies, were out of service, allowing raw sewage to pour into rivers and reservoirs. More details are available in the Water chapter of this report.

With a high proportion of the population lacking access to potable water, residents sometimes resorted to unsafe sources, such as wells and/or faucets contaminated by waterborne pathogens or chemicals. Specific incidents in Puerto Rico include an outbreak of leptospirosis, a bacterial infection spread when urine from infected animals gets into water or soil, which occurred in October 2017. In a preliminary analysis of site visits to schools, conducted in December, January, and February 2018, the HSS RSF described reports of gastrointestinal outbreaks at multiple schools, an increase in the numbers of sick students, and an increase in incidence of conjunctivitis (December) and influenza (FEMA, 2018), and reports of deaths from

leptospirosis at two schools. These conditions are commonly associated with poor water quality. The presence of mold can also lead to nasal congestion, wheezing, and red or itchy eyes or skin in sensitive individuals.

The incidence of skin-burrowing parasites that cause scabies or other skin infections was also reported to be on the rise in the month after Maria (Fofana, undated). The long-term risk of resurgence of Zika virus remains a concern, due to standing water, which is a breeding ground for mosquitoes.

The presence of mold and proximity to debris, pests, and vectors has also resulted in unsafe living conditions in highly impacted areas. During site visits to elder care facilities (public and private) conducted in December 2017 and January 2018, increases in conjunctivitis and respiratory problems were reported (FEMA, 2018). It was noted that some of the respiratory problems were exacerbated by the lack of power in residences, which had prevented use of medical equipment (e.g., continuous positive airway pressure and nebulizers for treating sleep apnea and respiratory diseases, respectively). Similar increases in gastrointestinal illness, skin infections, influenza, and conjunctivitis were reported in health care clinics that were visited in December and January (FEMA, 2018).

The risk of residential contamination from toxic chemicals leeching from Superfund sites was cause for concern amongst residents. Additionally, according to an EPA brief (October 11, 2017), residents were reportedly obtaining or trying to obtain drinking water from wells at Superfund sites. However, on October 31, 2017, the EPA reported that an investigation revealed the water originated from a drinking water system, not from Superfund site wells.

The prevalent and persistent absence of a reliable source of power has resulted in reliance on diesel-powered generators, heightening concern for air quality and the potential human health implications, particularly for those who suffer from respiratory disease (Reardon, 2017). The International Agency for Research on Cancer (IARC) has classified diesel engine exhaust as a Group 1 carcinogen, based on sufficient evidence that exposure is associated with an increased risk for lung cancer.

Increases in anxiety, depression, and PTSD were widely reported following the hurricanes. Reports from Ponce Health Sciences University also indicate an increase in the proportion of mental health patients from rural areas, particularly Utado and Cayey. The need for mental health services is especially great in Toa Baja, where storm damage was among the worst. Of the 2,500 people who have visited the emergency clinic since its opening after the storm, 90 percent were referred for mental health screenings (Dickerson, 2017). Suicide also appears to be an issue: Although the rate of suicide had fallen in the most recent three-year assessment periods, the rate spiked during the height of the financial crisis (2008-2013), and initial reports indicate that it spiked again following Maria. At least 253 people committed suicide in 2017, a 29-percent increase from 2016. Eighty-five percent of these suicides were among men (Governor of Puerto Rico, 2017b). As of January 22, 2018, the suicide hotline had received 3,050 calls since the storm, a 246 percent increase compared to the same time the previous year (Governor of Puerto

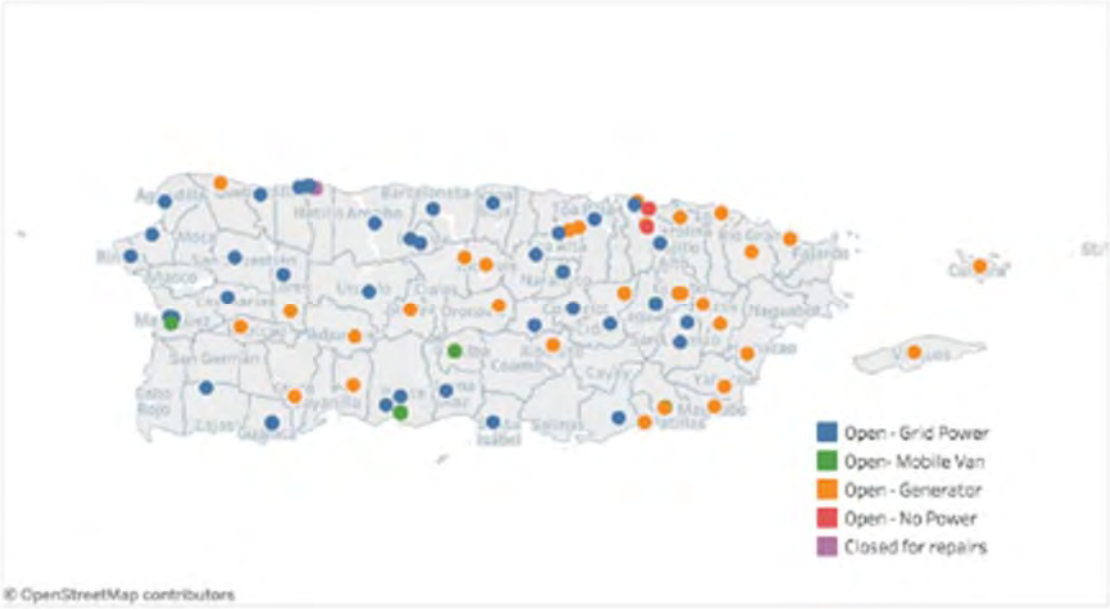
Rico, 2017b). Stakeholders also note that the official reported rate of suicide is likely an underestimate of actual suicides.

The Health and Social Services RSF conducted site visits to school and report that mental health is still their main concern within schools. The incidences of suicide and attempted suicide among minors have risen drastically since the hurricane, affecting children as young as eight years old. A December report on school visits explained that there was an increase in behavioral health needs among students, families, faculty and staff. The report suggested that the lack of basic services such as internet and electricity is adding to these issues, and recommended that an in-school, formal behavioral health program was needed (FEMA, 2018). These issues were reiterated in a report from January and February (FEMA, 2018).

Post-hurricane conditions

According to the Kaiser Family Foundation, as of March 2018, almost all health centers in Puerto Rico have reopened (one mobile van remains closed for repairs) (Figure 7.3). However, a health center's being "open" does not guarantee it is operating at full capacity. Approximately one in 10 (11 percent) of the permanent health center sites in the Commonwealth have limited or no grid power. Three health centers have intermittent grid power and rely on generators as a backup source of power; five are without use of grid power and rely solely on generators, and another health center is now using solar power (Kaiser Family Foundation, 2018).

Figure 7.3. Operational status of health centers in Puerto Rico



Source: (Kaiser Family Foundation, 2018)

Access to health care is variable across health services is also an issue identified by municipal leaders in a survey conducted between April 24, 2018 and June 8, 2018. As shown in Table 7.3, significant numbers of municipalities reported that key health care services were still not accessible to residents eight months after the hurricanes. Seven municipalities reported that primary, general care was not accessible. More specialized care, emergency care, and dialysis were even less likely to be accessible, with large proportions of municipalities reporting their citizens did not have access.

Table 7.3. Municipal Leaders' Perceptions of Availability of Health Care after the Hurricane

Availability of health services after the hurricane		Yes	No	Total
Primary care (general care clinic, doctor's office, community health centers)	N	42	7	49
	%	85.7%	14.3%	100.0%
Secondary care (hospital and emergency care, specialist)	N	31	14	45
	%	68.9%	31.1%	100.0%
Therapy centers	N	29	16	45
	%	64.4%	35.6%	100.0%
Dialysis centers	N	21	24	45
	%	46.7%	53.3%	100.0%

Source: HSOAC analysis of data from ICMA Assessment of Municipalities in Puerto Rico, June 15, 2018.

In summary, several health care system issues have emerged in the wake of the hurricanes. First, hospital and health clinic use have increased, compared to use of primary care. Second, changes in the population mix may be negatively affecting certain vulnerable communities, but it is unclear what future service needs may be for that changing demography. Third, health care services have some basic administrative issues, including cash flow and billing. And fourth, full health care system restoration issues need to be addressed urgently, inclusive of addressing both physical damage and workforce retention.

As of spring 2018, the EPA completed assessments at over 300 regulated facilities, EPA-led Superfund sites, oil sites, and chemical facilities and completed all hurricane-related response actions at these sites. The EPA did not identify any major spills or releases from these facilities associated with Hurricane Maria (U.S. Environmental Protection Agency, 2018c). Infectious diseases such as influenza have been controlled to within comparable rates in the continental United States, although concerns about water quality persist, as described in Chapter 12 (Water).

Key issues that remain for public and environmental health include lack of access to potable water, water safety and access concerns, and unsafe living conditions with respect to mold, proximity to debris, and pests. These concerns were echoed in a survey of local Puerto Rican government officials and staff from 73 of 78 municipalities conducted between April 24, 2018 and June 8, 2018. When asked to name their top public health threats at the time of the survey,

the number one concern was mosquito-borne disease (32% of municipalities), with water (19%) and solid waste/debris (14%) also falling within the top five public health threats named (ICMA, 2018). For public health, there is a concern regarding the interruption of essential services (e.g., cold chain for vaccines, storage of insulin), the operational status of some of the public health labs (with some samples being sent to CDC Headquarters for testing), access to essential services such as immunizations, and concerns about damage to critical public health facilities

Surveys of municipal leaders following the storm identify ongoing mental health challenges for their citizens as a result of conditions caused by the storms. One mayor conveyed that they would regularly see citizens shaking during heavy rain storms in the months following the hurricanes—something they attributed to post traumatic stress disorder.[111] In the early days of disaster response, many behavioral health services were up and running, as noted in a meeting held on October 16, 2017 with 20 behavioral health stakeholders, but access to them was difficult due to lack of transportation (FEMA, 2018). In order to address this issue, providers conducted deliberate outreach to those hard-to-reach communities. ASSMCA trained 300 mental health facilitators to provide care within the most affected of the 78 municipalities. They were reported to have entered the field on November 3, 2017 As of November 28, ASSMCA leadership reported that all mental health hospitals and treatment clinics were operational. The US PHS and the CDC fielded a two-question survey to assess distress and access. Of the 133-people surveyed, 18 percent endorsed distress and denied having access to people or resources. These data can be used as a benchmark to evaluate recovery efforts in the coming months. To help improve access to care, some routine procedures were suspended, such as requiring a primary care doctor referral for behavioral health care.

Social services

Background

History and structure

Social services include a range of activities designed to ensure the well-being of PDADs, including children, the elderly, and those with disabilities. Puerto Rico Law No. 171 of June 30, 1968 created the Department of Social Services, which was reorganized under Puerto Rico Law No. 1 of July 28, 1995 as the Department of the Family. Supported by a mix of federal and Commonwealth funding, the Department of the Family provides a wide range of human/social welfare services in Puerto Rico..

The Department of the Family houses many of the publicly provided services related to child welfare and social services. Four administrations and one corporation operate with fiscal and administrative autonomy within the umbrella agency under the Office of the Secretary, which

[111] Mentioned in an HSOAC roundtable of municipal leaders during the post-storm period

sets policy for the department. Administrators at the operational and programmatic components are responsible for executing policies established by the Secretary in their respective areas of service, including developing and implementing standards and procedures for programs and providing operational supervision of Integrated Service Centers (ICS). Select Administrations include the Administration for Families and Children (ADFAN), charged with operating programs to protect children and youth, social work, adoption, and abuse and domestic violence; Administration of the Socioeconomic Development of the Family (ADSEF), which administers federal programs such as Child and Adult Care Food Program, Nutrition Assistance Program (NAP) for Puerto Rico which takes the place of SNAP), and TANF; the Low-Income Home Energy Assistance Program; the Administration for Integral Development of Childhood (ACUDEN), which operates Head Start / Early Head Start and Child Care programs; the Child Support Administration (ASUME); and *Corporation for the Blind, and Physically or Mentally Disabled* (CIRIO), which provides services to individuals who are blind and those with mental/behavioral disabilities.

As measured by the FY 2017 budgets for the four Department of Family Administrations, annual social service expenditures for social services in Puerto Rico are approximately $2.6 billion.[112] Eight percent is earmarked for staffing and facilities. A report by the Child Welfare League of America states that, in 2014, Puerto Rico spent $150,558,280 for child welfare services, which includes all direct and administrative services provided to children and families by the state agency. Federal funds accounted for $26,582,396, and state and local funds accounted for $123,975,884.

In addition to the governmental agencies, a variety of non-profit organizations are involved in the provision of social services (e.g., child care providers and food banks). As of 2014, 11,570 non-profit organizations were actively providing these services: of those, 22 percent were community based(Estudios Tecnicos Inc, 2015). Organizations described as social service providers accounted for 776 providers, along with economic, social, and community development organizations (888), health services (373), and housing services (245).

Key assets

Assets in the social services subsector primarily consist of facilities and workforce (McIntyre, 2018).

Facilities

Designated facilities that provide social services include the following:

[112] Note that this estimate includes only the Department of Family, which is the primary provider of social services. However, these services are distributed across numerous agencies and an exhaustive accounting would increase this amount (e.g., the Department of Family Secretariat and OPPEA would add approximately $70M).

- 1,024 registered Head Start centers promote school readiness among children from birth to five years in low-income families, by focusing on cognitive, social and emotional development
- 737 registered child care centers provide a range of child care and early child education services
- 138 multiple activities and services centers for elderly people are available to senior citizens (as of the 2015-2018 State Plan on Aging).

Workforce

Table 7.4 shows the social services workforce across Bureau of Labor Statistics (BLS) staffing categories. As of May 2017, the workforce included 35,340 employees across all categories.

Table 7.4 Social services workforce (May 2017 estimates)

Staffing Category	Number of Staff
Child, Family, and School Social Workers	3,600
Childcare Workers	1,590
Clinical, Counseling, and School Psychologists	350
Community and Social Service Occupations	15,670
Community and Social Service Specialists, All Other	850
Community Health Workers	360
Counselors, All Other	250
Education Administrators, Preschool and Childcare Center/Program	260
Educational, Guidance, School, and Vocational Counselors	1,250
Healthcare Social Workers	750
Mental Health and Substance Abuse Social Workers	270
Preschool Teachers, Except Special Education	2,990
Psychiatric Aides	60
Psychiatric Technicians	120
Psychologists, All Other	100
Social and Community Service Managers	290
Social and Human Service Assistants	4,870
Social Work Teachers, Postsecondary	50
Social Workers, All Other	1,380
Substance Abuse, Behavioral Disorder, and Mental Health Counselors	280

Source: (Bureau of Labor Statistics, 2018h).

Pre-hurricane conditions

Population changes creating new vulnerabilities

As of 2012, 39.5 percent of the population age 65 and over were living at or below 100 percent of the federal poverty level (FPL), with Social Security (80.2 percent) and the Nutritional Assistance Program (40.9 percent) as their main sources of income. As mentioned above, the population of Puerto Rico has been increasing in average age, with 39.2 percent of the population projected to be age 60 or older by 2050 (Puerto Rico Office of the Ombudsman for Elderly, 2015). These economic and demographic conditions presented population-level challenges that will need to be addressed, as the aging of the population will increase demand for health and other support services. Furthermore, a reduction in student population and workforce

size in the health sector due to emigration from Puerto Rico posed additional challenges during disaster recovery.

Risk factors among children

As discussed in the chapter on People and Communities of Puerto Rico, a large proportion of children in Puerto Rico live in poverty. During the period from 2008 to 2012, 84 percent of children lived in census tracts with poverty rates of at least 30 percent, and this rate has remained fairly steady since 2012 (Annie E. Casey Foundation, 2018). Additionally, Puerto Rico failed to meet targets on other indicators of child well-being, especially the indicators *Children have permanency and stability in their living situation* (only 12.5 percent in conformity), and *Families have enhanced capacity to provide for their children's needs* (23.1 percent in conformity) (Administration for Children and Families of Puerto Rico, 2015). Additionally, data from a 2010 U.S. Department of Health and Human Services Child and Family Services Review of the ADFAN found that, as of the time of the review, Puerto Rico did not have a statewide information system to capture status, demographic information, location, and placement goals for children in the foster care system.

Lack of access to income and food assistance

The number of TANF recipients has been dropping consistently over time. The monthly average in FY2000 was 92,299, dropping to 15,259 in FY2017 (U.S. Department of Health and Human Services and Office of Family Assistance, 2018). A professor at Universidad Interamericana estimated that the number of current beneficiaries could be as low as 5,000. Theories about the reasons for this downward trend during a challenging economic environment included more cases reaching the 60-month limit, which increases attrition (i.e., exit rates are higher than entry rates), emigration from Puerto Rico, or other demographic changes that could affect the size of the eligible population (Cordero-Guzman, 2017). Another possibility, suggested by Interamericana staff, was that placing work requirements on benefits during an economic downturn (i.e., fewer jobs) would decrease eligibility.

As of 2016, 45.1 percent of Puerto Ricans had incomes below the FPL, and approximately 470,000 received benefits from NAP (38.9 percent) (American Fact Finder, 2016a). Because this program was funded via a capped block grant, $1.9 billion for 2017, it is not able to accommodate increased need (Wolkomier, 2017). On March 1, 2018, an additional $1.27 billion was made available through the Additional Supplemental Appropriations for Disaster Relief Act of 2017 for nine months (discussed in more detail below) (Caribbean Business Staff, 2018).

Hurricane damage

Impacts to this subsector include loss of and damage to physical structures and interruption of service to clients and beneficiaries. (Damage to public buildings is described in the Public buildings chapter of this report.) Anecdotal reports of data loss have been refuted by

knowledgeable agencies, although, limited access to existing data and/or the need to re-collect data appear to have been a challenge while ascertaining case status and/or locating and identifying participants after the storm. Like other subsectors, social services have been affected by emigration: As younger generations have migrated to CONUS, an increasing number of senior citizens are living alone and may therefore be more vulnerable to financial exploitation (Oficina Del Procurador De Las Personas De Edad Avanzada (OPPEA), undated).

Additionally, some areas are at risk of worsening following the disaster and warrant particular attention:

- preventing an increase in child maltreatment
- addressing limitations on the capacity of the social work and child protection workforce to manage an increased caseload
- increased risk to PDADs from diminished capacity to provide support
- expanding local community human services to the whole community, without a corresponding increase in resources (Puerto Rico Health and Human Services, 2018).

Post-hurricane conditions

On March 1, 2018, the Additional Supplemental Appropriations for Disaster Relief Act of 2017 made an additional $1.27 billion available for Puerto Rico's NAP for nine months (Caribbean Business Staff, 2018). In addition to this funding extension, the federal Food and Nutrition Service approved a request to extend a limited number of waivers to schools operating the National School Lunch Program and School Breakfast Program and to child care institutions that operate the Child and Adult Care Food Program thorough March 31, 2018, effectively extending the services they can provide (U.S. Department of Agriculture, 2017). It is not currently known how many people will be impacted by the end of the waivers. In addition, only 35 of 89 Women, Infants, and Children (WIC) clinics operated by PRDOH have access to the internet, forcing staff to track participant information manually (the WIC program provides supplemental food assistance, nutrition and infant development education, and breastfeeding guidance for eligible pregnant and postpartum women and their babies through age 5).

Education

Background

History and structure

The education system is important to prepare individuals to participate in the economy and society, and to provide the lifelong learning skills needed to adapt to changes throughout the life course. Starting in the mid-1940s, Puerto Rico's government committed itself to raising the educational attainment of Puerto Rico's population. To this end, between 1944 and 1962,

increases in public spending on education resulted in a sharp expansion of schools and teacher hiring.

Currently, 99 percent of the eligible population attends school. The language of instruction in Puerto Rico is Spanish. Therefore, English and other non-Spanish speaking students are identified as "Spanish learners." For the 2016-2017 school year, 1,490 were Spanish learners representing just 0.41 percent of the total student population (Puerto Rico Department of Education, 2017a).

Puerto Rico maintains separate governance structures for public and private schools, including parochial schools. However, all schools must be licensed and regulated by the Puerto Rico Department of Education (PRDE), which oversees all elementary and secondary public education in Puerto Rico and constitutes one of the largest school districts in the United States. Unlike public state education systems in CONUS, which are divided into self-governing local education agencies (LEAs), the Commonwealth's PRDE operates as one single LEA or school district. LEAs are subject to federal education regulations but have autonomy in terms of hiring/placing teachers, curricula, and resource allocation. The Puerto District school district is divided into seven regions, but decision-making occurs centrally (Kennedy and Migaki, 2017b). However, the government approved an education reform bill in March 2018 that includes the restructuring of its administrative regions into seven autonomous LEAs, which will oversee and manage the schools in each region of the Commonwealth (Lopez Alicea, 2017). The education reform also creates a new school choice environment by authorizing the creation of charter schools and instituting a voucher system that will be available to three percent of the student population.

Puerto Rico has three major university systems: the University of Puerto Rico, with 11 campuses; the Ana G. Méndez University System (SUAGM), with three major campuses and some satellites; and the Interamerican University of Puerto Rico (Inter), with nine campuses and two specialized schools. In addition, a total of 333 public and private post-secondary vocational or technical institutions serve the Commonwealth (Disdier and Jara, 2017), the most prominent being Huertas College, ICPR Junior College, Instituto de Banca y Comercio, National University College (NUC), and the Puerto Rico Technological Institute. Almost all vocational or technical institutions, colleges, universities, and schools are accredited by the Middle States Association of Colleges and Schools.

The education subsector in Puerto Rico includes K-12 and post-secondary education, and utilizes a variety of assets from the public, nonprofit, and private sectors. We report on Early Head Start and Head Start programs in the Social services section of this chapter. Education costs represent 16 percent of the Commonwealth's budgetary expenditures, including funding for both the PRDE and the University of Puerto Rico. As a comparison, Hawaii's expenditures in K-12 and post-secondary education represent 22 percent (State of Hawaii Department of Budget and Finance, 2017) of the state's budget (Hawaii is the only U.S. state that manages schools as one single school district). The proposed budgets for the 2018 fiscal year were $2.7 billion for

PRDE and $1.3 billion for the University of Puerto Rico (Puerto Rico Department of Education, 2017b). The 2018 total proposed budget for the Commonwealth was $25.6 billion (Financial Oversight and Management Board for Puerto Rico, 2017).

Key assets

Facilities

Due to enrollment decreases and Puerto Rico's economic difficulties reported in other chapters of this report, the school district closed 179 schools during the summer of 2017. As of September 2017, the district had 1,113 schools, enrolling 345,000 students (Kennedy and Migaki, 2017b). According to a 2015 report, Puerto Rico also has about 880 private schools and 144,034 private school students. Post-secondary schools include 333 post-secondary public vocational or technical institutions, with a total of 50,816 students, and 18 public universities, with a total of 62,523 students. Puerto Rico also has 72 private university-degree-granting institutions, 49 of which are for-profit and 23 of which are not-for-profit, with a total of 178,355 students (Disdier and Jara, 2017).

Workforce

As of 2016, the PRDE employed 30,438 public school teachers and a total of 48,820 full-time employees in both district offices and public schools (National Center for Education Statistics). In 2017, it was reported that the University of Puerto Rico employed an estimated 5,300 faculty members (Financial Oversight and Management Board for Puerto Rico, 2017) and, according to a 2015 report, 4,518 instructors worked in post-secondary vocational or technical institutions. In the private education sector, 11,645 teachers were employed in private K-12 schools and 10,898 faculty members in the private university system (Disdier and Jara, 2017).

Pre-hurricane conditions

High concentration of economically disadvantaged and special needs students

Puerto Rican schools have been serving a high concentration of economically disadvantaged students and students with disabilities. In 2016-17, the total number of economically disadvantaged students was 294,210, which represented 81 percent of the student population. During the 2016-17 school year, the number of students with disabilities in Puerto Rico was 118,329, which represented 32 percent of the student population (Puerto Rico Department of Education, 2017a), a higher percentage than in any U.S. state.

Lagging student performance

Puerto Rican students' performance has lagged far behind that of their counterparts in CONUS. According to data from the 2016-2017 school year, the high school graduation rate for Puerto Rico's students is 75 percent, and the average proficiency rate for students in grades 3 to 8 on the

"Pruebas Puertorriquenas de Aprovechamiento Academico" is 33 percent in math, 42 percent in English, 49 percent in Spanish, and 49 percent in science (Puerto Rico Department of Education, 2018). In 2014–2015, U.S. state-level graduation rates ranged from 69 percent in the District of Columbia and New Mexico to 90 percent in New Jersey and 91 percent in Iowa. Roughly two-thirds of states (34) reported graduation rates between 80 and 89 percent (National Center for Education Statistics, 2018).

The National Assessment of Educational Progress (NAEP) is a standardized test that is given to samples of students across all states and provides a good mechanism for benchmarking performance. In Puerto Rico, fewer than one percent of students scored at or above a proficient score on the 2017 NAEP math assessments for fourth and eighth graders. While fourth and eighth graders' math performance in 2017 showed significant improvement from 2015 data, Puerto Rico's NAEP scores are low relative to those in all U.S. states. More precisely, across the 50 states in 2017, the percentage of fourth-grade students performing at or above the proficient level ranged from 27 to 53 percent, and the percentage of eighth-grade students performing at or above the proficient level ranged from 19 to 50 percent (The Nation's Report Card, 2015).

The Program for International Student Assessment (PISA) also provides a mechanism for international benchmarking. In 2015, Puerto Rico's 15-year-olds performed below both the U.S. and Organization for Economic Cooperation and Development (OECD, an organization representing 37 countries) average on PISA. The scores for students in Puerto Rico were comparable to those of students in Brazil and Peru (National Center for Education Statistics, undated-b).

Financial and structural challenges in education system

The Puerto Rico education system is facing financial strains due to factors that include the aforementioned low student achievement, decline in student enrollment, and others. Historically the Commonwealth's education costs represented 16 percent of its budgetary expenditures. Per-pupil spending in Puerto Rico in FY 2015 was $8,007. At the national level, average FY 2015 expenditures per pupil were $11,454, ranging from $6,751 in Utah to $20,744 in New York. An estimated 56 percent of Puerto Rico's education expenditures were financed through the Commonwealth's General Fund and 36 percent through federal funds, primarily funding from Title I of the Federal Elementary and Secondary Education Act. Nevertheless, as a territory, Puerto Rico had less access to federal education funds and programs than do U.S. states (for similar reasons it also receives less federal funding for health).

Additionally, discussion is ongoing about the proportion of educational expenditures devoted to administrative staff salaries, including central office administrators, school administrators, and office support staff, compared to instructional staff, materials, and support prior to the storms. Past reports about PRDE have highlighted overspending on administrative personnel as a problem in the current system (e.g., Ladd and Rivera-Batiz (2006). However, data from the U.S.

Department of Education for 2015 to 2016 show that Puerto Rico's per-pupil spending on general administration and school administration was below the U.S. average. The only category for which HSOAC found above-average spending in Puerto Rico during 2015 to 2016 school year was food services.

In addition, enrollment in public schools has been declining due to insufficient funding, understaffing, and widespread building vacancy. A recent report of the PRDE indicates that enrollment declined from 423,934 in 2013 to 379,818 in 2016, and to an estimated 345,000 students at the beginning of the 2017-18 school year (Puerto Rico Department of Education). The enrollment decline has been attributed to both a decline in fertility as well as outmigration, both of which have led to a contraction of the school-age population (Ladd and Rivera-Batiz, 2006). Most funding support for Puerto Rico K-12 education system comes from the commonwealth. Since many commonwealth and federal funding sources are awarded on a per-student basis, the decline in enrollment has been accompanied by a reduction in funding for some educational grants. For example, since 2010, PRDE grants to Puerto Rico for elementary and secondary education programs have declined by about 25%. Before the storms, the government of Puerto Rico had released a plan to improve the K–12 system's efficiency and effectiveness by reducing the number of schools and creating a regionally administered system, with more autonomy given to regional and school-level directors. Other pre-storm challenges related to the stock of public buildings used for schools are covered in the Public buildings chapter of this report.

Hurricane damage

Infrastructure damage

Infrastructure inspections occurred between October 17 and November 16, 2017 (FEMA, 2018). All 1,113 K-12 public schools in Puerto Rico had been closed in the aftermath of the storm, and as many as 74 schools were closed permanently due to structural damage to the buildings (Governor of Puerto Rico, 2017a).[113] As of February 2018, roughly 20 percent of Head Start facilities were closed; more specific and recent information is not available (U.S. Department of Health & Human Services and Office of the Assistant Secretary for Preparedness and Response (ASPR), 2018).

In an assessment of a subset of schools completed in October and November 2017, many reported the presence of water damage, mold in classrooms, and pests (FEMA, 2018). Site visits conducted in December (n=12 schools) noted several reports of fumigation for pests, but the occurrence of ticks and termites persisted, and one school in Vieques reported rodent infestations (FEMA, 2018). The lack of formal training for mold remediation was also a concern (FEMA, 2018). The presence of mold was also reported during site visits to NGOs in December 2017

[113] There is some variability in the number of schools reported closed. This value is an upper limit of a range and comes from the Governor's Build Back Better Report.

(FEMA, 2018). In visits conducted by the RSF in January and February of 2018, many schools reported efforts to clear debris, manage pests, and clean mold (FEMA, 2018). However, it should be noted that visits were to a very limited subset of schools (n=9), and it is not clear whether the assessment of mold remediation was adequate.

Additional information on school damage collected from USACE damage assessments is reported in the Public Buildings chapter of this report (Chapter 15).

Impacts on school operations

Across Puerto Rico, schools were closed for a total of 33 to 70 days (FEMA, 2018). The loss of instructional time at these schools is likely to have a negative impact on student achievement for the current and perhaps even the next school year. The length of school closures varied by region, with schools in municipalities that faced greater damage experiencing the longest closures.

The lack of electricity, reliance on gas generators, and lack of potable water forced some reopened schools to remain on limited schedules. For example, due to extreme heat, schools without functioning air conditioning systems reduced school hours.

The lack of electricity also complicated food storage and preparation in school facilities. As mentioned above, about 80 percent of public school students are eligible for free or reduced lunch. In addition, many schools usually provide breakfasts and dinners for students.

Schools also faced significant transportation issues. Due to the debris in the roads and the existing terrain, one school visited by the HSS RSF had to use smaller school buses, resulting in an increased number of trips to and from the school. For some students, this meant that their day was extended by hours. In extreme cases, some students were left at schools in the morning with no supervision.

Finally, with many homes and schools sustaining significant damage, school supplies, including text books, were destroyed. It is unclear how widespread was the damage to school supplies and instructional materials, but this is also likely impacting schools' ability to reestablish normal functioning.

Impacts on students and learning outcomes

The education sector reports that student mental health is still their main concern and that incidences of suicide and attempted suicide among minors have risen drastically since the hurricane, affecting children as young as eight years old. A December report based on data from school visits noted an increase in behavioral health needs among students, families, faculty and staff (FEMA, 2018).

The educational impacts of these disruptions are difficult to estimate. Some effects have been mitigated through flexible decision-making. For instance, because of the hurricane, the date of the College Entrance Examination Board, also known as the "College Board" (the SAT equivalent in Puerto Rico), was postponed. However, school administrators remained concerned,

because many students are in homes without power, which may affect their ability to prepare for the test. Colleges and universities in Puerto Rico adjusted their deadlines for submission of test results, in acknowledgement of these issues.

Post-hurricane conditions

Some school buildings were utilized as shelters or disaster relief "service centers" soon after the storm and continued to serve in this capacity once students returned to school (Balingit and Hernandez, 2017). In some cases, this continued use delayed schools' ability to reopen and limited the services that were provided to students. However the use of schools as shelters provided students with a safe place to go during the day, which allowed parents to begin the process of recovering and returning to work. Nevertheless, it is unclear how many schools continued to serve as service centers after students returned to school, for how long, or how this function impacted schools' ability to resume normal operations.

As of March 8, 2018, the Department of Education estimates that between 64 and 88 percent of teachers and 67 to 87 percent of principals have reported back to work. Table 7.5 shows the percentages of teachers, principals, and other staff members who have reported back to work by region as well as student attendance by region.

Table 7.5. Education staff and student attendance as of March 8, 2018

Region	Arecibo	Bayamon	Caguas	Humacao	Mayaguez	Ponce	San Juan
Teachers	83%	64%	64%	72%	88%	68%	85%
Principals	87%	67%	72%	71%	84%	67%	87%
Other staff	95%	72%	75%	80%	95%	71%	82%
Students	81%	60%	65%	74%	88%	57%	79%

Source: Secretary Keleher's Twitter Account
Note: The Department of Education estimates having a total of 50,980 full-time employees (Puerto Rico Department of Education, 2017b).

Outmigration of students and school employees

The migration of individuals both within Puerto Rico and to CONUS caused by the hurricanes has decreased student enrollment across Puerto Rico. As of December 2017, the PRDE estimates that about 331,000 students were enrolled in schools after the hurricane, compared to 345,000 before the storm (Ujifusa, 2017). A 2017 report by the Center for Puerto Rican Studies at Hunter College estimates further declines in student enrollment throughout 2018 and into 2019. An estimated 22,710 to 42,771 of outmigrants are expected to be school-age children and between 8,068 and 16,443 will be under five years. More detail on outmigration can be found in the People and Communities chapter of this report (Chapter 6).

Remaining needs and recovery priorities

Puerto Rico must still address a number of immediate short-term challenges to prevent further damage to the health and safety of its citizens. Longer-term changes will need to address some of the pre-storm conditions that impacted the Commonwealth's ability to achieve well-being over time.

Short term

Over the next one to 12 months, priorities include:

- *Repairs to remaining health care, public health, and school building infrastructure damage.* As of March 2018, approximately 1 in 10 (11 percent) of the permanent health center sites have limited or no grid power. Three health centers have intermittent grid power and rely on generators as a backup source of power; five are without use of grid power and rely solely on generators, and another health center is now using solar power. Use of hospital and health clinics has increased in lieu of primary care facilities, which suggests a need to increase the operating capacity of the latter. Shifts in population make it difficult to anticipate future demand, and cash flow/billing issues create uncertainties about the ability to maintain continuity of service in some areas. From a public health perspective, lab and surveillance infrastructure is not functioning at full capacity, and concerns about mosquito-borne disease and other public health concerns are common. Additionally, educational and health outcomes are likely to continue to suffer with schools remaining in disrepair. Data on school buildings is discussed in the public buildings chapter.
- *Reliable access to safe drinking water to address safety concerns.* As of the end of February 2018, the large majority of water (88%) and wastewater (98%) treatment plants were operating, but below their full capacity. A lack of access to clean drinking water increases the risk for water-borne disease and exposure to toxic compounds in water.
- *Improved mental health care access to address suicide and other mental health issues.* As of this writing, most service centers were up and running, but access to them was reportedly difficult due to lack of transportation. The recent decline in annual suicide rate appears to have been followed by a post-storm spike, with rates in 2017 running higher than in the previous year (a 29% increase between 2017 and 2016) (Governor of Puerto Rico, 2017b). In addition, concern has been raised about the numerous reports of higher rates of anxiety, depression, and PTSD and the potential for domestic violence and substance use that can accompany these disorders. Trauma-based mental health care, particularly in the long-term recovery period, may need to be enhanced. Concerns also exist about about the quality and use of evidence-based treatment and the availability and capacity of mental health providers (including providers within schools). Support is needed for those who fall outside of the centralized nexus of behavioral/mental health initiatives (e.g., faith-based leaders).

Longer term

Over the next one to ten years, Puerto Rico's health and social systems require substantial reconfiguration to be resilient and sustainable over time.

- *Improved financial viability of the health system to sustainably provide health care services to the future population of Puerto Rico*. Short-term solutions have improved access temporarily. For example, in early 2018, CMS extended an opportunity to Puerto Rico residents to enroll in Medicare health and drug plans and to obtain health coverage through the Federal Health Insurance Exchange. While there have been some fixes to offset the Medicaid shortfall with an influx of funds, this is temporary and the future robustness of the system remains in question. Efforts have been proposed to increase the reimbursement rate for Medicare Advantage, cited as 43 percent below the national average, but there is no decision yet on that change. Concerns about the future viability of the system, including provider retention issues, have not yet been fully addressed.
- *A stronger and better funded social services sector to provide adequate services and benefits to PDADs*. Concerns have been raised about abandonment of elderly people in residential facilities and/or hospitals by family members who have left their communities, and about neglect/abuse of children. Addressing these challenges will require solutions to longer-term limitations in system capacity (e.g., low funding, fragmentation of provider networks), which were exacerbated by limited access to some records during and following the storm (some agency buildings have been closed due to damage and mold), limiting the ability to track children and elderly adults in need of service. NAP was expanded via supplemental disaster appropriation funding following the hurricane, PAN will revert to pre-storm benefit levels when supplemental disaster funding expires. Waivers allowing operators of school lunch programs and child and adult care food programs more flexibility in the meals they provided expired in June 2018, and WIC waivers are currently set to expire in August 2018. When waivers and supplemental funding expire, programs likely will contract, and individuals may lose benefits.
- *Improved or full functionality for all schools, with options to address the lingering effects of learning loss and mental health effects on students' ability to learn*. Efforts are needed to bring all schools up to full functioning and to continue to consider options to deal with the lingering effects of learning loss and mental health effects on students' ability to learn. At the system level, there is a need to figure out how to downsize the system to control costs and improve student achievement and attainment.

8. Housing

Overview

This chapter documents the damage and needs assessment conducted for the residential housing sector. It discusses background and pre-hurricane conditions and challenges for Puerto Rico's housing sector, damage resulting from Hurricanes Irma and Maria, and remaining short and long-term priorities to address within the sector. Puerto Rico's housing sector sustained substantial damage during the hurricanes, and efforts to build back are hindered by a number of challenges with pre-existing vulnerability of structures, governance of the housing sector, and financing pre-dating the hurricanes. In addition, it is important to distinguish between providing quick repair to structures damaged by the hurricanes so that families can rapidly return to their homes and longer-term fixes that can make Puerto Rico's housing stock less vulnerable to natural disasters. This distinction is made clear throughout the discussion below.

For the purposes of this assessment, the housing sector includes both owner- and renter-occupied units, including subsidized housing units, and we report data separately for these two subsectors when possible. Table 8.1 lists the key federal and commonwealth public agencies that oversee the housing sector in Puerto Rico and summarizes each agency's role. Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Housing" Sector Report.

Table 8.1. Agencies Responsible for Housing

Agency	Role	Relevant regulations
U.S. Department of Housing and Urban Development (HUD)	Certifies and issues Community Development Block Grants and develops housing policies for the United States. Also provides home loans through the Federal Housing Administration (FHA).	Housing and Community Development Act of 1974; 24 CFR 570; Public Law 115-123
U.S. Department of Agriculture-Rural Development (USDA-RD)	Issues and administers low-income Single-Family and Multi-family grants and loans in rural development areas.	7 CFR Part 1980; Pub. L. 101-625
Federal Emergency Management Agency (FEMA)	Administers federal disaster response and recovery housing programs.	Public Law 93-288; 44 CFR
National Flood Insurance Program (NFIP)	Administers programs and develops policies aimed at mitigating damage to houses caused by flooding by providing flood insurance for homeowners and encouraging communities to adopt and enforce floodplain management regulations.	42 U.S.C. 4001

Departamento de la Vivienda (DV) (PR Department of Housing)	Commonwealth governmental entity charged with developing and administering housing programs and policies.	Ley Núm. 97 of July 10, 1972
Autoridad para el Financiamiento de la Vivienda (AFV) Housing Financial Authority)	Government bank that uses public and private financing alternatives to help low- and moderate-income families build, rebuild, acquire, refinance, or expand their own homes.	
Administración de Vivienda Pública (AVP) (Public Housing Authority)	Ensures the maintenance, rehabilitation, and effective management of public housing projects to increase the availability of affordable housing, promote economic development and improve the quality of life of families to achieve self-sufficiency.	
Junta de Planificación (JP) (PR Planning Board)	Collects data and develops land-use plans for the Commonwealth. It is the Floodplain Manager required by the NFIP for the Commonwealth.	Ley Num. 75 of June 24, 1975
Oficina de Gerencia de Permisos (OGP) (Office of Permit Management)	In charge of issuing final determinations and permits, licenses, inspections, certifications and any other authorization or procedure that is necessary to meet the citizens' requests.	Ley 161 of December 1, 2009
Oficina para el Desarrollo Socioeconómico y Comunitario de Puerto Rico (Office for the Socioeconomic and Community Development of Puerto Rico)	Administers CDBG grants and programs for the Commonwealth.	
PR Housing Recovery Taskforce	Federal, Commonwealth, and private sector taskforce created to develop housing recovery strategies and courses of action.	
Autoridad para las Alianzas Público Privadas (PR Private-Public Partnerships Authority)	Commonwealth agency implements and administers public-private partnerships such as infrastructure projects, including the redevelopment of public housing projects.	

Data sources and methods

To identify pre-storm challenges facing the housing sector that should be considered and/or addressed in the recovery process, the HSOAC Housing Team reviewed the available literature and consulted with a number of entities. These entities included the Puerto Rico Department of Housing, the Puerto Rico Housing Recovery Task Force, the federal Housing Recovery Support Function (RSF), the Puerto Rico Home Builders Association, the Mortgage Bankers Association of Puerto Rico, the Resilient Puerto Rico Advisory Commission (funded by the Rockefeller Foundation), insurance experts, subject matter experts working with Enterprise Community Partners, Dewberry Engineers, local housing organizations, and Habitat for Humanity.

This damage and needs assessment also relies on data from FEMA, HUD, the Small Business Administration (SBA), the U.S. Department of Agriculture Rural Development, the Puerto Rico Department of Housing, the Puerto Rico Planning Board, and other entities. Table 8.2 details the data sources used to estimate damage and to determine the amount of assistance provided to date to repair and rebuild structures.

Table 8.2. Summary of Key Housing Data Sources

Dataset	Source	Date of Last Update	Evaluation Notes
Inspection-Based Damage Assessment			
FEMA property inspections	FEMA Individual Assistance Data Team	May 2018	De-identified records on approximately 600,000 on-site inspections, used to calculate FEMA Verified Loss (FVL).
SBA property inspections	SBA	Mar 2018	De-identified records on verified loss from inspections of approximately 82,000 households, used to calculate SBA Verified Loss (SVL). Dataset used to determine relationship between SVL and FVL via regression approach.
Public housing damage inspections	Puerto Rico Department of Housing and Public Housing Authority		
Multifamily housing project damage estimates	USDA		
Model-Based Damage Assessment			
Building footprints	Multiple sources	2018	No single dataset offers complete coverage. HSOAC compiled the best footprints from 2004-2018 datasets.
Parcel-level property data	Puerto Rico Municipal Revenue Collection Center (CRIM)	Oct 2017	Property data for 507,000 parcels of the total 1,449,571 parcels in Puerto Rico (35%). Includes Parcel Count, Year Built, Area, Number of Stories, Use Type, Construction Material(s).
Damage assessment points	Dewberry Engineers	2017	Dewberry Engineers placed points island-wide indicating if a building was “Affected” or “Destroyed.” Provides inference on building type for 53,212 parcels (3.7%).
Blue tarp distributions	USACE	Oct 2017	Data collected where blue tarps were distributed as of October 2017 (22,679 parcels; 1.6%). May be an indicator of tin (wood) roof type and/or wood building type.
FEMA pre-Substantial Damage Estimator (SDE) damage analysis	Strategic Alliance for Risk Reduction (STARR II) (FEMA contractor)	1/16/2018	SDE is a post-storm assessment tool used by many NFIP communities to determine where damage repair costs are 50% or greater than the pre-event market value of the structure. Preliminary analysis included 455,009 parcels (31%).
Hazus field data	FEMA	2012-2017	Input data for FEMA Hazus model gathered by FEMA Region II and Cooperating Technical Partner (CTP) in Puerto Rico. Most data exist for select areas/municipalities only.

Dataset	Source	Date of Last Update	Evaluation Notes
Hazus GBS and NSI data	FEMA/USACE	Data based on 2010 Census	Hazus General Building Stock (GBS) data (by census block) includes percentage-based distributions of foundation types and various other building characteristics. The National Structure Inventory (NSI), a collaborative dataset produced between FEMA and the USACE, includes similar characteristics. These data were used to fill gaps where other local or more reliable data was not available.
Permit database	FEMA CTP	2014	CTP maintains a database of permits for 82,290 parcels (5.7%). It is unclear as to whether the database includes applications only, approvals only or a combination of both. Permit data was leveraged on a case-by-case basis to help verify other uncertain data or to fill gaps where no other data is available.
PREPA use types	PREPA	2014	Use type (Residential, Commercial, Public Housing, Government, Industrial, PREPA Use) for 832,434 parcels (57%). Used to make initial distinctions to separate building footprints into sub-categories for ultimate residential sub-type distinctions.
Bare Earth LiDAR	USGS	2017	Light Detection and Ranging (LiDAR) ground elevation data was used to identify buildings on steep slopes that may have structural pylons supporting the building and could be vulnerable to damage from future floods or earthquakes.
Pre- and post-storm orthophotography	Dewberry, Vexcel, NOAA	2017	Imagery resources were leveraged as necessary to distinguish and develop building data while seeking to maintain existence of buildings from pre-Irma/Maria ground condition
Other Datasets Including Post-Storm Assistance to Date			
Revised flood zone and landslide risk GIS layers	PR Planning Board	2018	
Low income and special community GIS layers	PR Planning Board		
FEMA Individual Assistance	FEMA	5/15/2018	Individual records (with personal identifiers removed) of IHP registrations, inspections and payments
SBA loans	Small Business Administration	5/17/2018	Individual records (with personal identifiers removed) of SBA applications, inspections and loan amounts
Sheltering and Temporary Essential Power (STEP) Program	FEMA	6/18/2018	
VALOR program purchases	FEMA	6/13/2018	
National Flood Insurance Program claim payments	National Flood Insurance Program	4/25/2018	

Dataset	Source	Date of Last Update	Evaluation Notes
Claim payment by private flood insurers	Puerto Rico Department of Insurance	2/28/2018	
Claim payments on homeowners policies	Puerto Rico Department of Insurance	5/10/2018	As report *Puerto Rico: Disaster Recovery Action Plan,* May 10, 2018.

Damage assessment methods

The HSOAC Team used two different approaches to estimate the damage caused by Hurricanes Irma and Maria. The first is an inspection-based approach motivated by the procedure HUD uses to allocate Community Development Block Grant-Disaster Recovery (CDBG-DR) funds. The second is a modeling approach that uses data on the types and locations of structures in Puerto Rico, data on flood depths and windspeeds during the storm, and damage functions that project the amount of damage suffered by the structure. Each method is briefly outlined below. Results from both approaches are presented and compared in this chapter.

Inspection-based approach

The inspection-based approach starts with the property inspections that FEMA conducted for those requesting FEMA assistance following the disaster. FEMA received approximately 1.1 million applications for assistance following Hurricanes Irma and Maria. Once disaster survivors register, FEMA is required to verify losses to determine eligibility for their Individual Assistance (IA) program. An on-site inspection is typically used to verify losses. As of May 2018, FEMA had completed approximately 600,000 inspections. Inspectors record detailed information on the damage due to the disaster (such as square feet of roof damaged), and then a computer algorithm estimates the "FEMA Verified Loss" (FVL) separately for real property (structures) and personal property (household contents).

The FEMA inspections are the most comprehensive source of information on damage available, but FVL does not capture the full cost to repair. Instead, FVL is designed to measure the cost of making the home safe and habitable. To scale up the FVL to the full repair cost, data from inspections done by SBA are typically used. Some households apply for SBA disaster loans following the storms, and SBA conducts on-site damage assessments for these households.[114] The SBA inspection is akin to that done by an insurance adjuster, with the goal of estimating the full repair cost. FEMA provided the authors with the FVL data and a number of other variables for each of the approximately 600,000 inspections (stripped of personally identifiable information, or PII). SBA provided the authors with the verified loss ("SBA Verified Loss," or

[114] SBA provides low-interest disaster loans to homeowners, renters, businesses of all sizes, and private, nonprofit organizations following a presidential disaster declaration.

SVL) from their property inspections for each of the approximately 82,000 households that applied for home loans (again, stripped of PII).

Using data for homes with both SBA and FVL data, HSOAC then extrapolated an estimate of the full losses for both real and personal property for all homes damaged by the storms. Specifically, the HSOAC team applied a regression approach to estimate the average real property SVL (RPSVL) and personal property SVL (PPSVL) for all properties using average real property FVL (RPFVL) and personal property FVL (PPFVL) as independent variables, along with other regressors including median household income, percentage of registrants with damage due to flooding, and household characteristics (persons per household, residence size, number of occupied bedrooms, and number of floors). Because the data were de-identified, the HSOAC team collapsed the individual observations by ZIP code and performed the analysis at the ZIP code level.

Damage estimates based on this approach are presented later in this chapter.

Modeling approach

The HSOAC team also used a modeling-based approach to estimate storm damage. In this alternate approach, damage functions in Hazus-MH, FEMA's damage assessment software tool, were combined with flood depth grids developed by Dewberry Engineers and wind speed maps developed by Applied Research Associates to project overall damage. Projections were made separately for substantially damaged structures (structures for which the cost of repair is 50 percent or greater of the structure's pre-event market value) and structures with low to moderate damage.

To conduct this assessment, the HSOAC team identified three pilot municipalities for a detailed assessment. The three pilot municipalities selected – Carolina, Humacao, and Morovis – reflect the available data, diversity of development (urban, suburban, rural) and flood-related hazards (riverine/coastal, coastal, landslide) that exist across the island. Datasets listed in Table 8.2 were used to conduct a detailed assessment, and in June 2018, HSOAC sent field reconnaissance teams to spot check data within the three pilot municipalities and confirm assumptions made as part of a more detailed assessment. Results were used to extrapolate and refine housing data for the remaining 75 municipalities. Additionally, the HSOAC team reviewed various sources of cost data – including Xactimate, RS Means, and other sources – to develop average residential building replacement values (BRVs) for Puerto Rico based on housing type, number of stories, and quality of construction to determine housing costs island-wide.

Using these data, flood damage was estimated using a Hazus analysis of island-wide flood depth grids developed following Hurricanes Irma and Maria. The depth grids were combined with initial geospatial housing data to estimate flood depths and combined with depth damage functions (DDFs) developed by FEMA and the USACE to determine draft damage and losses. DDFs were refined as needed based on field reconnaissance data collected for three pilot

municipalities, and combined with refined final geospatial housing data to determine final flood damage and losses.

Wind damage was estimated using a Hazus analysis of island-wide wind speed maps developed by Applied Research Associates (ARA) following Hurricanes Irma and Maria. Similar to flood damage, wind speed maps were combined with geospatial housing data to estimate wind speeds and combined with Hazus wind damage functions (WDFs) customized by the research team to determine draft damage and losses. These WDFs were refined as needed based on field reconnaissance data collected for three pilot municipalities, and combined with refined final geospatial housing data to determine final wind damage and losses.

For all residential buildings, the total flood and wind damage were added together to determine the total damage repair cost. Next, the actual cash value (ACV) was estimated based on the BRV adjusted for depreciation to determine the pre-event market value of the structure. Finally, the damage repair cost was divided by the pre-event market value to determine if the residential building is substantially damaged.

Data gaps, assumptions, and uncertainties

Key assumptions are documented for each of the methodologies above. As discussed in this chapter, there is no comprehensive and reliable set of island-wide geospatial data files for residential units. HSOAC pieced information together from a number of sources, but efforts to improve housing-related data are needed. Also lacking are readily available data on home sales and sale prices.

Limited information is available on the condition of the considerable number of vacant properties in Puerto Rico. Some stakeholders believe that at lease some percentage of these vacant properties can be effectively used to house those currently living in the informal housing sector. Others want to focus on new construction, believing that the vacant structures are in poor condition or otherwise undesirable. Better information on the condition of the vacant structures is needed to assess what mix of the two approaches is best.

Data on the damage to rental properties is scant. FEMA IA inspections for real property damage are only conducted for owner-occupied structures. Damage to the public housing projects has been assessed to some extent, but we are unaware of any detailed assessment of damage to other assisted and unassisted housing. Also relevant would be the extent to which insurance was available to cover the damage to rental properties.

Finally, better and more transparent information is needed on the size of the informal housing sector (structures built without permits). The widely used figure that 55 percent of units are in the informal housing sector traces back to a 2007 consultant report for the Puerto Rico Home Builders Association (Asociacion de Constructores de Hogares, 2007).

Background

The Census Bureau estimates that prior to the 2017 hurricanes there were 1.572 million housing units in Puerto Rico serving 1.237 million households (Table 8.3, top rows) (U.S. Census Bureau American Fact Finder, 2016a). Many of these units were vacant: 335,000 units, or about 20 percent of the total. Single-family homes, both attached and detached, are the predominant type of housing in Puerto Rico.

Unlike the mainland United States, where the vast majority of residential units are wood-framed construction, Puerto Rico has a broad range of residential construction types, ranging from 1-story wood-framed structures with wood-framed tin roofs to high-rise reinforced concrete-framed structures with concrete roof decks. As discussed below, many of these structures are highly vulnerable to wind, flood, earthquake, or landslide risk.

Owner-occupied units in Puerto Rico total just under 850,000, with the vast majority (91 percent) in single-family structures. A rough estimate of the number of owner-occupied residential structures comes to 786,000. Though home ownership rates are generally high in Puerto Rico (70 percent), mortgages are less common than in other areas of the United States: the Census Bureau estimates that 41 percent of homeowners had a mortgage in Puerto Rico as opposed to approximately 67 percent in the United States as a whole. The median value of owner-occupied housing units was slightly below $120,000, based on data from 2012 through 2016, which includes both the value of the land and the structure.[115]

Table 8.3. Overview of Housing Sector in Puerto Rico Pre-Storm

Metric	Estimate
Population and Overall Housing Stock	
Population	3,337,000
Households	1,237,000
Housing units	1,572,000
Vacant housing units	335,000
Housing units for seasonal, recreational, or occasional use (these units are included in the total for vacant housing units)	77,000
Percent of housing units in single-family structures	79%
Number of housing structures (occupied and vacant)	1,310,000
Homeownership rate (percent of occupied housing units that are owner-occupied)	69%
Owner-Occupied Housing Units	
Number of owner-occupied units*	849,000
Number of owner-occupied structures*	786,000

[115] Studies by housing experts in Puerto Rico have estimated that the value of the structure averages 62 percent of the total property value (Estudios Tecnicos Inc, 2017b).

Percentage of occupied units in single-family structures	91%
Percentage of owner-occupied units with a mortgage	41%
Median value of owner-occupied housing units	$118,600
Median selected monthly ownership costs with a mortgage	$887
Median selected monthly ownership costs without a mortgage	$154
Renter-Occupied Units	
Number of renter-occupied units	388,000
Number of renter-occupied structures**	263,000
Median monthly gross rent	$460
Percentage of occupied rental units that are in single-family structures**	62%
Public housing units***	54,000 (14%)
Units in Housing Choice Voucher Program***	35,000 (9%)
Units in HUD Multifamily Assisted Program***	19,000 (5%)

Source: Unless otherwise noted, U.S. Census Bureau American Fact Finder (2016a). Population is from U.S. Census Bureau (2017b). Percent of owners with a mortgage from Kasper (2018).
*Assumes that owner-occupied structures with multiple units are entirely owner occupied.
**Assumes that renter-occupied structures with multiple units are entirely renter occupied.
***Percent of renter-occupied units in parentheses.

Renter-occupied housing units in Puerto Rico total 388,000, with a median rent of $460 per month (Table 8.3, bottom rows). A considerable number of rental housing units (approximately 30 percent) are subsidized, including approximately 33,000 using Housing Choice Vouchers, 55,000 public housing units, and 19,000 households receiving other types of assistance. The Puerto Rico Department of Housing and certain municipalities operate these programs with funding from the U.S. Department of Housing and Urban Development (HUD). Many public housing projects are in need of repair and maintenance as we discuss in pre-storm challenges below.

A substantial number of the 1.572 million residential housing structures are part of the so-called *informal* housing sector. While it is difficult to precisely define the term, homes in the informal housing sector were often built without approved engineering or architectural plans and the construction falls far short of the building codes in effect at the time of construction.[116] The structures could be on either public or private land, but the residents often do not have registered title to the land. A 2007 study commissioned by the Puerto Rico Builders Association found that 55 percent of residential and commercial construction was informal (Asociacion de Constructores de Hogares, 2007).[117]

[116] Puerto Rico's Build Back Better report uses "informal housing" to describe homes built by people on government land without permission and without following building code requirements ("Impact to Housing" section) (Governor of Puerto Rico, 2017a).

[117] The Builders Association found that 55 percent of the developed land area in Puerto Rico was developed without demonstrating compliance with planning and environmental regulations.

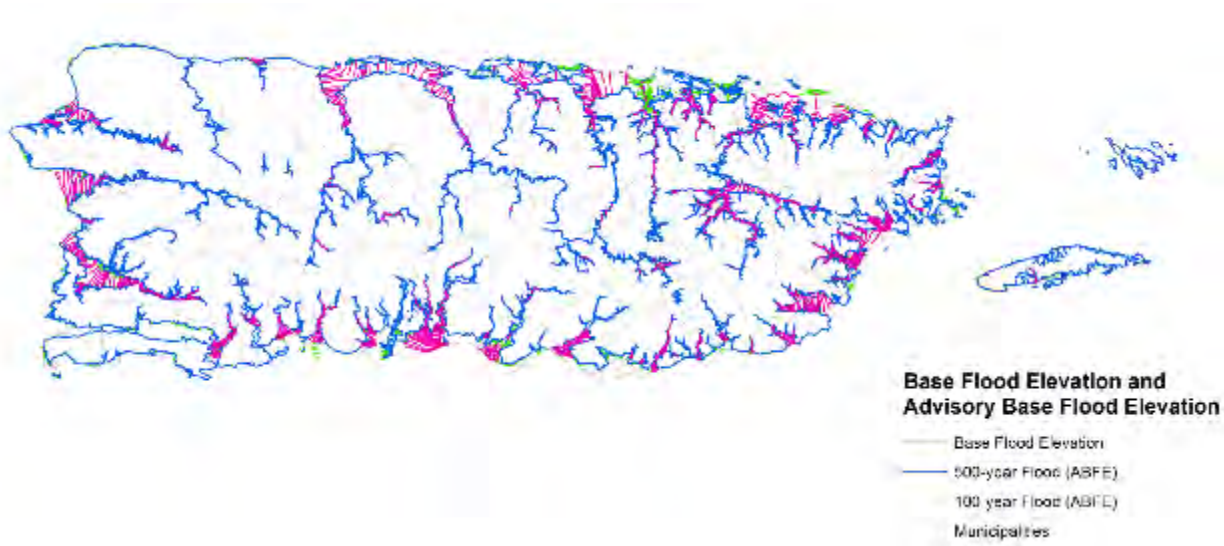
Pre-hurricane conditions

Prior to the arrival of Hurricane Maria, Puerto Rico's housing sector faced many challenges. Puerto Rico's poor economic condition had affected the housing market for many years. For example, between 2010 and the third quarter of 2017, home prices on the mainland increased 35 percent, while home prices fell 18 percent in Puerto Rico over the same period (Kasper, 2018). Fair market rents declined slightly (5 percent) between 2010 and 2018 (Kasper, 2018). This section includes a brief description of 12 separate challenges facing the housing sector.

High vulnerability to natural hazards

Housing that can resist natural and manmade hazards is crucial for minimizing the impact of disasters and improving recovery. Housing in Puerto Rico is exposed to risks from high winds, flooding, erosion, earthquakes, and landslides (Morelock and Barreto, 2000; Skibell, 2018). According to the detailed geospatial analysis done for this study, there are approximately 125,000 residential structures in areas with a one-percent chance of flooding each year (the 100-year floodplain), implying that roughly 10 percent of housing structures are in the 100-year flood zones. A map of the current 100-year flood zones is shown in Figure 8.1. FEMA is currently updating the flood maps for Puerto Rico, and also shown in Figure 8.1 are the areas proposed to be added to the 100-year flood zones.

Figure 8.1. Current and Proposed 100-Year Flood Zones



NOTE: Updated map in development as of this report date.

Landslide risk across the island is similarly high, with more than 40,000 separate landslide sites identified after the 2017 hurricanes (Morales Valez and Hugher, 2018). This is discussed further in Chapter 2 (Overview of Hurricane Irma and Hurricane Maria) and Chapter 9 (Natural

and Cultural Resources). The number of structures in areas with high landslide-risk warrants further investigation.

A substantial percentage of the housing stock in Puerto Rico is not sturdy enough to withstand these risks and is often built in high-risk locations, such as near rivers and coastlines or in earthquake liquefaction zones (Morelock and Barreto, 2000). In some cases, this is because structures were constructed before stringent building codes were adopted in the Commonwealth; in other cases, this is because structures were not built to codes that were in place at the time of construction (see next subsection) (Government of Puerto Rico, 2018a).

Poor enforcement and high cost of building permit process

Building regulations based on international best practices and mechanisms for enforcing those regulations (e.g., adequate staffing of inspectors and the ability to enact fines and other compliance mechanisms) can ensure that structures are built to withstand hazards and are located in areas with low hazard exposure. Following such practices will result in less damage when storms do hit, and faster recovery by communities from such storms.

Building codes were first enacted in Puerto Rico in the 1960s and have since gone through a series of revisions and updates (Commonwealth of Puerto Rico Regulations and Permits Administration, 1999). The most recent major revision was in 2011, to align the building codes to those of International Code Council, a standard setting body for international building codes (Commonwealth of Puerto Rico Oficina de Gerencia de Permisos, 2016). The 2011 codes were designed to protect against Category 3 hurricanes; the codes in place immediately prior to 2011 were designed to protect against Category 2 hurricanes (Commonwealth of Puerto Rico Oficina de Gerencia de Permisos, 2016; Dooley, 2017). Discussion is underway in Puerto Rico on how best to update the building codes.

As discussed above, an estimated 55 percent of structures in Puerto Rico have been built without building permits. This means that a large number of structures are likely not built to code and often in risky areas such as flood zones or areas vulnerable to landslides. In addition, has been an inadequate number of inspectors to ensure compliance with land use plans and building construction so enforcement has been poor.

One reason why a substantial percent of residential structures are built without permits is that the building permit process is costly and time consuming. Despite efforts by the Government of Puerto Rico to streamline the permitting process,[118] Puerto Rico still falls far behind the mainland U.S. in its "Dealing with Construction Permits" ranking in the World Bank's *Doing Business* report (World Bank Group, 2018). Puerto Rico ranked 131st out of 190 countries in

[118] Puerto Rico Public Law 161 of 2009, the Law for the Reform of the Permitting Process of Puerto Rico, was intended to streamline the permitting process by centralizing the application for development and construction permits to one agency. The law was amended in 2013 and 2017 (prior to Hurricanes Irma and Maria). However, it is unclear whether the reform has been successful.

2017, compared with an overall U.S. ranking of 39th. This is discussed further in Chapter 5 (Puerto Rico's Economy).

Inconsistent application of land use plans

Land use plans are important for avoiding development in particularly risky areas, conserving important natural resources, and integrating population location with economic development goals and initiatives. Land use planning in Puerto Rico, however, appears lacking in both coordination and effectiveness. The Puerto Rico Planning Board recently completed a land-use plan for the Commonwealth, but according to Planning Board staff, the plan is not well coordinated with municipal plans.[119] Furthermore, municipal plans are required to be approved by the Planning Board, but in many cases, this has not happened.[120]

Given the lack of coordinated, binding land-use plans, government agencies tend to use a case-by-case approach for development approvals. The result can be residential and economic development in risky areas or in areas not compatible with conservation or economic development goals. A 2002 study, for example, concluded that uncontrolled rural development, which is closely linked to the widespread practice of informal housing in Puerto Rico, was "having an adverse effect on soil erosion and sedimentation on water bodies, increasing flash flood events and contamination of ground waters" (URS Corporation, 2002). This study also noted that the "disorganized pattern of development," paired with the ineffective regulatory and zoning guidelines on rural areas, "increased Puerto Rico's vulnerability to natural hazards."

Lack of property title or unregistered titles

Lack of clear property title is common in Puerto Rico, and this status affected hundreds of thousands of Puerto Ricans after Hurricanes Irma and Maria. This is a consequence of migration flows dating back to the 1930s and 1940s, when industrialization drew rural Puerto Ricans to urban areas. Insufficient affordable housing prompted takeovers of farming land for housing, resulting in the widespread formation of informal, unsanctioned communities. Many properties have also been subdivided without any formal change or modification in title.

Even when title is clear, the title may not appear in an official property registry. There is no requirement to register title to properties in Puerto Rico, and families sometimes went decades without registering their land or structures with the government and many have never registered their properties. Estimates are that only about 70 percent of titles are recorded in the land registry, and many of those are likely out of date (Governor of Puerto Rico, 2017a). Data from a sample of properties in selected municipalities, furthermore, show the percentage of parcels with title in some municipalities could be less than 50 percent (Government of Puerto Rico, 2018a).

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[119] Puerto Rico Planning Board, personal communication, March 8, 2018.

[120] Law No. 81 of August 1991 (Law of Autonomous Municipalities) gave municipalities more authority in land-use planning.

Lack of good property title records makes it difficult for both public and private entities to provide assistance following disasters and complicates processes for collecting the property taxes that fund community services.

Confusing address system

Addresses in Puerto Rico typically rely on "urbanizations," or neighborhoods and community names. In addition, the address numbers on streets are sometimes not monotonically increasing or decreasing (Kasper, 2018). Often there are multiple uses of the same street name in a community, which means that both the community name and urbanization must be specified to identify a location. This complexity hinders emergency response and makes it difficult to map properties in geographic information systems and determine the risks to which they are exposed. It also limits the use of modern tools to develop and enforce land use plans and building codes.

High housing construction costs

The price of new housing in Puerto Rico in recent years has not fallen in line with the declining median income due to economic contraction, pushing new housing out of financial reach for most residents. Explanations for the persistence of high prices often point to the high construction costs associated with obtaining raw materials and transporting them to building sites in the Commonwealth. These issues are discussed further in Chapters 5 and 13 of this report. Also contributing to high construction costs is the costly and time-consuming permitting process discussed above.

Faced with Puerto Rico's high construction and permit costs, economic theory suggests that housing developers produce less housing at a higher cost and pass on those costs to homebuyers in the form of higher prices.

Lack of comprehensive or accessible housing data

There is no central source of data related to the housing stock, including title, permits, land use, property tax and location. Data is distributed across multiple agencies at both the municipality and commonwealth level. There is a need for integrated and validated data that is transparent and accessible to provide an evidence base to inform planning and decision-making related to reconstruction and future development. More readily available information is also needed on housing sales, prices, construction and on the rental market. This lack of available and transparent data on sales and rentals has prohibited the development of consumer based products such as the Multiple Listing Service (MLS) that is available to consumers in the rest of the Untied States, nor are there sites consolidating available rental listings.

Low percentage of homes with insurance

Risk-based insurance premiums are central to providing developers and homeowners with the appropriate signals of where to build and what types of structures to build or retrofit. They are also a way to reduce taxpayer outlays for disaster response and recovery costs. Despite the many risks facing residential structures in Puerto Rico, however, the percentage of homes with either homeowners' insurance, or both homeowners' and flood insurance, is low.

Homeowners policies in Puerto Rico cover loss due to wind, and also typically cover earthquake damage. The take-up rate for homeowners' insurance is estimated at 31 percent, and some of those with insurance are thought to be underinsured (Governor of Puerto Rico, 2017a). At the end of 2017, there were only slightly more than 44,000 flood policies on residential structures.[121] It is likely that the majority of the flood policies cover structures in the high-risk flood zone, but the percentage of policies inside the high-risk flood zones is not known. Even if all flood policies were in high-risk flood zones, however, the flood insurance take-up rate would still be less than 35 percent for structures in high-risk flood zones.[122]

Increasing Foreclosure Rates

The housing market is intricately linked to the economy and demography. As noted in earlier chapters, Puerto Rico's prolonged economic recession led to job loss, prolonged emigration, declining home values and increases in mortgage delinquencies and foreclosures.

Vacancy and blight

As residents have emigrated, some have left behind vacant properties. In 2016, there were an estimated 334,000 vacant properties in Puerto Rico. Of these, 178,000 were not listed on long-term rental, short-term rental, or sale markets nor for seasonal or recreational use (U.S. Census Bureau American Fact Finder, 2016a). From 2009 to 2016, the total number of vacancies increased by 51 percent, and the number not on the market or for seasonal or recreational use increased by 59 percent (U.S. Census Bureau American Fact Finder, 2016a). Many of these properties are likely also blighted, but figures on the number of blighted properties prior to the 2017 hurricane season are not available as of the writing of this report.

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[121] Flood insurance in Puerto Rico is available from both the National Flood Insurance Program (NFIP) and private insurers. At the end of 2017, there were just over 4,200 NFIP policies and another 40,000 private policies on residential structures, (Kousky and Lingle, 2018).

[122] 44,000 is 35 percent of the estimated 124,000 residential structures in areas with 1 percent or more annual risk of flooding.

Need for affordable housing

HUD defines affordable housing as housing for which occupants pay no more than 30 percent of their income for gross housing costs. According to American Community Survey data, monthly housing costs for owners exceed 30 percent of income for 46 percent of homeowners in Puerto Rico. Gross rent exceeds 30 percent of income for 56 percent of renters who pay rent (U.S. Census Bureau American Fact Finder, 2016a).[123] According to the 2014 State Housing Plan, the projected numbers of residents in need of affordable housing services from the Government of Puerto Rico government included:

- 29,792 persons on the public housing waiting list (as of May 2014) and 7,955 on the Section 8 waiting list (as of June 2014)
- more than 4,100 homeless persons as of 2013
- an expected growth of 14,212 low- and moderate-income households during the next five years (Puerto Rico Department of Housing, 2014).

Puerto Rico has affordable housing programs, but not enough to meet this demand. In addition, according to a 2010 study for HUD (Finkel et al., 2010), the Public Housing Administration is expected to face a $3 billion backlog in needed maintenance and capital improvements. For example, a 2016 inspection of 96 public housing units by HUD's Office of Inspector General revealed that 64 failed to comply with HUD's minimum housing quality standards (Puerto Rico Department of Housing Office of Inspector General, 2016).

Lack of resilient infrastructure to support housing

Livable housing is dependent on many different types of infrastructure, including physical infrastructure (e.g., electricity, waste management, water, roads) and community infrastructure (e.g., schools, hospitals, economic centers). As detailed in other chapters of this report, in Puerto Rico much of this infrastructure was in poor condition prior to the storm and thus vulnerable to flood, wind, and other hazards. For instance, due to a fragile electric grid, parts of the Commonwealth experienced frequent rolling black and brownouts prior to the storm.

Hurricane damage

Damage estimates: inspection-based approach

FEMA inspection results

The number of registrants for FEMA assistance following Hurricanes Irma and Maria totaled over 1.1 million (Table 8.4, bottom row). There were approximately 1.23 million occupied housing units in 2016 (Table 8.3), implying that approximately 90 percent of households in Puerto Rico applied for assistance. When they registered for FEMA assistance, approximately

[123] Excludes a sizeable number of non-owners who do not pay rent.

two-thirds of owners (527,000 out of 768,000) indicated that the storms had caused damage to their real property, and just under three-quarters indicated personal property loss. Fifty-eight percent of renters (197,000 out of 341,000) indicated personal property damage when they registered.

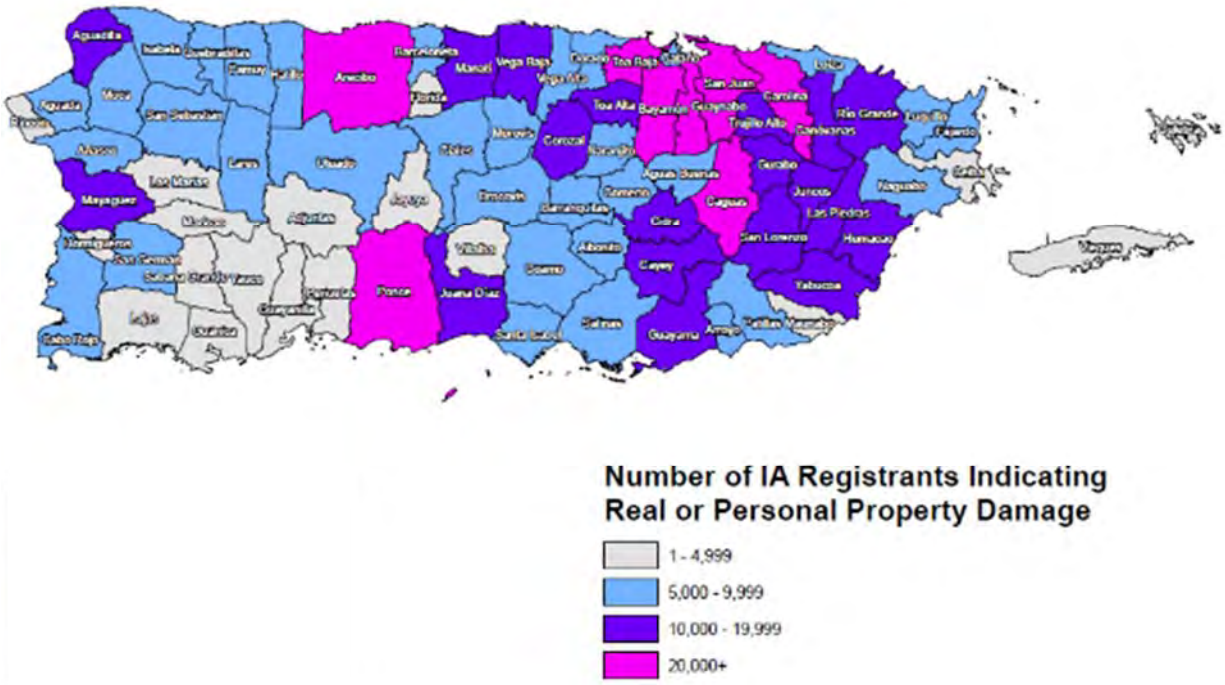
Table 8.4. Registrants for FEMA Assistance for Properties with Damage as of February 2018

	Owners	Renters	Unknown	Total
Registrants indicating real property damage	527,000 (69%)	183,000 (54%)	6,000 (86%)	715,000 (64%)
Registrants indicating personal property damage	561,000 (73%)	197,000 (58%)	5,000 (71%)	763,000 (68%)
Registrants indicating real or personal property damage	624,000 (81%)	239,000 (70%)	6,000 (86%)	869,000 (78%)
Total registrants for FEMA Individual Assistance Program*	768,000	341,000	7,000	1,115,000

Note: percentage of column total in parentheses.

Figure 8.2 shows the number of FEMA registrants indicating either real or personal property damage by municipality. The distribution across municipalities is driven in part by the distribution of population across Puerto Rico.

Figure 8.2. Map of IA Registrants by Municipality Indicating Real or Personal Property Damage



Overall, FEMA inspections were completed for 596,000 properties (first row of Table 8.5). Nearly all of the inspections were done at properties at which the registrant indicated damage to either real or personal property occurred. Table 8.5 reports RPFVL for owner-occupied properties with inspections. Properties are binned according to RPFVL cutoffs that FEMA typically uses to classify damage. The table also reports the breakdown of PPFVL using the same dollar cutoffs.

Table 8.5. FEMA IA Inspection Status as of May 2018

	Owners	Renters	Unknown	Total
Registrants receiving FEMA inspection	**436,000**	**158,000**	**2,000**	**596,000**
Registrant indicating real property damage	407,000	131,000	2,000	539,000
Registrant indicating personal property damage	393,000	130,000	2,000	525,000
Registrant indicating either real or personal property damage	435,000	157,000	2,000	594,000
RPFVL				
None (RPFVL = $0)	149,000	--	2,000	--
Affected (RPFVL = $1 – 3,499)	236,000	--	<500	--
System damage (RPFVL = $3,500 – 16,999)	43,000	--	<500	--
Structural damage (RPFVL >= $17,000)	3,000	--	<500	--
Destroyed	4,000	--	<500	--
PPFVL				
$0	192,000	53,000	2,000	246,000
$1 - 3,499	208,000	91,000	<500	299,000
$3,500 – 16,999	36,000	14,000	<500	50,000
>= $17,000	0	0	0	0
Registrants without inspections	**332,000**	**183,000**	**4,000**	**520,000**
Registrant indicating real property damage	120,000	53,000	4,000	177,000
Registrant indicating personal property damage	167,000	67,000	4,000	238,000
Registrant indicating either real or personal property damage	189,000	82,000	4,000	275,000
Not primary residence	14,000	5,000	4,000	23,000
Has Insurance	55,000	2,000	500	57,000
No substantiation of loss submitted	4,000	4,000	50	11,000
No contact for inspection	13,000	7,000	0	20,000

NOTE: RPFVL categories can be described as follows: *affected* properties are generally habitable; *system damage* includes damage to one of the structure's systems, such as electrical or HVAC; and *structural damage* or *destroyed* are self-explanatory.

As can be seen, the number of properties in the structurally damaged and destroyed categories is modest (7,000). It could be that the dollar cutoffs to include properties in these bins

make sense for disasters in the mainland U.S. but not in Puerto Rico. This issue warrants further investigation.

Inspections were not conducted for 520,000 registrants, and overall, just over 50 percent of these (275,000 out of 520,000) indicated either real or personal property damage (Table 8.5, bottom section).[124] There are several possible reasons why these properties were not inspected. Twenty-three thousand of the 275,000 properties were not primary residences, and FEMA does not conduct inspections for non-primary residences because the occupants are not eligible for FEMA assistance. Fifty-seven thousand indicated they had insurance, and it is possible that FEMA determined that the insurance was adequate to cover the loss. In an additional 11,000 cases, no substantiation of losses was submitted to FEMA, even though the registrant had indicated damage occurred. FEMA was not able to contact 20,000 registrants to schedule inspections. FEMA may have determined that many of the remaining registrants suffered insufficient loss of the types covered by FEMA to warrant an inspection. However, there was no explicit indication of this in the data provided.

Regression analysis results

Using the regression analysis approach described earlier in this chapter applied by ZIP code, RPSVL was estimated as a function of RPFVL and other predictors to help approximate RPSVL across all of Puerto Rico. RPFVL was a statistically significant predictor of RPSVL, as was income. One might expect the effect of RPFVL on RPSVL to vary with income, but the interaction between RPFVL and income was not statistically significant. Other variables considered were not statistically significant once RPFVL and income were included in the regression. Similar results were found for the PPSVL for owners and PPSVL for renters. (Renters do not have real property damage because the real property is owned by the landlord.)

Table 8.6 summarizes the regression results used to project real and person property damage based on the relationship between SVL and FVL.

[124] Registrants without property damage might have applied for assistance due to lack of power, inability to access the property, etc.

Table 8.6. Regression Results for SBA Verified Loss (in $1000s)

Regressors	Owner: Real Property (RPSVL)	Owner: Personal Property (PPSVL)	Renter: Personal Property (PPSVL)
Mean RPFVL ($1000s)	0.676** (3.11)		
Mean PPFVL ($1000s)		1.19** (3.35)	0.246 (0.61)
Median household income ($1000s)	0.300** (2.66)	0.079** (3.31)	0.096** (2.08)
Constant	25.99** (5.07)	4.42** (3.74)	5.61** (2.08)
R-squared (adjusted)	0.34	0.54	0.27
Number of observations	374	374	235

Note: t-statistic indicated in parentheses. Coefficients on fixed effects omitted. Unit of analysis is ZIP code-status category combination. Regression restricted to observations with more than five FEMA and five SBA property inspections.
**The 95-percent confidence interval does not contain zero.

HSOAC used the relationships in Table 8.6 to project total losses for the vast majority of FEMA registrants that do not have SBA inspections. These relationships differ in two important ways from those used in the draft CDGB-DR plan submitted by Puerto Rico in May 2018 (Government of Puerto Rico, 2018a) to make the same projections. First, they include a constant, which acknowledges that total loss may be positive even if FVL is zero. Second, they consider income, which captures the reality that the incomes of households that have not been referred to SBA are substantially lower than households that have been referred to SBA.125 Even though the relationships in Table 8.6 allow extrapolations to lower income households, these extrapolations are outside the sample used to estimate the regressions and should be interpreted with care.

Real and personal property loss results

Using the inspection-based approached described above, the HSOAC team projects $18.4 billion in combined real and personal property losses for the just under 600,000 renters and owners with FEMA IA inspections. These results are summarized in Table 8.7 below. The bulk of the losses are for real property ($14.1 billion), with an additional $4.3 billion for personal property. This total does not include real property losses incurred in the rental housing sector.

[125] The median income for registrants who have not been referred to SBA is $12,000 and the median income for those who have been referred is $26,000 (calculated at the individual registrant level).

Table 8.7. Damage Estimates for IA Registrants with Inspections

	Owners	Renters	Total
Number of registrants	434,000	157,000	591,000
Average real property loss	$32,500	$0[a]	--
Average personal property loss	$6,600	$9,300	$7,300
Total real property loss	$14.08 B	$0[a]	$14.08 B
Total personal property loss	$2.86 B	$1.46 B	$4.32 B
Total loss	$16.89 B	$1.46 B	$18.40 B

[a]Real property loss is not assessed for renters because the real property is owned by the landlord and renters are not eligible for assistance for damage to the landlord's property.

These projections include some of the costs needed to bring those parts of the structure that were damaged up to code. For example, if the electrical system was damaged, that part of the electrical system that needs to be replaced or repaired would be brought up to code. However, the estimates do not include the cost of code-required elevation because, at the time of the SBA inspection, it was not determined whether elevation would be required by code. They also do not include the cost of additional mitigation that would make the home less vulnerable to natural disasters.

As reported above, over 500,000 FEMA registrants did not have property inspections and 275,000 of these indicated that they suffered either real or personal property damage. It could be that these registrants indeed suffered little or no damage. However, it could also be that inspections were not done at these properties for various reasons, even though some were damaged. The HSOAC team multiplied the average loss projected for properties with inspections (conditional on the registrant indicating damage)[126] by the number of registrants without inspections indicating damage (from Table 8.5) to provide an estimate of the losses for registrants without inspections. The results are presented in the "Upper Estimate" column of Table 8.8 below. The "Lower Estimate" assumes zero losses at properties without FEMA inspections. As can be seen, the difference between the two estimates is approximately $6 billion.

[126] The average loss values presented in Table 8.7 include all IA registrants with inspections. A high percentage of these owners indicated that they had suffered real property losses, and high percentages of owners and renters indicated personal property losses. After adjusting for the percentage who indicated that they did not suffer losses, the average loss in each category is somewhat higher than the numbers shown in the table. These higher average values were used to estimate potential losses for properties without inspections.

Table 8.8. Damage Estimates Factoring in Losses for Registrants Without FEMA Inspections ($ Billions)

	Lower Estimate	Upper Estimate
Owners		
Real property damage		
Losses for owners with FEMA inspection	14.08	14.08
Losses for owners without inspections	0	4.19
Personal property damage		
Losses for owners with FEMA inspection	2.86	2.86
Losses for owners without inspections	0	1.22
Total owners	14.53	18.92
Renters		
Personal property damage		
Losses for renters with FEMA inspections	1.46	1.46
Losses for renters without inspections	0	0.76
Total renters	1.46	2.22
Owners and Renters		
Total owners and renters	18.40	24.57

Estimates for real property losses in the rental housing sector[127]

The Puerto Rico Public Housing Authority (PRPHA) is the second largest housing authority in the U.S., with over 54,000 units across 340 properties. PRPHA reports that 15,396 public housing units were damaged (28 percent of the total) (Puerto Rico Department of Housing, 2018). The Puerto Rico Department of Housing also owns in excess of 30 public housing projects. The preliminary estimated damage as of April 2018 is $397 million at a total of 362 combined PRPHA and DOH properties (Puerto Rico Department of Housing, 2018). The United States Department of Agriculture (USDA) also reported that damage assistance was requested at 12 of 92 projects administered by the agency. The 12 projects consist of 768 units, and damage estimates totaled $2 million.[128]

In addition to the assisted housing units listed in Table H.10, there are approximately 30,000 households using Housing Choice Voucher and 18,000 households in project-based Section 8 units.[129] Damage estimates for these other types of assisted housing and unassisted housing are

[127] For the purposes of this discussion, HSOAC considers public housing, privately-owned, government-subsidized rental housing, and nonsubsidized rental housing as all part of the rental sector.

[128] Data provide to authors by USDA.

[129] Commonwealth of Puerto Rico, May 2018, p. 46.

not available. However, we do have some indication of the damage in the rental sector. As discussed above, 341,000 renters registered for FEMA assistance and FEMA inspections were conducted for 158,000 (46 percent). Of these, the FEMA inspector determined that 17,000 suffered moderate real property damage and 6,000 suffered major property damage, with approximately 1,100 units in structures that were destroyed.[130] Thus, approximately 15 percent of those units inspected suffered moderate or greater damage. The percent of all rental units with damage (inspected or not) would thus range from roughly 8 percent (assuming none of the noninspected units suffered real property damage) to 15 percent (assuming that the noninspected units are similar to the inspected units).

Damage estimates: modeling approach

Table 8.9 summarizes the characteristics of the housing stock pre-storm based on the datasets assembled for the modeling-based approach. The 1.276 million structures (both vacant and occupied) tracks well with the number of housing structures according to the ACS (1.310 million; see Table 8.3). HSOAC estimates 124,000 structures in the high-risk flood zones (areas with at least a 1 percent chance of flooding per year) based on the current flood maps for Puerto Rico. Of these 124,000 structures, nearly 13,000 are in floodways and nearly 3,000 are in high-risk V-zones (velocity zones).[131]

[130] FEMA definition of *moderate damage*: Used when the home has incurred less than 4 feet of flood water on the first occupied floor and/or; Heating/cooling system requires a technician to repair and/or; Windows or doors require repair to be safe and secure and/or; Roof cover or siding damage preventing safe and sanitary occupancy and/or; a professional is required to clean the occupied areas of the home and/or; reconnection of utilities is necessary for occupancy and/or; road or bridge repairs are required to gain access.
FEMA definition of *major damage*: Used when the home has incurred 4 feet or more of flood water on the first occupied floor and/or; Majority of the foundation walls or piers are collapsed or significantly separated from the floor frame and/or; Majority of the roof or wall components are structurally damaged and/or; the only access bridge has collapsed.

[131] V-zones are those areas in coastal flood zones that are subject to storm waves. A floodway is the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height.

Table 8.9. Characteristic of Pre-Storm Housing Stock (Number of Structures)

Construction Type	All Residential Structures	In Floodplain[a]	In Floodway	In V-Zone
All wood construction	124,037	16,238	1,732	498
Manufactured housing	32	12	1	-
Combination of wood and concrete construction	140,398	21,364	2,274	485
Mixed use	553	44	9	1
All concrete construction	839,269	69,926	7,318	1,201
Multi-Family Residential/ Condominiums	171,588	16,850	1,647	673
Total	1,275,877	124,434	12,981	2,858

[a]Includes structures in floodways and V-zones.

Table 8.10 provides estimates of the number of substantially damaged structures during Hurricane Maria using the modeling approach described earlier in this chapter. Substantially damaged structures are those for which the repair cost equals or exceeds 50 percent of the structure's pre-event market value. Overall, nearly 166,000 structures suffered substantial damage. For comparison, 407,000 residential property owners who registered for FEMA assistance indicated real property damage (Table 8.5). Note, though, that the 166,000 structures include renter- and owner-occupied structures as well as vacant structures.

Table 8.10. Number of Substantially Damaged Structures Due to Hurricane Maria According to Modeling Approach

Flood Zone	Substantially Damaged
In floodplain	29,020
In floodplain but not in a floodway or V-zone	25,814
In floodway	2,483
In V-zone	723
Not in floodplain	136,903
Total	165,923

The estimated cost of repairing damaged structures is presented in Table 8.11. The overall estimate is just under $34 billion. The vast bulk of the estimated damage occurred outside of the floodplain and was caused by wind. Substantially damaged structures account for $21.9 billion, or 65 percent of the total. These estimated repair costs include more than just the cost of simply restoring the property to its pre-storm condition. Rather, they include the cost of completing repairs that are done to code. For example, if a low-quality roof was destroyed by the storm, the repair cost reflects the cost of rebuilding the roof to code.

Table 8.11. Repair Cost of Damaged Structures According to Modeling Approach ($ Billions)

Structure Location	Substantially Damaged Structures	Non-Substantially Damaged Structures	All Damaged Structures
In floodplain	3.6	1.8	5.4
i. In floodplain but not floodway and V-zone	3.2	1.6	4.7
ii. In floodway	0.3	0.2	0.5
iii. In V-zone	0.1	0.1	0.2
Not in floodplain	18.3	10.2	28.5
Total	21.9	12.0	33.9

Damage estimate comparisons

The $34 billion estimate is roughly double the $14.1 to $18.3 billion loss estimate for owner-occupied residential structures using the FEMA and SBA inspections. There are several reasons to expect the modeling estimate to be larger than the inspection-based estimate.

- **Multi-family units**: The estimates in Table 8.11 include approximately $6.7 billion for multi-family units, which are not included in the inspection-based approach.
- **Vacant and seasonal use units**: Approximately 21 percent of units are vacant in Puerto Rico (or for seasonal use). The modeling approach covers the cost of repairing both vacant and occupied structures, while the inspection-based estimate based on FEMA and IA inspections excludes vacant structures. Removing these properties from the modeling estimate after the $6.7 billion is excluded would reduce the modeling estimate by an additional $5.7 billion.
- **Renter-occupied single-family or duplex units**: Even after the $6.7 billion is excluded from the modeling estimate for multi-family units, it still includes losses for many renter-occupied single-family homes and duplexes. In contrast, the inspection-based estimate does not consider renter-occupied structures. Census data indicates that approximately 200,000 single family homes and duplexes are occupied by renters. Taking account of these reduces the modeling estimate by roughly another $4.3 billion.[132]

Combining all these reductions reduces the $33.9 billion projection to $17.2 billion, which is consistent with the results from the inspection-based approach. Table 8.12 summarizes the structure damage comparisons from each method using these equivalent comparisons.

[132] The 200,000 single family homes and duplexes occupied by renters amounts to about 20 percent of the roughly one million single family homes and duplexes occupied by owners or renters. Twenty percent of ($33.9 – 6.7 – 5.7) billion is $4.3 billion.

Table 8.12. Summary of Structure Damage by Type According to Both Methods ($ Billions)

Structure Type	Inspection-Based Approach (Low)	Inspection-Based Approach (High)	Modeling-Based Approach
Single family or duplex			
Owner-occupied	14.1	18.3	17.2
Renter-occupied	--	--	4.3
Vacant or for seasonal use	--	--	5.7
Multi-family (3+ units)	--	--	6.7
Total	14.1	18.3	33.9

Even though the two approaches have different strengths and weaknesses, they yield similar results for the repair costs of owner-occupied structures damaged by Maria. The advantage of using the FEMA and SBA inspections to estimate repair cost is that the resulting predictions are based on actual inspections, however incomplete. In contrast, the models used in the modeling approach are validated to some extent using real world data, but are still model projections of damage caused by observed wind speeds and flood levels. A major downside of inspection-based approach, however, is that the SBA inspections are done for relatively few properties. Recall that SBA inspections were done for 68,000 properties—a small percentage of the nearly 600,000 properties with FEMA inspections and the 715,000 FEMA registrants indicating real property damage. There are multiple reasons to think these 68,000 properties are not representative of all damaged properties. First, they are owned by the higher-income households that are considered for an SBA loan. Second, it is conceivable the properties of owners applying for SBA loans may not be the worst damaged—it may not be financially feasible for the owner to apply for a loan large enough to repair a destroyed structure.

Post-hurricane conditions

Assistance and Reimbursement Related to Residential Damage

Government and private organizations have provided substantial resources to address the housing-related damage caused by the disaster. Table 8.13 provides an overview of the assistance from public and private sources related to the residential losses due to Hurricanes Maria and Irma. The numbers provided below reflect conditions as of May 2018 unless otherwise noted.

Table 8.13. Assistance Received for Real and Personal Property Damage

Source of Assistance	Number of Recipients	Assistance Approved ($ Millions)
FEMA		
FEMA Individual Assistance Program		
FEMA home repair or replacement assistance programs	134,000	$517
FEMA personal property assistance program[a]	211,000	$402
FEMA STEP Program[d]	23,325	$221
FEMA Blue Roof Program	125,981	n/a
USACE Operation Blue Roof	59,469	n/a
FEMA VALOR program outlays[e]	525	$1.2
Insurance		
NFIP payments[b]	413	$18
Private flood insurance[b]	1,399	$14
Homeowners insurance[b]	59,123	$358
Public housing insurance[b]	--	$71
Insurance held by Puerto Rico Housing Finance Authority	--	$10
USDA property insurance	320	$1
Commercial residential policies (5+ units)	n/a	n/a
SBA Home Loans[c]	40,948	$1,200
USDA grants and loans	87	$6.3
NGO and charitable outlays for housing repair and reconstruction	n/a	n/a
Total	--	$2,820

[a]Includes transportation assistance.
[b]Government of Puerto Rico, May 10, 2018, p. 51, 58, 59.
[c]Does not include business loans or economic injury disaster loans (EIDLs).
[d]https://www.tuhogarrenace.com, data as of June 24, 2018.
[e]Incident Complex-Puerto Rico, Common Operation Picture, FEMA, June 14, 2018.

Government and private organizations have provided substantial resources to address the damage to the housing stock caused by the disaster. As of May 2018, FEMA had approved substantial payments through its Individual Assistance Program. FEMA had approved $517 million to 134,000 registrants through the home repair and replacement assistance programs and provided an additional $402 million in personal property assistance (including a relatively small amount of transportation assistance) to 211,000 registrants. Although assistance was provided to a large number of homeowners and renters, the number receiving home repair and replacement assistance is less than 50 percent of the 287,000 registrants (from Table 8.5) with inspections that showed positive RPFVL. The number receiving personal property assistance is approximately 60

percent of the 349,000 registrants with inspections and positive PPFVL.[133] One potential reason for the discrepancies is that FEMA determined that some registrants with FVL had other sources of assistance. Further examination of this issues is warranted.

FEMA administers the Sheltering and Temporary Emergency Power (STEP) program, a housing repair program that provides recovery grants to the Puerto Rico Department of Housing.[134] The STEP grants are to be used by the Department of Housing to hire local contractors to make up to $20,000 in emergency repairs to individual homes, and an additional $40,000 for the purchase and installation of an emergency generator. This program is intended to eliminate the need for families to stay in shelters for extended periods of time by making the repairs necessary for them to live in a safe and sanitary home until more extensive repairs can be made. As shown in Table 8.13 to date, the STEP program has assisted 23,325 households and disbursed $221 million though the Department of Housing.

Both FEMA and USACE programs that disperse blue tarps free of charge to households that lost their roofs in the hurricane. Both are intended to be temporary fixes until more permanent roof replacements can be secured. The FEMA Blue Roof Program distributes self-help tarps to municipalities that can be acquired by homeowners to self-install on their own roofs. This program has dispersed 125,981 blue tarps to municipalities. Operation Blue Roof, administered by USACE, utilizes local contractors to install blue tarps for the homeowner using methods that last up to 30 days. Operation Blue Roof has installed 59,469 tarps to date.

Through the Voluntary Agencies Leading and Organizing Repair (VALOR) program, FEMA provides building materials and supplies to NGOs and charities working around the Commonwealth to make essential and necessary repairs to homes damaged by the hurricane. These materials come at no cost to the voluntary organization, and to date, the program has assisted 278 families and spent $31,000 on building supplies.

Insurance was another substantial source of assistance for losses due to Hurricanes Maria and Irma. The largest payouts ($358 million) were on homeowners' policies written by private insurance companies (insurance section of Table 8.13). Modest payments were made on policies written by NFIP and providers of private flood insurance. Insurance policies held on government-owned public housing are expected to pay $71 million with additional recoveries on policies held by the Puerto Rico Housing Finance Authority. HSOAC was not able to obtain

[133] Through mid-May, FEMA had provided $1.14 billion through its Individual and Household Assistance Program (IHP), often also referred to as the Individual Assistance program. The bulk of the total ($0.919 billion) was for the home repair and replacement and personal property assistance programs listed in Table 8.13. Roughly half of the remaining $221 million was for rental assistance with the rest for medical, dental, funeral, moving, and other types of expenses. Overall, 448,000 registrants received some payment through the IHP program. This $221 million in assistance is not included in the table because it does not pertain to damage to real or personal property.

[134] STEP is funded through the FEMA Public Assistance program (as opposed to the IHP).

information on the number and amount of insurance claims paid on commercial residential structures.[135]

SBA also provided substantial resources for the repair or replacement of damaged structures. As can be seen, SBA has provided $1.2 billion in low-interest loans to nearly 41,000 households. Businesses that own residential structures are generally not eligible for grants from FEMA, because they are expected to purchase insurance if they do not want to bear the risk themselves. Business are eligible for low-interest loans from the SBA, but the data obtained for SBA did not separate out loans to businesses in the housing sector from other business loans.

Post-hurricane foreclosures

Black Knight Financial Technology Solutions reported in April 2018 that 100,000 of Puerto Rico's 400,000 first-lien mortgages are in the some state of delinquency or foreclosure, more than half of which are hurricane-related (Black Knight Financial Technology Solutions, 2018). Over time, mortgage holders have increasingly shifted to federally-backed loans (Kasper, 2018). The FHA loan default rate was about 7 percent in 2016 and 2017, but jumped to approximately 18 percent in February 2018 (U.S. Department of Housing and Urban Development, 2018b). There has been a moratorium on foreclosures since the storms, and it is currently in place unit August 16, 2018 (Tanzi, 2018). Officials overseeing federal loan programs as well as Puerto Rico mayors have expressed concern that foreclosure rates will rise once the moratorium is lifted (Kasper, 2018).

Unmet needs for housing-related losses

The estimate of unmet needs for housing-related losses is the difference between the estimates for real and personal property damage and the assistance provided thus far. Table 8.14 combines the estimates of real and personal property loss from the inspection-based and modelling approaches and the totals for assistance. Structural damage to multi-family dwelling is excluded because information on how much of the estimated $6.7 billion in damage to these structures (as shown in Table 8.12) will be covered by insurance is not currently available.[136] If the owners of multi-family dwelling carry insurance that cover the bulk of losses, the estimate for unmet need will not differ much from what is presented in the table.

After netting out assistance, the estimate of unmet need ranges from $28.4 to $31.9 billion.[137] The unmet need is large and reflects the low take-up rates for homeowners, flood, and renter

[135] Commercial residential in the insurance field typically refers to residential structures with five or more units.

[136] Consistent with excluding real property losses for multi-family dwellings, the $81 million in public housing insurance and insurance held by the Puerto Rican Housing Finance Authority (from Table 8.13) is excluded from that total amount of assistance in Table 8.14.

[137] As discussed in the methods section, FEMA Individual Assistance is meant to make the home safe and habitable, not to fully repair damage. Because work may have to be redone, FEMA combined structure repair and replacement

insurance. FEMA has provided some assistance to make structures safe and habitable and to replace essential personal property, but the amounts are small relative to the overall estimated loss. Households that are low-income, or in the informal housing sector, or both will have difficulty securing resources to rebuild and repair without government assistance.

Table 8.14. Unmet Need for Real and Personal Property Losses for Residential Structures (excluding real property losses for multi-family units)

Damage or Assistance	Amount ($ Billions)
Estimated damage	
Owner-occupied	14.1 to 18.3
Renter-occupied single-family and duplex	4.3
Homes that are Vacant or for seasonal use	5.7
Personal property damage	4.3 to 6.3
Total	28.4 to 34.6
Assistance	2.7
Remaining need	25.7 to 31.9

Note: Missing from these figures are real property damage to multi-family structures and insurance payments on multi-family structures.

As discussed previously, these projections include some of the costs needed to bring those parts of the structure that were damaged up to code. However, the estimates do not include the cost of code-required structure elevation or of voluntary elevation. They also do not include the cost of additional mitigation to non-damaged parts of the structure that would make the home less vulnerable to natural disasters.

Remaining needs and recovery priorities

Substantial resources are needed to repair residential structures damaged due to the 2017 hurricanes. In addition, a goal of this recovery process to not just build back structures to pre-storm conditions, but to make them less vulnerable to natural disasters going forward. In some cases, it may make sense to move households to safer areas. After Hurricane Maria, FEMA developed ABFEs and associated mapping (see Figure 8.1). The Commonwealth mandates the use of best available flood hazard data and adopted the ABFEs for new construction and substantial improvements. Furthermore, FEMA mandates the use of best available flood hazard

payments may not make much difference in the full repair cost for the structure. Thus, there may not be a one-to-one tradeoff between FEMA individual assistance and unmet need. In this analysis, however, we assume that FEMA IA assistance for repair and rebuilding and for personal property loss is fully deducted from estimated damage.

data/information for FEMA-funded actions. The Commonwealth also initiated a process for updating its building code.

The resources needed to repair rental properties remain unclear, and for the reasons discussed above, the totals may not fully reflect the cost to repair structures in the informal housing sector.

Remaining needs based on the HSOAC assessment of pre-hurricane conditions and hurricane damage are presented below, divided into short-term and longer-term challenges.

Short term

Short-term challenges (within the next one to 12 months) are those associated with restoration of a functioning housing sector, while also ensuring that recovery proceeds in a responsible manner.

- *Repairs to residential structures substantially damaged or destroyed during the 2017 hurricane season.* An estimated 166,000 structures were substantially damaged or destroyed. Resources are needed to repair or replace these structures as well as to bring up to code those portion of the structure that were not damaged. This challenge applies to the substantial number of homes in the informal housing sector, as well as to homes outside the informal housing sector built before more-protective building codes were adopted or for which building codes were not enforced.
- *Better enforced land-use plans and improved compliance with building permit requirements.* Puerto Rico appears to have had little success in enforcing build permit requirement, both due to a lack of resources for qualified inspectors and an uneven history of requiring building permits before construction can proceed. A major challenge during the recovery will be to require and enforce building permits, which has implications for both personnel and processes to enforce building codes and collect penalties.
- *A strategy to provide adequate affordable housing.*

Longer term

Over the next one to ten years, Puerto Rico's housing stock, building code, and insurance systems require substantial reconfiguration in order to be resilient and sustainable over time.

- *A process for establishing property titles* . There are a considerable number of structures built on land to which the structure owner does not have clear title. A longer-term need is therefore to resolve title issuehs. Title must be established to qualify for most types of federal assistance for structure repair or replacement.
- *A comprehensive property registry.* There exists no comprehensive property registry to determine and levy taxes, which is important to the financing of infrastructure and other improvements that can reduce ongoing risks.
- *A modernized property address system.* A modern property address system is needed to more accurately construct databases of home locations and disaster risk, as well as to improve the response time of emergency responders.
- *An integrated housing data system.* Such a system, which could include the updates noted above, is necessary for the Government of Puerto Rico to analyze property issues and make informed decisions while administering federally-funded programs. FEMA

officials would also be able to respond faster in the recovery process, thus helping individuals and communities to rebuild faster. Municipality planners and officials would benefit from integrated data to help prepare plans and strategies to rebuild communities.

- *A strategy to increase take-up rates of risk-based insurance and maintain them over time.* Risk-based insurance premiums are central to providing developers and homeowners with the appropriate signals of where to build and what types of structures to build or retrofit. A difficult challenge for Puerto Rico will be how to increase take-up rates, as well as maintain them, as memory of the hurricanes fade.
- *New resources and strategies to improve housing resilience to disaster risk.* Resources and strategies are required to retrofit or replace the large number of structures in Puerto Rico that were not substantially damaged in the storms but remain vulnerable to wind, flood, earthquake, and landslide risk. This applies to the large number of homes in the informal housing sector, as well as to homes outside the informal housing sector built before more protective building codes were adopted or for which building codes were not enforced.

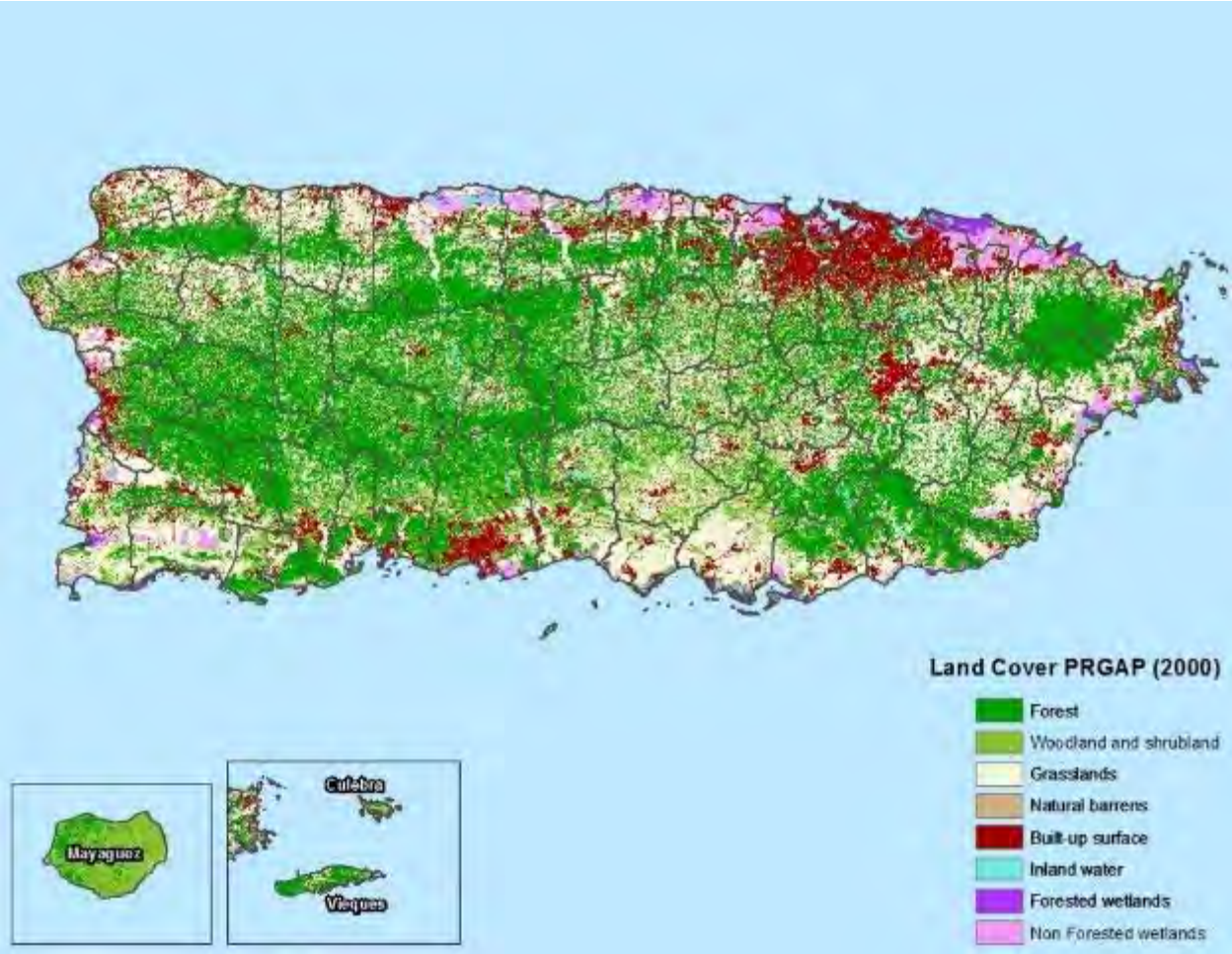
9. Natural Resources

Overview

This section documents the damage experienced by Puerto Rico's natural resources in the wake of Hurricanes Irma and Maria, as well as pre-hurricane and post-hurricane conditions for this subsector. For purposes of this assessment, we define natural resources broadly to include coastal resources, forestry, key species, landslides, debris, and solid waste/landfills. For simplicity, this section is organized into three natural resources sections: (a) Coastal resources, (b) Forestry and key species, and (c) Other natural resources (landslides and waste management). Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Natural and Cultural Resources" Sector Report. Information on pre-storm conditions, hurricane impacts, and post-storm conditions in the water sector, including flooding, stormwater management, sedimentation in reservoirs, and surface water quality issues, are discussed in the Water chapter of this report.

As described previously, Puerto Rico's main island is mountainous, with the Cordillera Central mountain range extending from the eastern to the western part of the main island, separating the northern and southern coasts. Differences in wave energy and runoff levels produce variability in coastal marine ecosystems such as coral reefs, mangrove swamps, and seagrass beds off Puerto Rico's coasts (Miller and Lugo, 2009). Figure 9.1 shows the diverse land cover in the Commonwealth. With its relative isolation, complex topography, and tropical climate, Puerto Rico has not only a diverse range of habitats, but also many plant and animal species that are found nowhere else in the world.

Figure 9.1. Simplified Land Cover Classification Map from Puerto Rico Gap Analysis Project (2000)



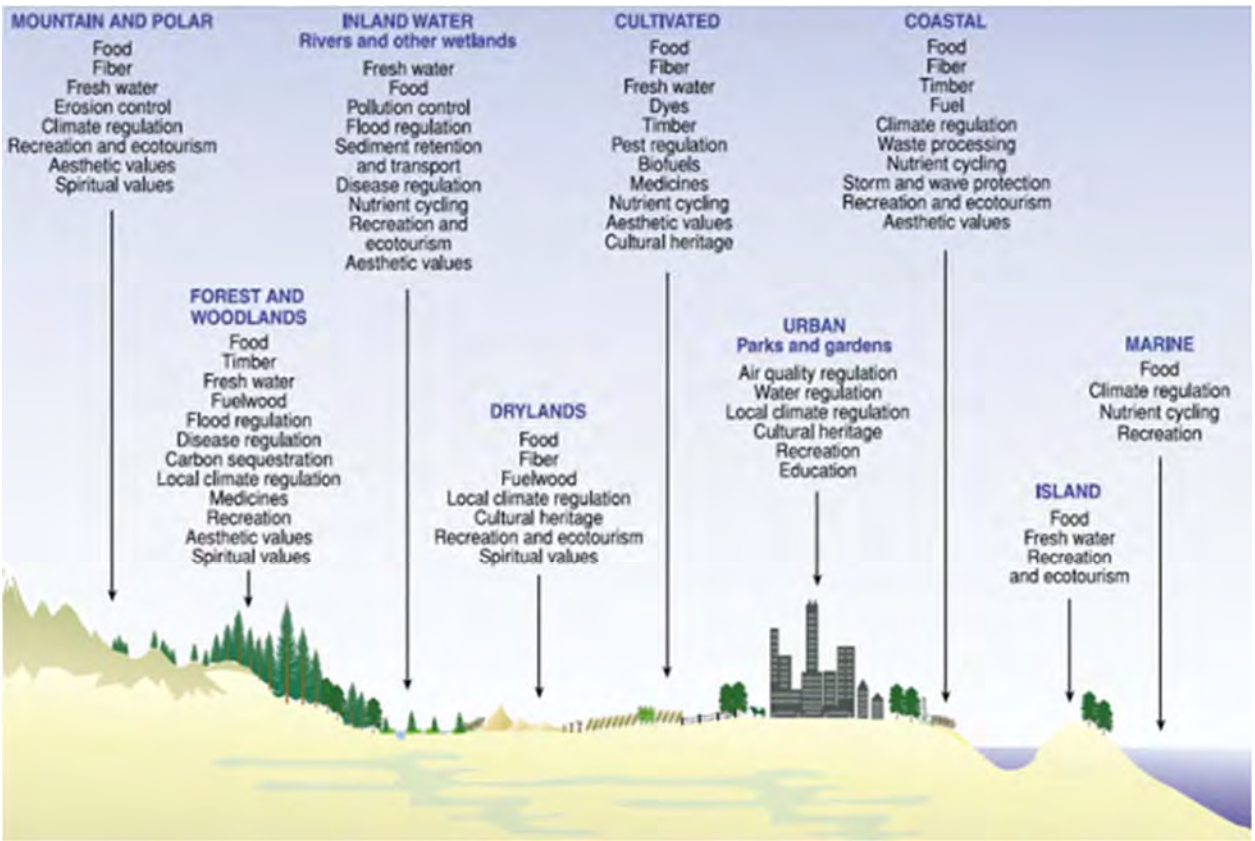
SOURCE:(Gould et al., 2008).

Not only do natural resources support plant and animal life in Puerto Rico and its coastal regions, they provide residents with food, clean water, recreational opportunities, and economic opportunities (e.g., fisheries, tourism, agriculture). Moreover, important ecosystem services, such as flood protection, water and air purification, sedimentation control, and habitats for threatened and endangered species, protect and enhance human health and built infrastructure.

The availability and functioning of natural resources affect many aspects of life in Puerto Rico. Importantly, hurricane damage to these assets affects their functionality and Puerto Rico's ability to effectively recover in a resilient manner. As shown in Figure 9.2 natural resources support human health, protect the built infrastructure, and enhance economic activity. For example, Puerto Rico's forests, mangroves, and wetlands provide land stabilization, water purification, and habitat for food sources and also provide protection to built infrastructure by mitigating flooding from storm surge and stormwater runoff as well as excessive sedimentation and landslides. Coastal resources such as coral reefs, seagrasses, and marine wetlands work

together to attenuate wave action and storm energy, providing the first line of protection to the 44 coastal municipalities (Puerto Rico Climate Change Council (PRCCC), 2013). Natural resources are also significant contributors to economic functions such as agriculture, the supply of materials, recreation, and tourism. The natural resource assets as defined here are components of interrelated systems working together to provide complementary and more robust services; and as a result, the functioning of one resource can affect the functioning, status, and long-term resiliency of others. Human activity can also enhance, or more commonly impede, the functioning of these systems. Hurricane damage to these assets will affect their functionality and Puerto Rico's ability to recover effectively in a resilient manner.in a resilient manner.in a resilient manner.

Figure 9.3. Functions of Natural and Cultural Resources

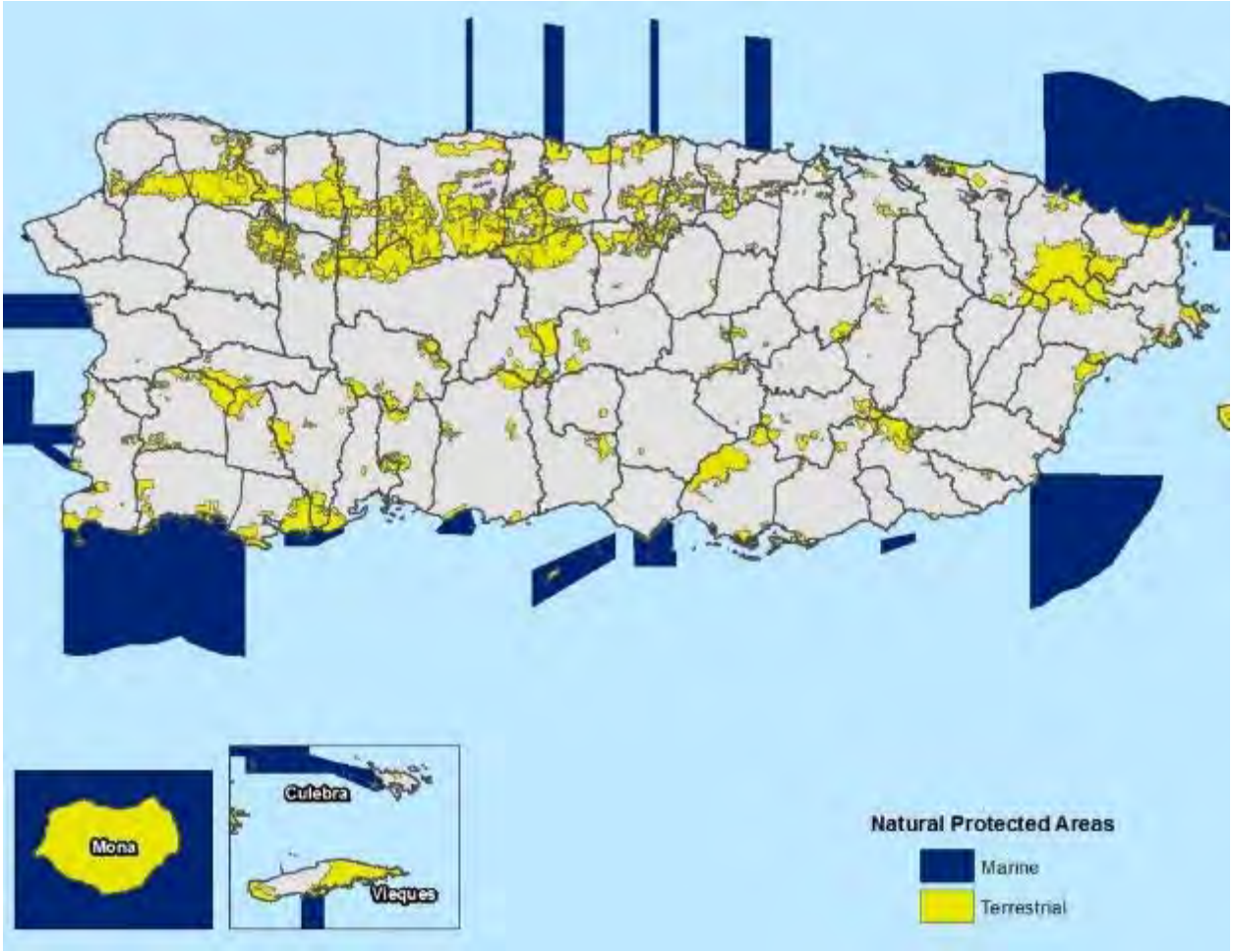


Source: Millenium Assessment as cited in (Endreny, 2016)

The industrialization of Puerto Rico through "Operation Bootstrap" from the 1940s through the 1970s (see Chapter 5 on Economy) led to a concentration of manufacturing and industry that left a legacy of pollution and hazardous waste (Miller and Lugo, 2009). Military operations at Roosevelt Roads have also resulted in hazardous waste and unexploded ordnance from bombing exercises near Vieques. Given these and other existing challenges, it is surprising that a little

more than 16 percent of Puerto Rico's natural land is permanently protected (Figure 9.4) (Caribbean Landscape Conservation Cooperative (CLCC), 2015b) —significantly less than in the continental United States, where approximately 26 percent of the land is permanently protected, or in nearby Cuba and the U.S. Virgin Islands, 17 and 52 percent, respectively) (Para la Naturaleza, undated)—significantly less than in the continental United States, where approximately 26 percent of the land is permanently protected, or in nearby Cuba and the U.S. Virgin Islands, 17 and 52 percent, respectively).

Figure 9.4. Terrestrial and Marine Natural Protected Areas in Puerto Rico

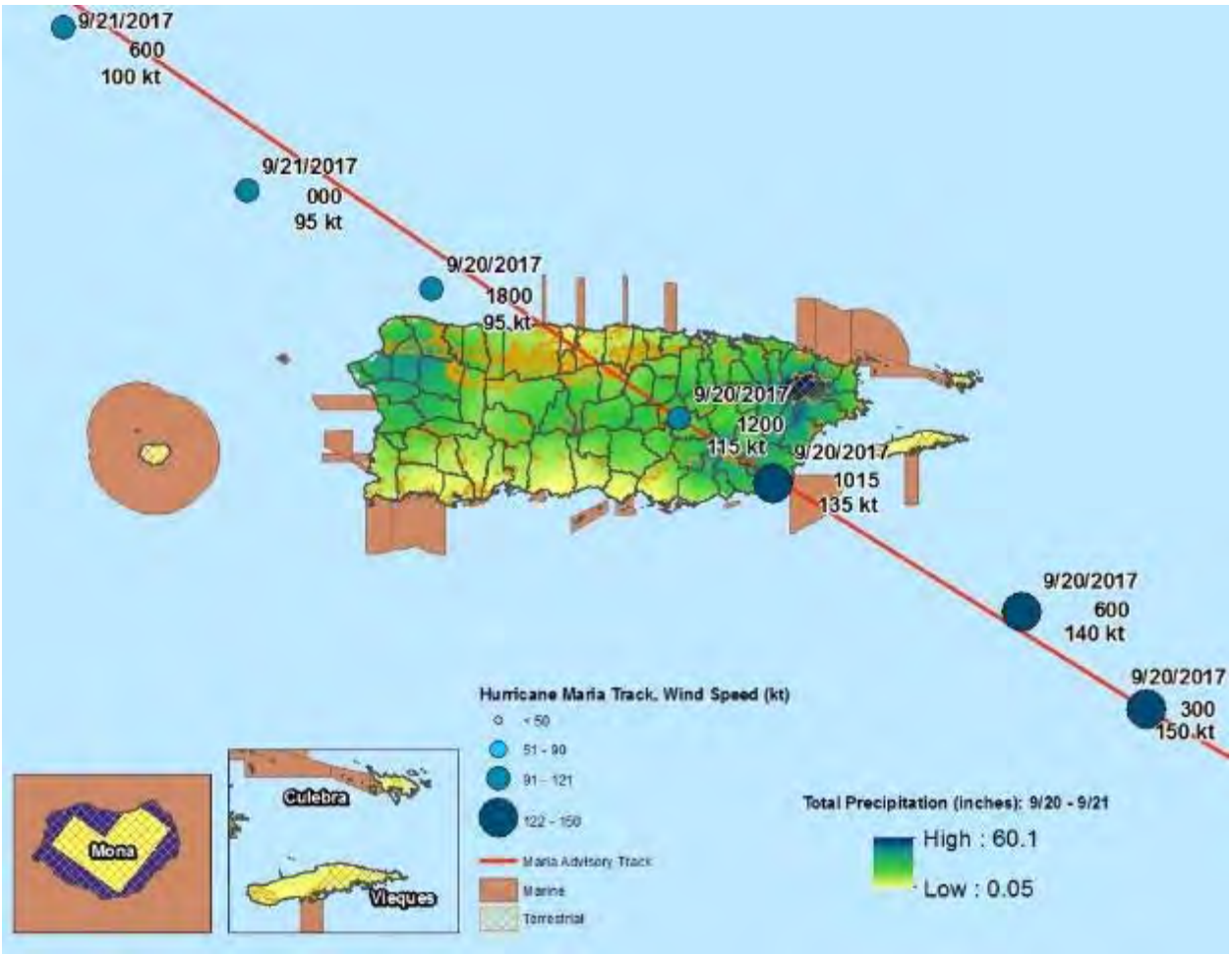


SOURCE: (Puerto Rico Department of Natural and Environmental Resources, 2015a)

The map in Figure 9.5 below helps to illustrate Hurricane María's consequences in terms of precipitation intensity, wind speeds, and storm surges. The path of the storm itself contributed to variability in destructive forces across the island. Other factors, such as human intervention in natural landscape processes (e.g., by building structures and roads) and topographic relief (e.g., intense precipitation associated with the high elevation of the El Yunque National Forest in the

northeastern part of the island and the Cordilleras in the central regions), also contributed to the general pattern of hurricane impacts, as described later in this chapter.

Figure 9.5. Cumulative Precipitation from 9/20-9/21 over Puerto Rico (in inches), with Data on Wind Speed, Hurricane Track, and Protected Areas



Source: (National Weather Service (NWS), 2018);(Puerto Rico Department of Natural and Environmental Resources, 2015a; Pasch, Penny and Berg, 2018).

It is important to bear in mind that disruption from storms and other "natural"[138] disasters is part of the natural regeneration or transition for many of these assets, and therefore pre-storm conditions have limited relevance (but do nonetheless provide a first-order baseline with which to compare).[139] However, natural recovery is hampered by human interference in these processes

[138] Disruptions such as hurricanes, earthquakes, fires, and other naturally occurring incidents are often classified as disasters due to the disruptions they have on human activities rather than for their impacts on the natural world.

[139] This means that restoring pre-hurricane conditions may not always be desirable from the perspective of the natural system. Though this is more relevant to the development of courses of action, we note it here because, for

through numerous activities such as deforestation, habitat segmentation, pollution, introduction of invasive species, shoreline development, overfishing, and other activities. And to some extent, the perception of "damage," as well as recovery goals, is influenced by expectations for the condition and function of these natural resources. For example, there may be a desired beach-width or urban tree density for recovery, irrespective of natural processes, because hurricane-induced damage has significant negative effects on housing and urban storm water runoff and air quality.

Table 9.1 provides a breakdown of the natural resources in Puerto Rico and discussed in this chapter. Note that total quantity as measured here is not necessarily an indicator of quality or importance overall. Table 9.2 shows the Commonwealth and Federal agencies responsible for natural resources in Puerto Rico.

Table 9.1. Puerto Rico's Natural Resources

Type of resource	Amount of resource
Coastal Resources	
Coral reefs	193 miles^2 (a)
Seagrasses	240 miles^2 (b)
Dunes	7 areas on the north coast Volume unknown (c)
Beaches	129 miles of coastline/300 beaches (d)
Wetlands	337 miles^2 (e)
Mangroves	26 miles^2 (f)
Natural Resources	
Forests	1826 miles^2 (g)
Critical wildlife areas	448 miles^2 (h)
Species of Greatest Conservation Need (includes commonwealth priorities and federally listed species)	316 (h)[140]

Sources: (a) (Puerto Rico Climate Change Council (PRCCC), 2013)(b) 240 miles^2 in (Caribbean Landscape Conservation Cooperative (CLCC), 2015a); (c) (Data Basin, 2016) (d) (Puerto Rico Climate Change Council (PRCCC), 2013); (e) (Diaz and Lilvestrom, 2010) (f) 1999-2003 estimate in (Commonwealth of Puerto Rico Department of Natural Resources, 2016); (g) (Brandeis and Turner, 2013); (h) (Puerto Rico Department of Natural and Environmental Resources, 2015a)

some natural assets, the hurricanes' effects might be more accurately classified as "natural disruption" rather than damage.

[140] DNER has identified 316 species of greatest conservation need, which include 78 federally listed threatened and endangered species in addition to the DNER priority species. These species are classified into five categories as follows: critically endangered (CR), endangered (EN), vulnerable (VU), low risk (LR), data deficient (DD). Puerto Rico Department of Natural and Environmental Resources, (Puerto Rico Department of Natural and Environmental Resources, 2015a).

Table 9.2. Examples of Agencies Responsible for Natural Resources

Agency	Role	Relevant regulations
Commonwealth Agencies		
Department of Natural and Environmental Resources (DNER), (Departamento de Recursos Naturales Y Ambientales or DRNA)	Authorized to enforce protection of natural resources, manage water resources, and protection of wildlife. Responsible for coastal management between 0-9 miles offshore. NOAA often works in partnership on coral reef, sea turtle and marine mammal protection. Responsible for Coastal Management Zone Plan (1978).	Commonwealth Law No. 29 of 1976; Commonwealth Law No. 136 of 1976; Commonwealth Law No. 241 of 1999; Conservation Easement Act of 2001 The Law for the Protection, Conservation, and Management of Coral Reefs (referred to as 1999 Coral Law 147), July 15, 1999; Law 268 (Legacy Lands Act) 2003
Federal Agencies		
United States Fish and Wildlife Service (USFWS)	Responsible for conserving, protecting, and enhancing fish and wildlife, and their habitats, including programs related to migratory birds, endangered species, fish and marine mammals, and inland sport fisheries. FWS also manages national wildlife refuges, including five units of the Caribbean Islands National Wildlife Refuge (NWR) Complex in Puerto Rico. USFWS Coastal Program is to identify “important coastal resource problems and solutions and develop partnerships for on-the-ground conservation in high priority coastal areas.” Administers the National Coastal Wetlands Conservation Grant Program and the Wildlife Conservation and Restoration Program (WCR)	Coastal Wetlands Planning, Protection and Restoration Act, 1990, Marine Mammal Protection Act Endangered Species Act (ESA) of 1973; Fish and Wildlife Coordination Act (FWCA of 134, as amended; EO 13112. Invasive Species of 1999. The Caribbean Ecological Services Office of the USFWS was established in 1974.
U.S. Forest Service (USFS)	Protects the health, diversity, and productivity of national forests and grasslands, including by managing the El Yunque National Forest. In Puerto Rico, the USFS also works with private and state landowners in these areas and promotes research at the International Institute of Tropical Forestry (IITF), including the Luquillo Experimental Forest. In Puerto Rico, the USFS also works with private and state landowners in these areas and promotes research at the International Institute of Tropical Forestry (IITF), including the Luquillo Experimental Forest	Endangered Species Act (ESA) of 1973; National Environmental Policy Act of 1969; National Forest Management Act of 1976; Resource Conservation and Recovery Act (RCRA) of 1976

Agency	Role	Relevant regulations
NOAA	Responsible for fisheries law enforcement in Exclusive Economic Zone (EEZ), the area between 9 and 200 nautical miles off the coast. It is responsible for commercial fisheries management, marine mammal protection, coral reefs, federally managed marine management areas (MMAs), and endangered species. There are 300 fish/marine species in Puerto Rico managed under four fisheries management plans.	Magnuson Stevens Act of 1976, Marine Mammal Protection Act of 1972, Endangered Species Act of 1973
USCG	Responsible for at-sea federal fisheries law enforcement and Marine Environmental Protection (marine mammals, sea turtles and endangered species protection; pollution prevention; invasive species prevention). NOAA is responsible for onshore federal fisheries law enforcement (this typically occurs at commercial fisheries offloading ports). Puerto Rico is responsible for at-sea and onshore territorial (0-9 nautical miles from shore) fisheries law enforcement.	
EPA	Enforcement authority to require substantive actions are taken to address serious environmental or health risks.	1899 Rivers and Harbors Act, Section 404 of the 1972 Clean Water Act. Resource Conservation and Recovery Act (RCRA)
Corps of Engineers	Issues and denies construction permits	1899 Rivers and Harbors Act, Section 404 of the 1972 Clean Water Act

Sources: (Puerto Rico Department of Natural and Environmental Resources, 2015b; "Ecological Services in the Caribbean," undated)

Data sources and methods

Data sources

Table 9.3 summarizes key damage assessment data sources used to understand the health of natural resources in Puerto Rico. A few damage assessments have been conducted since the hurricanes, including the Landslide Incidence assessment; however, most assessments reflect pre-storm conditions. There are multiple geospatial datasets that can provide useful information for NCR sector damage assessments. For example, high spatial resolution satellite observations can be used to determine differences in the pre- and post-hurricane status of beach erosion. Potential data sources include optical imaging from commercial satellites (Planet, 2017), as well as optical, LiDAR, and classified land use and land cover maps from government sources (National Oceanic and Atmospheric Administration Office for Coastal Management, 2017). Another important resource is the Environmental Response Management Application (ERMA)

for the Caribbean, which provides useful information on coastal management (NOAA's Office of Response and Restoration, 2015) Additional information on benthic ecosystem types is available through the Caribbean Landscape Conservation Cooperative (CLCC) (Caribbean Landscape Conservation Cooperative (CLCC), 2014).

Table 9.3 Summary of Key Damage Assessment Data Sources: Coastal, Forestry, and Key Species Natural Resources

Dataset	Source	Date of Last Update	Evaluation Notes
Habitat GIS data	Puerto Rico State Wildlife Action Plan	2015	GIS data of various coastal habitat types.
Water quality remote sensing data	NOAA	2018	Remote sensing shows Chl-a, Kd-490 and sewage runoff.
Benthic habitat data	NOAA	1999	Benthic habitat mapping was performed by NOAA in 1999.
PR GAP Analysis	U.S. Department of Agriculture Forest Service, International Institute of Tropical Forestry	March 2008	Land cover distribution (including forests) and species richness for 2000
Natural and Protected Areas	Caribbean Landscape Conservation Cooperative (CLCC)/DNER	December 2016	Protected Areas Conservation Action Team (PA-CAT) includes partners at the federal and state level as well as non-profits and academic institutions
Critical Wildlife Areas (CWA)	DNER	2015	Locations necessary for species of interest
Landslide Incidence	USGS	October 2017	Preliminary mapping of landslide incidence from Hurricanes Maria and Irma
Landslide Incidence	University of Puerto Rico	May 2018	Detailed mapping of landslides based on satellite and aerial remote sensing.
Remote sensing	Various sources (federal government and private)	Ongoing	Pre- and post-hurricane remote sensing is being collected by satellites (such as Landsat) and airborne platforms
Site-level monitoring data of Gesneria pauciflora populations	University of Puerto Rico at Rio Piedras (UPRRP), DNER, and FWS	September 2015 – August 2017	Site locations in Maricao Commonwealth Forest (MCF) and surrounding private lands

Dataset	Source	Date of Last Update	Evaluation Notes
Site-level observation data of the Puerto Rican Sharp-shinned Hawk populations and nesting sites and other habitat conditions	USGS Mississippi Cooperative Fish and Wildlife Research Unit, Mississippi State University	2012-2016	Site locations in forest reserves and private lands across the Cordillera Central and the Cayey and Luquillo Mountains
Acoustic recordings of sites across five watersheds and analysis of this data to determine Elfin woods warbler status	Sieve Analytics is source for the data assessment; so we assume they collected this original field data	Unknown	Data assessment is going to collect about 100,000 one-minute recordings at 100 sites; we assume the original data was a similar amount of data

Methods

The damage assessment process and methodology are unique to each specific natural asset. Table 9.4 below provides a summary of the methodologies and expected results for the assessments detailed in Table 9.3. The subsections that follow describe the approach and the anticipated output for the many assets within Coastal Resources in more detail.

Table 9.4 Summary of Natural Resources Assessment Approaches and Expected Results

NCR Asset/ Function	Assessment Focus	Methodology and Sampling Strategy or Goal	Results expected
Coral Reefs	Coral reef damage	Probabilistic sample design was utilized to choose sites prioritized by coral cover, storm protection provided, and endangered species. Assessments were performed with a combination of diver based transect and roving surveys.	Full assessment of reef damage at sample sites and triaged response to stabilize damaged corals.
Seagrasses	Seagrass damage	Damage indicators and remote sensing were used as a proxy for seagrass health	Inform appropriate locations for seagrass restoration
Beach Erosion & Dunes	Sand dunes erosion	UAVs or drones and image analysis to measure volume and area of dunes and vegetative cover	Ecological restoration strategies to increase size and stability of dunes in priority areas
Wetland & Mangroves	Wetlands damage	Assessment uses site visitations and aerial imagery to assess vegetative damage, changes in ecological structure and hydrology.	Habitat management and short-term recovery recommendations for priority sites
Beach Erosion & Dunes	Beach erosion	Compare aerial photograph pre- and post-hurricane to determine meters of beach loss	Evaluate high risk areas and economic analysis of assets at risk; recommendations for beach amelioration strategies
Forestry	Forest/ Nursery/ Urban forest damage	Use LiDAR, hyperspectral, and thermal remote sensing, and high-resolution photographs, collected by NASA G-LiHT campaign to assess damage; Site visits and field surveys of urban forests and	Identify tree loss and repairs needed for forests and nurseries to support forest recovery process

NCR Asset/ Function	Assessment Focus	Methodology and Sampling Strategy or Goal	Results expected
		nurseries	
Waste management	Illegal dumpsites and landfill capacity	Inventory of illegal dumpsites; Estimation of landfill capacity lost from hurricane-related debris. Details of assessments currently unknown	Geospatial map of illegal dump sites and landfills with capacity and potential threats to environment and human health
Reservoir/ recreational fishing	Fish population and communities	Electrofishing to sample fish species diversity and population; water quality parameters	Comparison of fish populations to pre-hurricane status; changes in water quality parameters
Flood hazard/fish passage	Barriers to fish passage	Geospatial mapping of fish passage barriers	Prioritization of stream crossing structures to repair or remove
Sedimentation and erosion	Volume of sedimentation from landslides	Remote sensing-based assessment of landslides to inform sedimentation impacts	Total sediment loading in priority watersheds
Key species (e.g., Elfin Wood Warbler, PR Plain Pigeon)	Distribution and habitat assessment	Acoustic sampling and other remote sensing methods using satellite imagery; Field surveys; Habitat assessments	Detection of species and distribution of their presence across different sites; Level and variability of habitat disturbance

Data gaps, assumptions, and limitations

At the time of this writing, damage assessments led by various entities are still ongoing and there are still areas where data are limited or incomplete. Some assessments are focused only on local areas, and there is a lack of baseline data for many assets, making damage from the storms is difficult to separate out for other already-occurring types of environmental damage.

Little is known about the damage to the island's trail system, and it is recommended that a full identification and inventory process occur to better understand the impact to recreation and tourism. Other concerns focus on the lack of data on water quality, sedimentation damage to coral reefs and marine ecosystems, damage to fisheries (which have been declared a disaster), and the location and size of informal dumps.

The long-term effects of hurricanes on natural resources are highly uncertain: natural systems can take years and even decades to recover from a high-intensity storm, and they interface with other natural systems and the built environment, which also affect recovery. Prior to the storms, ecosystems were already experiencing stressors and environmental damage due to the impacts of human activity. Therefore, restoring ecosystems to pre-storm conditions that were already significantly impaired may not be appropriate or the best use of resources. As a result, even when assessments are reported, they will not address the gap in our ability to understand the immediate- and long-term negative effects of hurricanes Irma and Maria. For example, at-risk reef sections are being re-attached, but their ultimate survival is uncertain. Additionally, many of the coastal assessments require pre-and post- storm measurements that align seasonally, and it

may take several years to compile enough data to assess post-storm trends. Future monitoring of natural assets is required to more fully respond to the recovery needs of this sector.

Given that many assessment results are not yet available, much of the information in this report relies on open source information (e.g., academic publications and news reports) and our review of available assessment proposals and statements of work (e.g., those delivered directly to FEMA NCR staff for review). When possible, we have supplemented the discussion using spatial data (e.g., GIS, remote sensing).

We discuss in this chapter a variety of expert analyses that are under way. While these assessments are being led by experts in their respective fields, these efforts have not yet been independently peer-reviewed, and there could be important limitations to some of these assessments. However, the HSOAC team does not have perfect visibility into how these assessments are being done and is not aware of any process for bringing additional issues to light and potentially addressing them in time to influence how the information is used in the development of courses of action. Some of the methodological issues that could become problematic include:

- Failure to execute the assessment as outlined in proposals or statements of work
- Use of baseline information that is dated
  - Problems acquiring comprehensive and temporally consistent baseline data
- Spatial gaps in data (missing locations or institutions) and limitations in analytic breadth (e.g., surveys examining a fraction of important factors), including:
  - Pre-storm data that limits both the types and locations of possible assessments
  - Focus on areas that may not provide generalizable results to all affected areas of Puerto Rico
  - Limitations and errors resulting from using indirect measures of damage, which may not fully represent impacts in both the short and long terms
- Use of limited observational data, and data proxies, combined with modelling, which may yield initial approximations, although actual damage will be unknowable in a practical sense
- Normal uncertainties and errors introduced by standard sampling, extrapolation, and modeling methods.

Coastal resources

Puerto Rico's island environment features rich coastal areas, including coastal, estuarine, and marine ecosystems. Key physical features of these ecosystems include sandy dunes and beaches, rocky shorelines, mangroves, estuaries, submerged seagrasses, and coral reefs (Miller and Lugo, 2009). Puerto Rico also has 32 documented species of marine mammals,[141] including baleen

[141] Marine mammals are generally considered "charismatic megafauna" and can be a large draw for tourists worldwide.

whales, toothed whales, dolphins, manatees and seals. Coastal areas are tremendously important for Puerto Rico's future, because they serve as the natural land-sea barrier (protecting inland areas from erosion and flooding), provide critical habitat, and help facilitate tourism.

Coastal resources in Puerto Rico are comprised of coral reefs, mangrove forests, seagrasses, wetlands, dunes, and beaches. They provide critical ecosystem services such as storm and flood protection and habitat for fisheries and other flora and fauna that support food production. These natural resources also provide opportunities for recreational and economic activities. Natural coastal habitats such as sand dunes, wetlands, coral reefs, mangroves, sea grasses and beaches all provide flood protection and storm surge attenuation; however, after a strong storm there is often a significant amount of structural and ecological damage to these ecosystems. These ecosystems also provide habitat for important commercial and recreational fisheries and nurseries, serve as tourist attractions, act as water filtration systems, and provide habitat for protected and endangered species. As an example, due to its ecological and economic value, a roughly five-acre mangrove swamp at Naguabo is protected by the Commonwealth (Miller and Lugo, 2009).

Background

History and structure

The three major management and law enforcement agencies responsible for coastal resources in Puerto Rico are the National Oceanic and Atmospheric Administration (NOAA), the U.S. Coast Guard, and Puerto Rico's Department of Natural and Environmental Resources (DNER or DNRA in Spanish).

Commercial and recreational fisheries in Puerto Rico are managed by NOAA's National Marine Fisheries Service (NMFS) and the Caribbean Fisheries Management Council under the Magnuson Stevens Act (2006), and the DNER. Under the Act, NOAA is responsible for fisheries management in the Exclusive Economic Zone (EEZ), which in Puerto Rico includes water between nine and 200 nautical miles offshore. NOAA is responsible for onshore federal fisheries law enforcement for the 300 fish/marine species federally managed under four fisheries management plans (National Oceanic and Atmospheric Administration (NOAA) Fisheries Southeast Regional Office Caribbean Operations Branch, 2018). DNER is responsible for and has jurisdiction over all territorial waters (0-9 nautical miles from shore) and is responsible for at-sea and onshore territorial fisheries law enforcement. The Coast Guard is responsible for at-sea federal fisheries law enforcement under their Living Marine Resources Mission. The Coast Guard also performs Marine Environmental Protection, which includes marine mammal, sea turtle and endangered species protection; pollution prevention and invasive species prevention.

DNER is responsible for all onshore coastal resources, such as beaches, dunes, and mangroves, as well as for 26 marine management areas.[142] DNER has recently published two

[142] Personal communication between National Marine Protected Areas Center, NOAA and Kate Anania, RAND. 15 Feb 2018.

major coastal management plans: one for the Jobos Bay National Estuarine Research Reserve (JBNERR) for the years 2017-2022 (supported by NOAA's NERRS program), and another for the Natural Estuarine Reserve of Laguna del Condado (Plan de Manejo para la Reserva Natural Estuarina de la Laguna del Condado), published in 2016.

Puerto Rico has 34 Marine Protected Areas,[143] which are managed to protect areas of ecological importance, to manage commercial fisheries, to ensure safety for recreational activities, and to protect sensitive areas from damage. Seven of these sites are federally protected, five are protected in federal/territorial partnerships, and the remainder are managed by Puerto Rico.[144] The types of protected areas include Fishery Management Areas, National Estuarine Research Reserves, National Wildlife Refuges, and Natural Reserves. In these areas there can be restrictions on commercial fishing and vessel access, as well as seasonal closures.

NOAA enforces marine mammal and coastal endangered species protection (such as sea turtles) under the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973. NOAA has support services that fund and research coral reefs, estuaries, and coastal zones. While NOAA has designated offices and funds for these habitats, NOAA must partner with Puerto Rico for any support provided in Puerto Rico's territorial waters. For example, DNER has ultimate jurisdiction over Jobos Bay, but NOAA provides funding and research support to the area. NOAA supports the National Estuarine Research Reserves System (NERRS), and Jobos Bay is a NERRS site (Office for Coastal Management, National Estuarine Research Reserves and Puerto Rico Department of Natural and Environmental Resources, 1981).

Wetland regulations are overseen by the Environmental Protection Agency (EPA), U.S. Fish and Wildlife Service, National Resources Conservation Service, and the U.S. Army Corps of Engineers (COE) (Miller and Lugo, 2009). DNER and the Planning Board of Puerto Rico also have a role in guiding wetland protection.

DNER is also empowered to develop a program to conserve, protect, and manage reef ecosystems under the Law for the Protection, Conservation, and Management of Coral Reefs (referred to as 1999 Coral Law 147).[145] In 2010, with the support of the Coral Reef Conservation Program (CRCP) and input from stakeholders, DNER identified three priority issues for the management of coral reefs, including improving the water quality of reef ecosystems by reducing pollution from terrestrial sources; reducing effects from human activities that are most damaging to reef ecosystem health; and promoting recovery from previous storm events and anticipate the effects on reef ecosystems from increased storm frequency and intensity, water temperature and acidification, and air pollution. In 2016, Puerto Rico established Regulation 8809, which

[143] Personal communication between National Marine Protected Areas Center, NOAA and Kate Anania, RAND. 15 Feb 2018.

[144] Personal communication between National Marine Protected Areas Center, NOAA and Kate Anania, RAND. 15 Feb 2018.

[145] Known as the Departamento de Recurso s Naturales Y Amientales (DRNA).

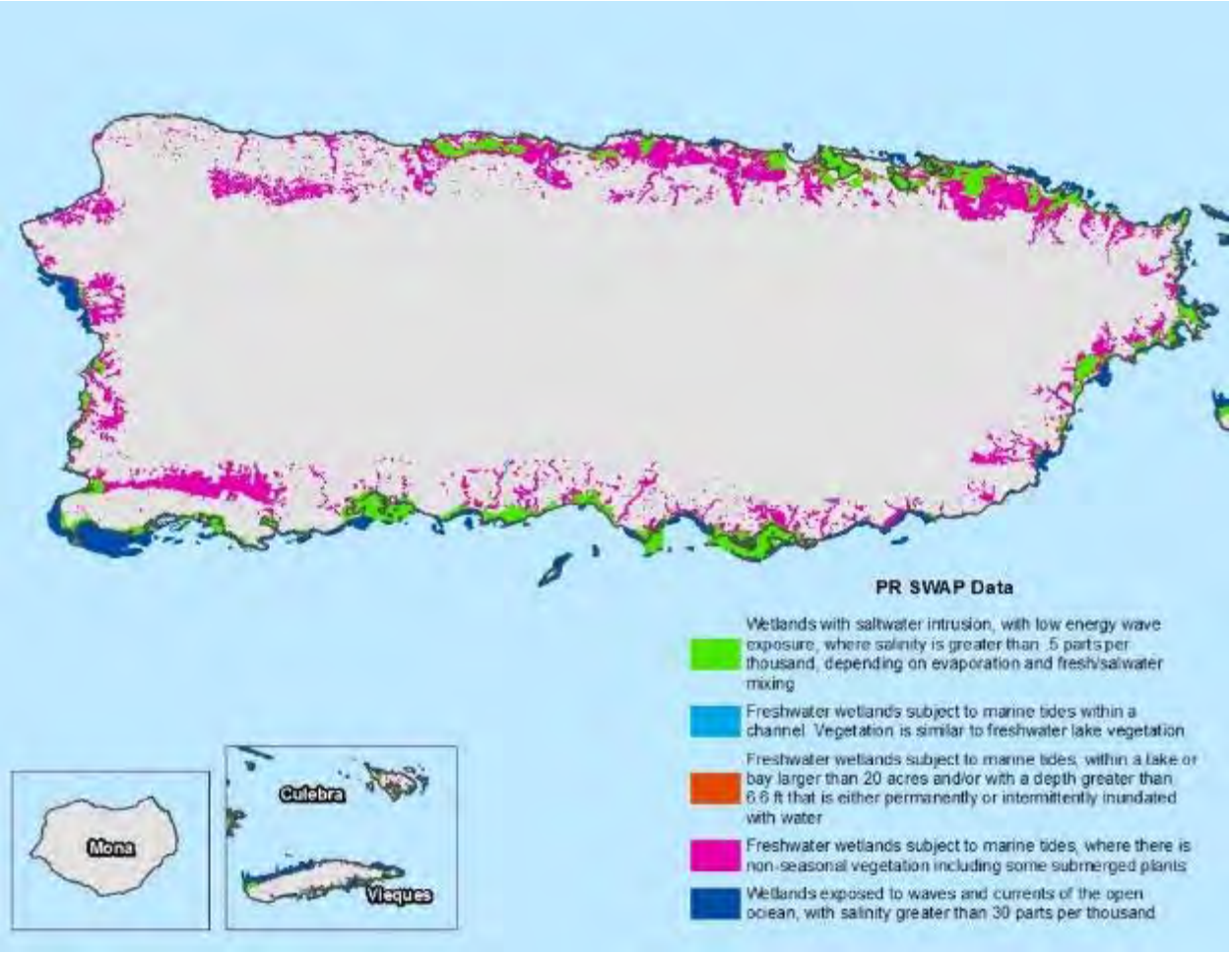
implements management mechanisms for protecting and conserving reef ecosystems and communities including penalties for inappropriate activities (Puerto Rico Department of Natural Resources, 2017).

NOAA offers support to DNER for various coastal habitats, including coral reefs and estuaries. NOAA's Coral Reef Management Priorities for Puerto Rico were developed in 2010 (National Oceanic and Atmospheric Administration, 2010). Sites were chosen for the program based on three criteria: biological value, degree of risk and threat and site viability. The top four sites that were identified as immediate priority reefs are Culebra, North East Reserves, Cabo Rojo, and Guanica and Marine Extension. In 2015 NOAA's Coral Reef Conservation Program identified several challenges facing Puerto Rico's coral reef management and conservation programs, noting the lack of formal commitment, long-term financing, and a supportive constituency for coral reef management as well as difficulties in enforcement and compliance (National Oceanic and Atmospheric Administration, 2015c).

Key assets

Key assets in coastal resources in Puerto Rico described here include sea grasses, mangrove forests, coral reefs, dunes and beaches, and fisheries. Some of the waters immediately surrounding Puerto Rico are highly productive. The presence of the mangrove swamps, seagrass beds and coral reefs is a major reason for this "oasis" effect (Miller and Lugo, 2009). In addition to their inherent ecological value, they also provide habitat for fish, conch, and shellfish that are commercially valuable (Miller and Lugo, 2009). Seven types of wetland ecosystems are common in Puerto Rico: saltwater aquatic, saltwater flats, saltwater marsh, saltwater swamps (mangroves), freshwater aquatic, freshwater marsh, and freshwater swamps (Figure 9.6). Wetlands are rich in both species density and diversity. Wetlands provide services such as coastal protection, water filtration, habitat, spawning grounds, and carbon sequestration (Puerto Rico Climate Change Council (PRCCC), 2013). Puerto Rico has 337 square miles of wetlands; 36 percent of these are estuarine or freshwater while 27 percent are marine wetlands (Diaz and Lilvestrom, 2010) (Figure 9.5).

Figure 9.6. Marine or Brackish Wetlands of Puerto Rico



Sources: (Puerto Rico Department of Natural and Environmental Resources, 2015a; Gould et al., 2008)

Seagrasses are an ecologically valuable resource. They provide habitat and nursery ground for many species, including commercially valuable fisheries. Seagrasses provide wave attenuation to reduce storm damage and help filter pollutants from the water. Finally, seagrass root systems decrease sediment and turbidity in the water column, increasing clarity and the distance light can travel to the bottom of the water. Puerto Rico's clear water is a tourism draw. Submerged seagrasses comprising seven species can be found in the shallow waters of coral reef lagoons, bays, and mangrove channels along the Puerto Rican coast, particularly on the southwest and eastern coasts of the main island and between the main island and Vieques (Puerto Rico Department of Natural and Environmental Resources, 2015a). These plants are critical to the coastal ecosystem for general and nursery habitat, as a food source, and for sediment filtration and nutrient absorption (Miller and Lugo, 2009).

Mangrove forests are very prominent coastal features in Puerto Rico, and are an especially valuable ecological resource because they provide high levels of coastal protection and habitat

for multiple species. Mangroves are also estimated to be habitat for 70 to 90 percent of marine life with recreational or commercial value for at least part of their life cycles (Puerto Rico Department of Natural and Environmental Resources, 2015a). The services provided by mangroves have been valued at between $51.8 to 233.1 million per square mile (Puerto Rico Climate Change Council (PRCCC), 2013). Mangrove forests in Puerto Rico are densest off of the coast in the northeast part of the main island, particularly in the coastal areas around San Juan (e.g., Bosque de Pinones), though mangrove forests also exist in other coastal areas (Puerto Rico Department of Natural and Environmental Resources, 2015a).

Coral reefs are another critical habitat in Puerto Rico. Coral reefs are concentrated off the southern coast of Puerto Rico's main island and around the islands of Mona, Culebra, and Vieques, though they exist off of much of the coast and in the waterways between Puerto Rican islands (Puerto Rico Department of Natural and Environmental Resources, 2015a). They provide a physical barrier for wave energy, thus reducing storm impacts. Coral reefs are also usually biodiversity hotspots, and their complex structures provide food, habitat, and nursery grounds for many marine species. Snorkeling and scuba diving on healthy coral reefs is a large tourism industry. Studies have shown that the benefits provided by coral reefs, seagrasses and mangroves are increased when all three systems are healthy. Restoring just one system provides benefits, but restoring all three systems in tandem provides increased protection beyond the sum of the benefits, plus an increase in coastal system resilience (Guannel et al., 2016; Gillis et al., 2014).

Puerto Rico has over 310 miles of coastline—roughly 130 miles of it made up of 300 beaches, 97 of which are classified as swimmable. Dunes are found in Aguadilla, Isabela, Camuy, Hatillo, Arecibo, Barceloneta, Manatí, Dorado, San Juan, Carolina, Loiza, Luquillo and Culebra.[146] Only a small percentage of Puerto Rico's shoreline hosts sandy dunes and beaches, which are more prevalent in the north. Beach and dune ecosystems provide critical storm protection and habitat, but can be challenging to manage because they have natural accretion and erosion cycles that can be exacerbated by impacts due to human activity (such as high traffic through sensitive areas or sand harvesting), climate change (such as sea level rise), neighboring ecosystems (corals and other reef types help beaches retain sand) or major storms. Dry beach and dune areas are home to a variety of plants, and shallow water sandy areas can host productive seagrass habitats.

Most of Puerto Rico's commercial fisheries are small-scale, multi-species and multi-gear fisheries. Most target demersal (bottom of the water column inhabiting) or pelagic (mid-water column inhabiting) species – in other words, species that are not particularly close to the ocean water surface. A few large-scale longline vessels from the continental U.S. take harbor in Puerto Rico's EEZ for a few days each year, but large-scale fishing pressure is not common. Less data are available on recreational fisheries, but it is estimated that recreational fishing in Puerto Rico

[146] Personal communication between Dr. Robert Mayer, Director - Vida Marina / Center for Conservation and Ecological Restoration and Susan Resetar, RAND. 31 May 2018.

has a larger take than commercial fisheries. Most recreational fishing is from shore or private boats; charter fishing is not a large industry in Puerto Rico (Puerto Rico Climate Change Council (PRCCC), 2013).

Pre-hurricane conditions

Approximately 419,000 residents of Puerto Rico live within one kilometer of the coast and 2.3 million live within the 44 coastal municipalities of the Commonwealth (Puerto Rico Climate Change Council (PRCCC), 2013). Human activity, combined with natural processes and environmental changes, has damaged or severely eroded coastal areas of Puerto Rico over several decades. Prior to the 2017–2018 hurricane season, coastal resources—including mangroves and wetlands, seagrasses, coral reefs, and beaches and dunes—were stressed by pollution, over-fishing, ocean acidification, sea-level rise, erosion, excess warming, development practices, recreational damage, and other human-induced effects, collectively making them more vulnerable to hurricane damage.(Dee, Horii and Thornhill, 2014; Miller and Lugo, 2009)

There are several compounding causes of coastal degradation over time, including hurricanes. Sea-level rise and erosion are other major drivers. It should be noted that seagrasses, corals, wetlands/mangroves and beaches and dunes all provide more storm protection when all of the systems are maintained and healthy in tandem. For example, healthy corals and seagrasses provide wave attenuation, which reduces storm impacts on beaches and wetlands; wetlands filter water pollutants and limit water quality-related stressors on corals and seagrasses.

Seagrasses across the Caribbean have been threatened by dredging, effluent from both municipal and industrial sources, oil spills, nutrient enrichment, sedimentation and erosion (from construction and also as a result of naturally existing processes), disruptive commercial fishing practices, introduction of non-native species, aquaculture (cropping), temperature changes (related to power plants, and also naturally existing processes), storm scouring (e.g., by previous hurricanes), and effects related to the El Niño Southern Oscillation (ENSO) and climate change, among others.

Coral reefs have faced many environmental and anthropogenic stressors, including ocean acidification, storm energy damage, and exposure to pollution from runoff and other sources, including sunscreen. Although coral harvesting is illegal in the United States, it still occurs and can damage coral reefs. Additionally, coral reef fishes are harvested as part of the ornamental fish (saltwater aquarium) industry, which, while legal and regulated, can also stress the coral reef ecosystem (Dee, Horii and Thornhill, 2014). Coral reefs are sensitive to climate-related stressors, including increasing temperatures and ocean acidification, which lead to “coral bleaching” events. Although coral-reef-driven tourism is a large draw for many visitors to Puerto Rico, damage from tourists dropping anchors or kicking or touching reefs can also degrade coral reef health over time.

Mangrove and wetland loss has been exacerbated by exclusively human activities such as dredging, construction, waste disposal, and cutting.(Miller and Lugo, 2009) Mangroves can be

damaged by high wave energy, high winds, exposure to pesticides and pollution from runoff, extraction for firewood or other human uses, and a number of other environmental factors that can cause stress (e.g., changes in salinity, depth, temperature, and oxygen). Mangroves evolved to be resilient to high winds and wave energies, but stressors such as pollution and human-induced hydrology changes have made it more difficult for mangrove ecosystems to withstand storm impacts.

Beach and dune system health is highly variable and depends on sediment transport in the system. A balanced beach and dune system has a typical cycle of many years of slow accretion followed by a rapid depletion due to storm activity. Human impacts such as walking or riding ATVs on dunes can damage vegetation that stabilizes dune structure; weakened dunes are more likely to wash out under storm surge. Beach and dune post-storm recovery rates are dependent on three variables: the health and stability of dune systems, coastal development, and the presence and status of naturally occurring coastal protections, such as mangrove forests, seagrasses, coral reefs, and beach rocks.

Many of Puerto Rico's beaches and dunes had been eroded before the 2017 hurricane season due to both natural and anthropogenic causes. Sand mining, coastal development and hard shore protection (such as walls, riprap, breakwaters or jetties), ATV use, winter swells, large storms, and hurricanes have depleted Puerto Rico's beaches and dunes. In the 1960s and 1970s, dunes had been diminished due to large-scale mining for sand. Additionally, between 1995 and 1999, beaches were heavily eroded by hurricanes, and recovery was slower than is typical after heavy storms. Finally, man-made structures such as jetties, breakwaters, marinas, and seawalls, as well as insufficient construction setbacks, have changed sediment flow patterns and resulted in lower rates of sand accretion at some beaches. Additionally, shoreline walls can increase wave energy in the shallows, making the habitat inhospitable for juvenile fishes. Because of the pre-storm anthropogenic impacts, coastal areas may recover less effectively than if they had been in a healthier state before the storm. It is estimated that the coastline of Puerto Rico is eroding at a rate of one meter a year, although not uniformly (Puerto Rico Climate Change Council (PRCCC), 2013). Sea level rise, continued human development, and increasing storm intensity are all expected to worsen damage to Puerto Rico's beaches.

Hurricane damage

While limited systematic data have been collected on damage to coastal resources resulting from the 2017 hurricane season, priority sites (based on economic and ecological value) have been assessed. During a hurricane, pollutants, debris, and sediment enter the ocean, damaging and disrupting the ecosystems by covering seagrasses and reef systems and altering the hydrology of these systems in ways that can lead to additional damage and long-term impacts to eco-system function. Large quantities of freshwater entering the ocean will carry sediment, pollutants, and excessive debris to ocean systems, altering pH, salinity, and turbidity. Sewage systems can also experience disruptions and cause contamination of inland and coastal areas, water resources, and

recreational sites such as beaches. On the coast, strong wave action and storm surges induced by high winds may structurally damage corals and mangroves, scour seagrass beds, and erode beaches.

A rapid assessment found that Hurricane Maria significantly impacted wetland buffers and increased wetland stress severely for forested wetlands, and less so for emergent wetlands in 20 sites on the island. Seventy-five percent of these sites had an increase of stress, mostly due to changes in hydrology or debris, and tree defoliation, disease and damage. General hurricane impacts also included changes in biodiversity, invasive species, and a change in the proportion of various types of vegetation (Soler-Figuero and Ambienta Inc, 2018). Mangroves were damaged during Hurricane Maria due to high winds, flooding, debris, and hydrologic damage. There were multiple incidents of private vessels getting caught in mangroves and causing damage to the mangrove communities when owners extracted their boats.[147] Results of a post-hurricane assessment that was performed in April of 2018 at five sites (chosen based on expert input and the economic and infrastructural importance of the locations) found 30 to 95 percent mangrove mortality across sites, and less than 0.001 to 0.05 square miles of total vegetation loss (Interagency Coastal Resource Working Group, 2018).

Dunes experienced damage in the form of erosion, breaching, and loss of vegetation, especially in areas where there were high levels of foot and vehicular traffic and illegal sand extraction. Damage to dune systems due to Hurricanes Irma and Maria in 2017 and the northeasterly swells in 2018 were assessed at 24 high-priority sites on the north coast of the island in the following municipalities: Isabela, Camuy, Hatillo, Arecibo, Manatí, Dorado, and Luquillo (Mayer et al., 2018).[148] Results of these assessments confirmed that sites were degraded due to heavy foot and vehicle traffic and illegal sand extraction, which prevented the growth of stabilizing vegetation (Mayer et al., 2018). An assessment of vegetation at three sites following Hurricane Maria and a repeat assessment following 2018 winter storms confirmed that vegetation cover and sand volume had further decreased after the 2018 winter storms (Mayer et al., 2018). Baseline data collected during this assessment will allow future quantitative monitoring of vegetation and sand quantity on the sites studied.

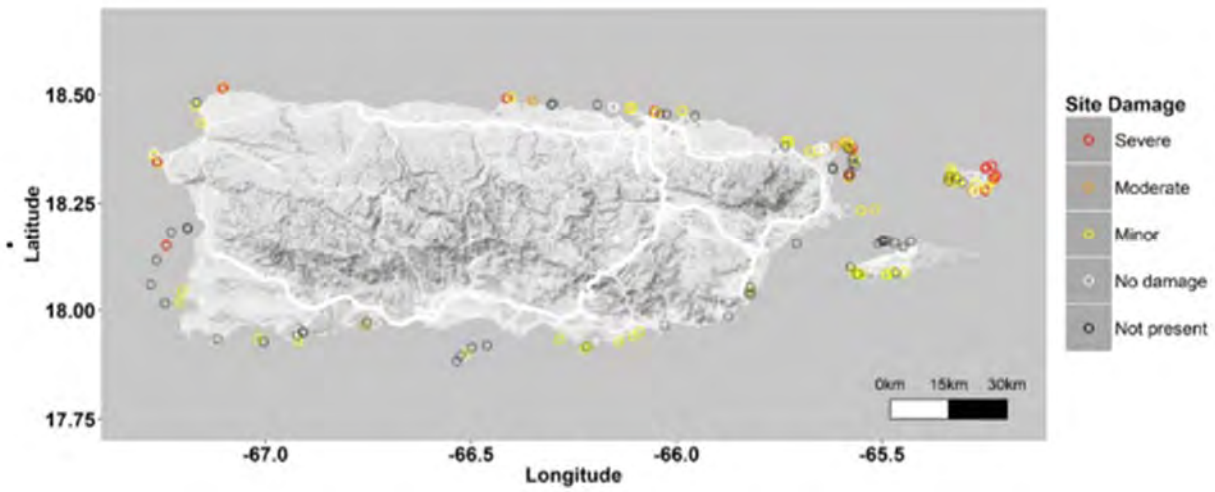
Corals and seagrasses serve as natural buffers to inland areas during hurricanes. Following Hurricane Maria, corals, especially those in shallower waters, have been damaged and broken off (and those triaged for likelihood of survival are being reattached). Preliminary assessments indicate moderate to severe coral reef damage in the areas of Culebra, Vieques, and the northwest coast of Puerto Rico. Over 0.15 square miles of coral reef at 153 sites were assessed for storm damage (Figure 9.7). There was high variability in the level of damage, with some sites

[147] Private email communication between Hal Frave, NOAA and Nilda Jimenez and Steven Wall, NOAA. 2 March 2018.

[148] Dune sites that were not assessed because of time and funding limitations include: Aguadilla, Barceloneta, San Juan, Carolina, and Culebra.

showing 100 percent damage, and other locations displaying little to no damage. As can be expected, those reefs on the path with the most storm energy (northeast, north and western parts of the island and Vieques and Culebra) displayed the most damage; an average of 11 percent or approximately 21 square miles of reefs in Puerto Rican waters were damaged in the storms (National Oceanic and Atmospheric Administration, 2018a). The most severely impacted species of coral were those that are most valuable for building reef structure and Endangered Species Act (ESA)-listed corals. Only 20 percent of broken reefs have been stabilized.

Figure 9.7. Sites Assessed for Coral Reef Damage



Source: (National Oceanic and Atmospheric Administration, 2018a)

Many of the same factors that damage coral reefs will also damage seagrasses. In Puerto Rico, data about pre-storm seagrass habitat was not available on the same scale as data about coral reefs, so the HSOAC team used remote sensing. To determine damage, researchers assessed locations based on freshwater discharge points (pollution and sedimentation issues), eroding shorelines (increased wave energy and sedimentation), hurricane-related vessel groundings (uprooting and physical scarring of seagrasses), high reflectance areas (can indicate bare seafloor), and previously identified vulnerable areas (Kaufman, 2018). Figure 9.8 summarizes probable and possible areas of seagrass damage based on remote sensing. The total probable damage to seagrasses totaled 51.9 acres (Kaufman, 2018).

Figure 9.8. Locations with Probable and Possible Seagrass Damage

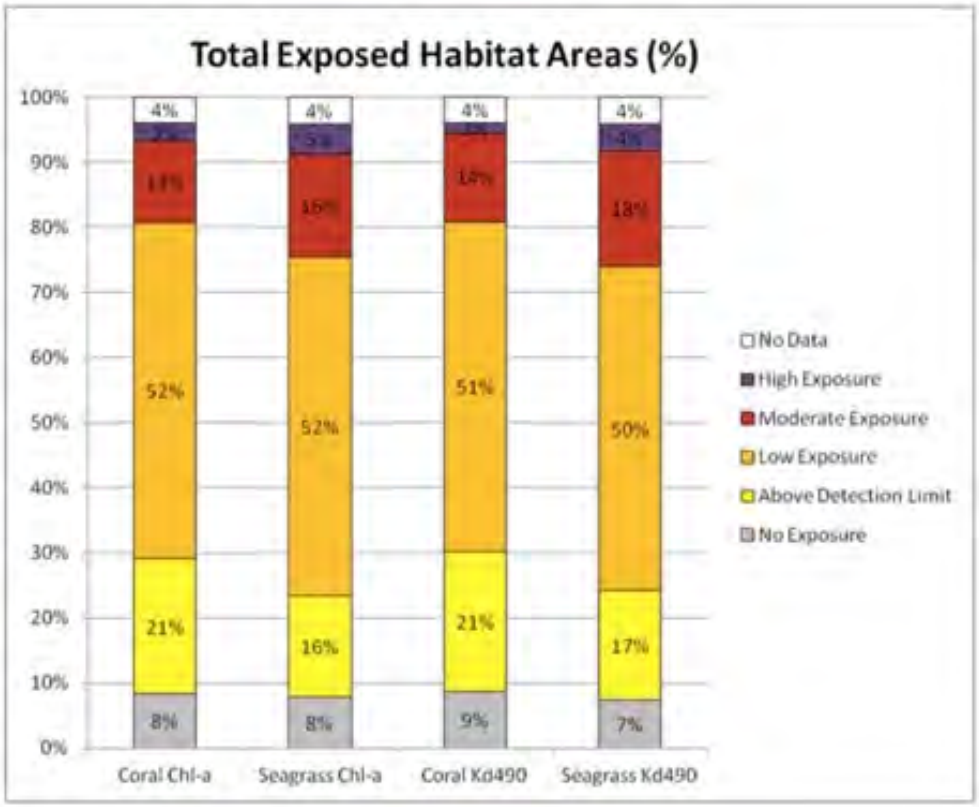
Source: (Kaufman, 2018)

In addition to physical damage, coral reefs and seagrasses also experienced post-hurricane stress caused by diminished water quality from excessive sedimentation, sewage, and other pollutants. Remote sensing was used to detect additional damage indicators to coral reefs and seagrasses. In spring of 2018, NOAA used remote sensing techniques to assess levels of chlorphyll-a (chl-a) and Kd-490. Chl-a is used to measure the amount of chlorophyll produced by phytoplankton in a system. If chl-a levels are low, that means the system does not have a significant amount of organic matter and is generally not considered a productive system; for some ecosystems, this is a normal state. Kd-490 is a diffuse attenuation coefficient, which measures how well light penetrates a water column and is used as a proxy for turbidity. A highly turbid system inhibits photosynthesis of seagrasses, and can indicate high sediment levels, which can reduce both sunlight and oxygen access for seagrasses and corals—essentially smothering the ecosystems (Hernandez, 2018b).

Figure 9.9 below summarizes the results on the remote sensing analysis, showing that between 16 and 22 percent of coral reefs and seagrasses were exposed to moderate to high levels of chl-a and Kd-490. It is thought that it takes approximately eight years for a coral reef to recover from storm damage, so if hurricanes occur more frequently than coral reefs are able to recover, it can be expected that hurricanes will cause long-term degradation to coral reef systems (Puerto Rico Climate Change Council (PRCCC), 2013). Moreover, stressed seagrass beds are at risk of being overrun by opportunistic invasive species.[149]

[149] Personal communication with Dr. Brent Murry, June 8, 2018.

Figure 9.9. Percentage of Coral Reefs and Seagrass Habitats Exposed to Varying Levels of Chl-a and Turbidity



Source: (Hernandez, 2018b)

The loss of function from damaged coral reefs and seagrasses, particularly in the areas off the coast of San Juan, Fajardo, Rincon, Culebra and other urban and tourist areas, could put important cultural sites and infrastructure at greater risk from future storm flooding. Fish and other wildlife that depend on these areas for habitat may also have been impacted due to excessive sedimentation and habitat loss. After Hurricane Maria, Scripps Institute for Oceanography reported that Mosquito Bay and Laguna Grande lost their phosphorescence due to levels of freshwater runoff and high winds, and they have since recovered. Bahía Fosforescente experienced minimal impacts from the hurricanes (Scripps Institution of Oceanography and Latz Laboratory, 2017).

Post-hurricane conditions

NOAA began a large-scale coral reef assessment at the end of February 2018. In an effort to mitigate against loss of and additional damage by loose corals, coral pieces were reattached to damaged reefs during the assessment process to increase their probability of survival (National Oceanic and Atmospheric Administration, 2018a). As of May 8, 2018 over 5,400 corals had been

successfully triaged and reattached (National Oceanic and Atmospheric Administration, 2018a). Triage sites were all ranked as having both severe damage and significant numbers of live, broken fragments or unattached colonies. The majority of triage work occurred in the northeast, at Culebra and Vieques and in the north. An additional risk to coral reefs during and after a hurricane are the high levels of sediment and runoff that enter marine systems, combined with an increase in turbidity.

Beach erosion assessments are underway, and are some of the most complete assessments of natural resources damage currently in progress. These types of assessments occur on a somewhat ongoing basis due to the visibility and relevance of beaches close to inhabited areas, as well as their use for recreation and as a sea buffer.

On February 9, 2018, the U.S. Secretary of Commerce declared a fisheries disaster in Puerto Rico as a direct result of the 2017 hurricane season (U.S. Department of Commerce Office of Public Affairs, 2018). Declaring a fisheries disaster means that Puerto Rican fishermen are eligible for Small Business Administration disaster loans, FEMA public assistance, Economic Development Administration grants, and Department of Housing and Urban Development Community Development Block Grant-Disaster Recovery funds (U.S. Department of Commerce Office of Public Affairs, 2018). Details on the economic impacts of the 2017 hurricanes are in Chapter 5.

Forestry and key species

Background

History and structure

In 2009, Puerto Rico had 118 natural areas, including federal reserves, Commonwealth forests and refuges, and non-government conservation areas. El Yunque National Forest (EYNF) in the Luquillo Mountains is the largest conservation area in the Commonwealth (11,336-hectares (28,000 acres)). Puerto Rico has 14 Commonwealth forests, which are operated under the principles of multiple-use resource management. All have trail systems, and some have well-developed bike trails and camping facilities.

Most forested land (about 85 percent) is owned by private landowners, followed by the Commonwealth of Puerto Rico (11 percent), and a small percentage managed by federal agencies. This diverse ownership is an important consideration for managing the recovery of Puerto Rico's forests after Hurricane Maria.

Table 9.5. Forested Area in 2009 for Puerto Rico by Ownership Class

Ownership Class	Forest Area (miles^2)
U.S Forest Service	42.3
U.S. Fish and Wildlife Service	18.4
Dept. of Defense/Dept. of Energy	10.4
Commonwealth	210.8
Non-industrial private	1613.8

Sources: (Brandeis and Turner, 2013)

An assessment of protected areas for the Puerto Rico Gap Analysis Project[150] identified 90 stewardship areas, with 77 managed in some way for conservation. Of these areas, 59 percent were managed by Puerto Rico Commonwealth agencies, 30 percent by federal agencies, and 11 percent by other organizations. However, an important finding of this project was that management plans for many of these stewardship areas either do not exist or are outdated and do not adequately reflect current conditions. The inventory of protected areas through the Gap Analysis Project has undergone a comprehensive review of their management status through a partnership of multiple stakeholders and the Caribbean Landscape Conservation Cooperative (CLCC), known as the Protected Areas Conservation Action Team (PA-CAT) (Commonwealth of Puerto Rico Department of Natural Resources, 2016). The current spatial distribution of protected areas is shown in Figure 9.10 below.

[150] The Puerto Rico Gap Analysis Project (PRGAP) was an effort to identify conservation "gaps" by gathering information using established methods on Puerto Rico's land cover, vertebrate occurrences, natural history, and land stewardship to determine the degree to which animal species and natural communities are represented in conserved lands. For more information on the analysis go to: https://data.fs.usda.gov/geodata/other_fs/IITF/index.php

Figure 9.10. Land Stewardship of Terrestrial Natural Protected Areas in Puerto Rico

Source: (Puerto Rico Department of Natural and Environmental Resources, 2015a; Gould et al., 2008)

Key assets

Forests and other natural areas

Approximately 53 percent of Puerto Rico was covered by woody vegetation (forests, woodlands, or shrublands) in 2000, the most recent data available across vegetative types (Figure 9.11) (Gould et al., 2008). Forests and other natural areas in Puerto Rico have undergone substantial changes over the past few centuries. The clearance of land for agricultural development was associated with widespread deforestation, which also has implications for the extent and quality of habitat for many threatened and endangered species. This pattern of forest clearance has been followed by the regeneration of many forests with Puerto Rico's transition towards a more industrialized economy after World War II (Commonwealth of Puerto Rico Department of Natural Resources, 2016).

Figure 9.11. Distribution of Forest Cover in 2000 with Locations of Conservation Priority Areas

SOURCE: (Puerto Rico Department of Natural and Environmental Resources, 2015a; Gould et al., 2008)

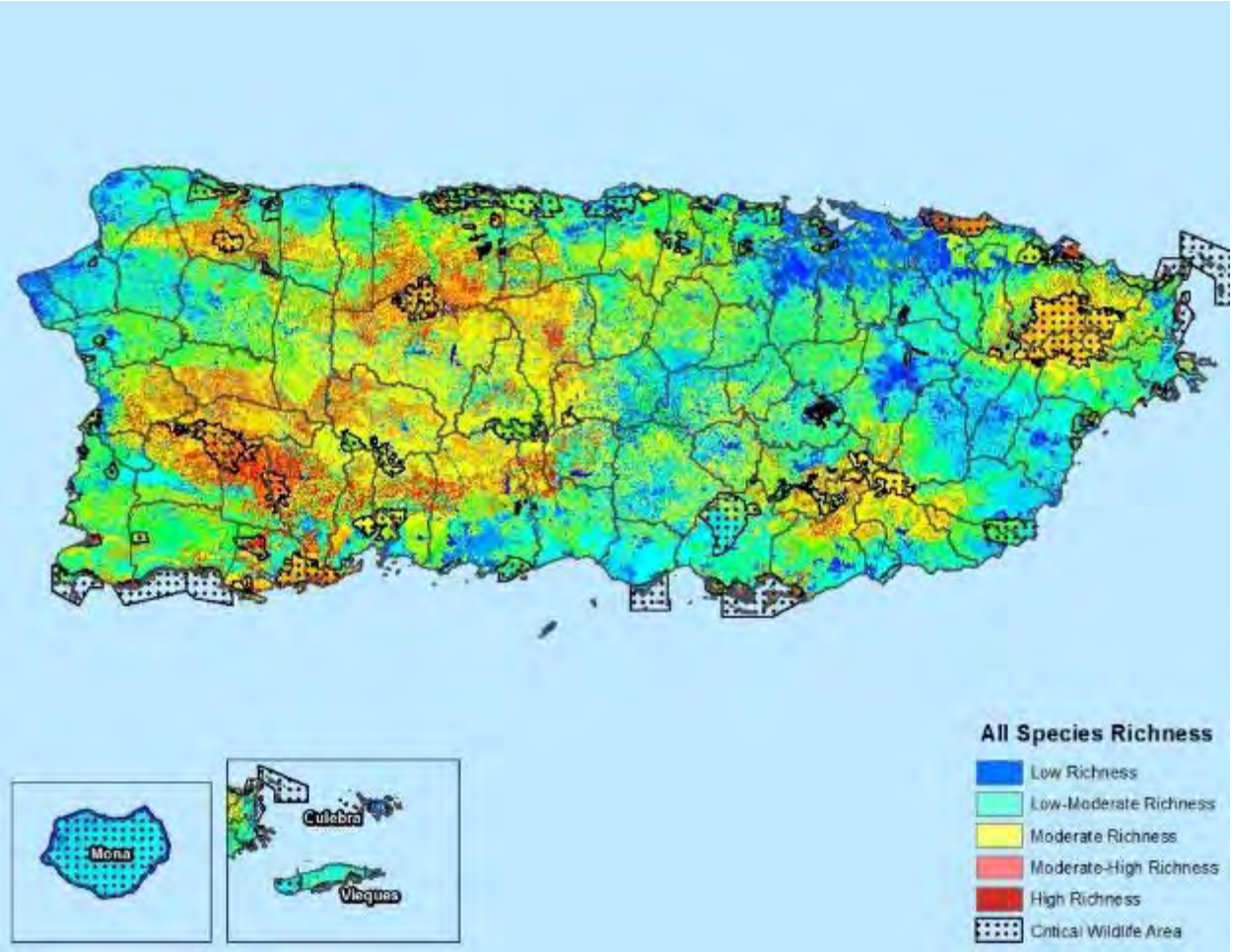
Threatened and endangered species

Puerto Rico, like many tropical islands, has rich biodiversity with many endemic species that are at risk of extinction (Figure 9.12). According to USFWS, Puerto Rico has federally listed 13 threatened species, 58 endangered species, and six at-risk species (Conservation in Puerto Rico, undated). Puerto Rico has also identified an additional 239 species that are of greatest conservation need.

Biodiversity refers to the biological variety important for maintaining ecosystem, habitat, and species health. Healthy ecosystems provide ecosystem services, such as water and air purification, carbon dioxide sequestration, and temperature regulation; natural protection and increased resiliency against storm surges, floods, and hurricanes; and mitigation against landslides, soil erosion and sedimentation. Food production relies on biodiversity for a variety of foods and for pollination, pest control, nutrient provision, genetic diversity, and disease prevention and control. Thus, biodiversity also provides economic benefits by contributing to productive agriculture, forests, and fisheries; and providing recreation and tourism opportunities.

Another effect of this reduced diversity is that the number of threatened and endangered species will likely increase and some existing species likely will go extinct.

Figure 9.12. Total Species Richness (amphibians, birds, mammals, and reptiles) with Critical Wildlife Areas



SOURCE: (Puerto Rico Department of Natural and Environmental Resources, 2015a; Gould et al., 2008)

Pre-hurricane conditions

Before Hurricane Maria struck, multiple ongoing issues were affecting Puerto Rico's forests and wildlife. Examples of ongoing problems include urban and suburban development pressures, lack of sustainable land use planning, invasive species threats, forest and other habitat fragmentation, climate change, wildfires, pests and diseases, and impacts from economic challenges (Puerto Rico Department of Natural and Environmental Resources, 2015a; ReImagina Puerto Rico, 2018). Problems that affect threatened and endangered species and other species of greatest conservation need include invasive species, changes in habitat availability or accessibility, impacts from natural events, pollution, small or scattered populations in fragmented

habitats, and lack of environmental management organizational and enforcement capacity (Adams, 2018). These issues range across spatial and temporal scales, from longer-term pressures (such as climate change) to short-term shocks (such as droughts or hurricanes), and island-wide (such as sustainable land use planning) to more localized issues (such as invasive species threats). Further, many of these issues are interrelated and individual impacts cannot easily be separated.

A range of management strategies have been developed and implemented to address such concerns. For example, forestry sector activities include promoting species diversity, maintaining habitat connectivity, reducing the impact of invasive species, developing comprehensive economic and conservation plans. Ongoing management approaches by DNER to address wildlife problems, as described in the *Puerto Rico State Wildlife Action Plan,* have included identifying and addressing the greatest conservation needs of Puerto Rico's fish and wildlife population, identifying habitats of greatest conservation need, creating and enhancing biological corridors, trying to eradicate invasive species, applying landscape-scale conservation and habitat restoration tools, and working with local, NGO, and federal agency partners to conserve, protect, and enhance Puerto Rico fish and wildlife habitat and species (Puerto Rico Department of Natural and Environmental Resources, 2015a; Commonwealth of Puerto Rico Department of Natural Resources, 2016). Pre-existing action plans such as these serve as useful guides for understanding the status of Puerto Rico's forests, habitats, and species of greatest conservation need, and for identifying potential recovery strategies following Hurricanes Irma and Maria.

Forests and other natural areas

Forest cover has increased rapidly over the past few decades, from 702,000 acres in 1980 to 1,698,000 acres in 2009 (Commonwealth of Puerto Rico Department of Natural Resources, 2016). This regeneration of Puerto Rico's forests is reflected in the age structure of forests, with 68 percent classified as young secondary forests and 12 percent as mature forests. The composition and structure of these secondary forests, which include native and non-native species, will likely change as they follow different successional pathways (Commonwealth of Puerto Rico Department of Natural Resources, 2016).

However, Puerto Rico's forests faced several challenges before the hurricanes. A 2009 assessment found that 62.0 percent of trees with diameter at breast height (d.b.h.) greater than five inches showed some sign of damage or disease, mostly due to conks, fungus, or other signs of advanced decay (Brandeis and Turner, 2013). Ongoing priority issues for the management of forest systems included forest fragmentation, ecosystem services that forests provide for water resources, natural and anthropogenic disturbances, invasive species, and economic opportunities (Commonwealth of Puerto Rico Department of Natural Resources, 2016).

The USFS National Reforestation, Nurseries, and Genetic Resources team (RNGR) visited all known tree nurseries operating in Puerto Rico in 2003 and 2007, along with more recent

follow-up visits. Prior to the storm, there were 14 nurseries on the island, 11 were operated by the Commonwealth and 3 were operated by private sector.

Threatened and endangered species

In addition to the federally listed 13 threatened species, 58 endangered species and six at-risk species (Conservation in Puerto Rico, undated), DNER has identified many more species of concern, just as many states do. DNER has identified 316 species of greatest conservation need (SGCN) using five categories from the International Union for the Conservation of Nature (IUCN) Red List to classify priority species (Puerto Rico Department of Natural and Environmental Resources, 2015a).[151]

Key threatened and endangered species identified by the DNER, USFWS and other federal agencies for assessment because of damage to their habitat and risk from opportunistic invasive species include the:

- Puerto Rican plain pigeon (*Patagioneas inornata wetmorei*)
- Puerto Rican sharp-shinned hawk (*Accipiter striatus venator*)
- Elfin-woods warbler (*Dendroica angelae*)
- Puerto Rican parrot (*Amazona vittata*)
- Yellow-shouldered blackbird (*Agelaius xanthomus*)
- Virgin Islands (VI) boa (Chilabothrus granti)
- Gesneria Pauciflora
- Puerto Rican crested toad (*Peltophryne lemur*, Sapo Concho)
- Puerto Rico harlequin butterfly (*Atlantea tulita*, Mariposa Arlequin)

Hurricane damage

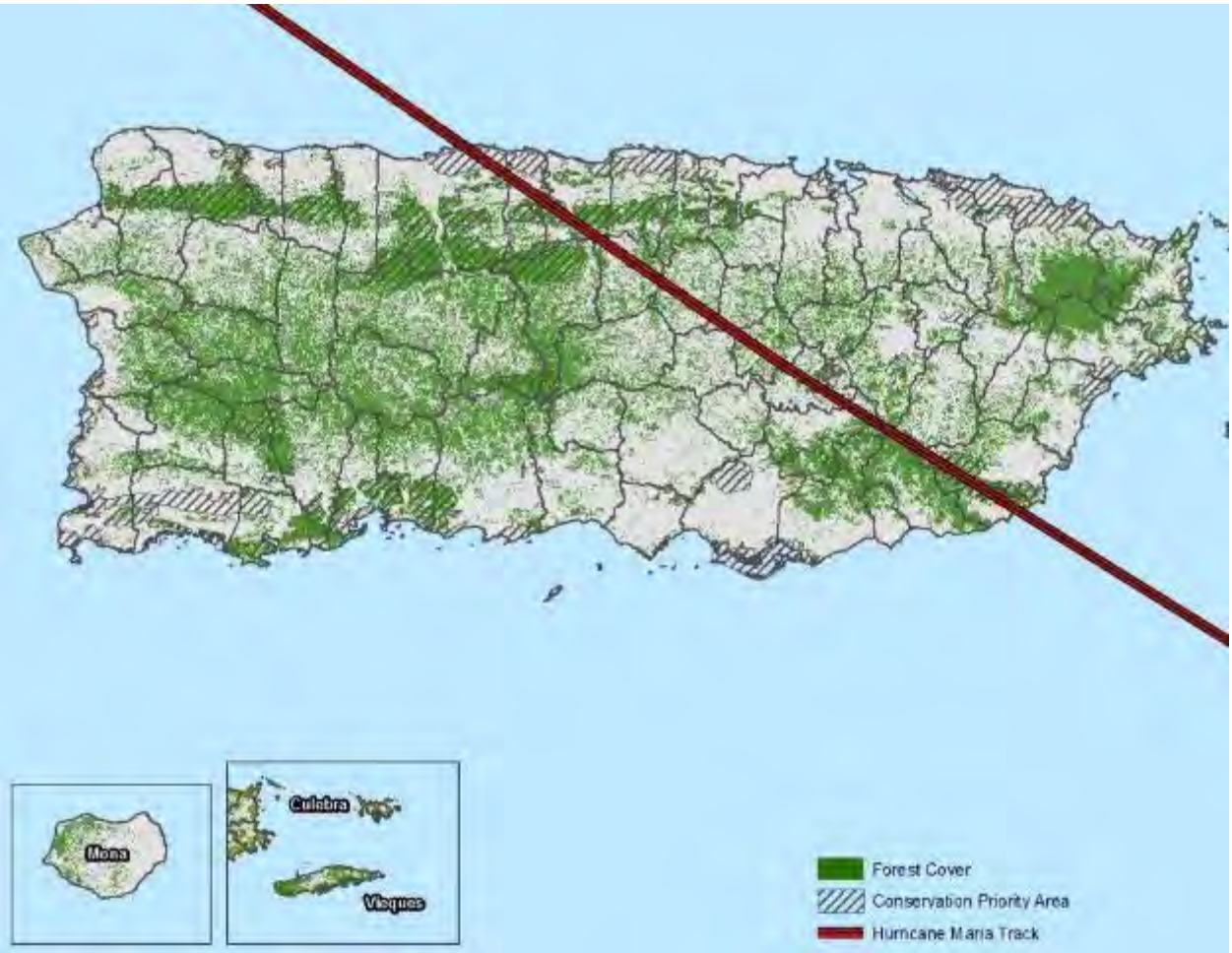
Forests and their inhabitants are at great risk in hurricane conditions. High winds can change the shape of the forest canopy by downing trees or stripping them of their leaves, creating debris, and altering the number and species of trees in the forest. Forests and other areas can also be reshaped by landslide activity in response to intense rainfall. Animals that survive the storm are affected by the change in forest structure, which may reduce overall food supply and increase competition for what remains.

Forests and other natural areas

Figure 9.13 shows the path of Hurricane Maria over Puerto Rico's forested areas and natural protected areas.

[151] These categories are Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Low Risk (LR), Data Deficient (DD). See Appendix A, Table A.X for definitions. (Puerto Rico Department of Natural and Environmental Resources, 2015a)

Figure 9.13. Path of Hurricane Maria Over Puerto Rico's Forested Areas and Natural Protected Areas



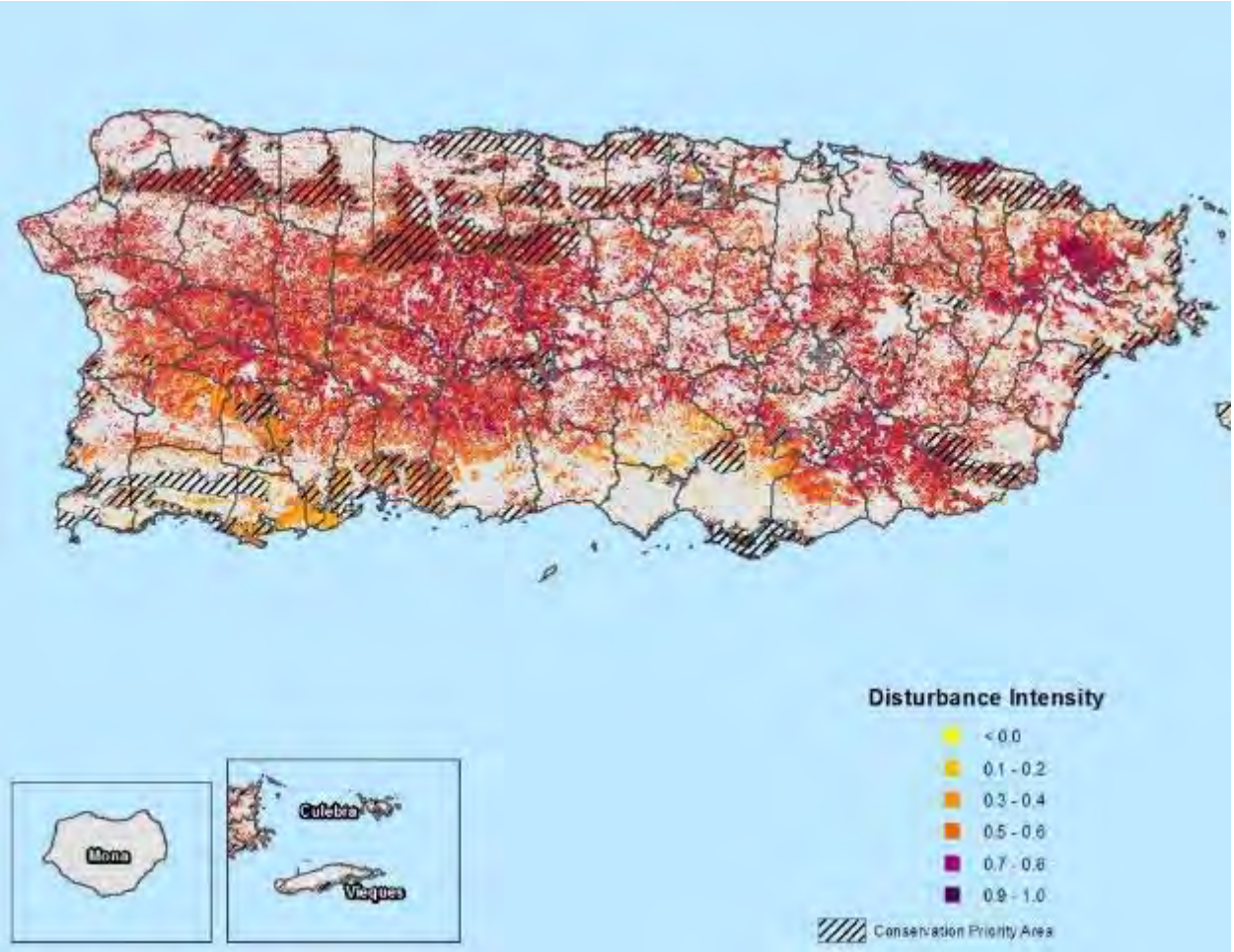
Source: (National Hurricane Center, 2018; Gould et al., 2008; Puerto Rico Department of Natural and Environmental Resources, 2015a)

Widespread damage to forests has affected forest functions that support plant and animal habitats, provide ecosystem services, and offer recreational and tourism opportunities. This has also increased the potential for more stormwater runoff, landslide risk, and additional sedimentation within waterways, water storage reservoirs, and utility systems. Damage assessments will estimate the impact of the hurricanes on multiple aspects of forest functioning, including island-wide changes in forest structure, impacts on urban forests, and damage to tree nurseries that are needed to support the recovery process.

A rapid assessment of damage to forests across Puerto Rico used Landsat 8 satellite observations to measure changes in photosynthetic capacity as an indicator of tree damage, suggesting that Hurricane Maria caused mortality or severe damage to between 23 and 31 million trees across Puerto Rico (Figure 9.14) (Feng et al., 2018). More-targeted remote sensing analysis in El Yunqué National Forest indicates severe damage to most of the 28,400 acres of the national

forest, confirming earlier reports of large-scale tree canopy defoliation (Finer and Olexy, 2017). However, more-comprehensive island-wide assessments using LiDAR data and field sampling are ongoing; these will provide greater visibility into the extent and severity of long-term damage to forests, (Cook et al., 2013; Keller, 2018). Preliminary results based on LiDAR observations in Rio Abajo State Forest and El Yunqué National Forest suggest average declines in canopy height of 6-7m since 2017.

Figure 9.14 Map of Disturbance Intensity, Measured by the Change in Non-Photosynthetic Vegetation (NPV) for Forested Areas in Puerto Rico, along with Locations of Conservation Priority Areas.



Notes: Darker shades of red represent more intense disturbance (Fang et al., 2018); (Puerto Rico Department of Natural and Environmental Resources, 2015a)

The impact of the hurricanes on urban forests was measured in three selected urban areas using field surveys and remote sensing data. It was found that tree cover declined by 25 percent in San Juan, six percent in Ponce, and four percent in Mayaguez. The total area of tree cover lost was highest in Ponce (5.8 miles^2), then San Juan (4.2 miles^2) and Mayaguez (1.5 miles^2). Tree

cover losses, impacts on ecosystem services, and costs to replace damaged urban forests are in Table 9.6.

Table 9.6. Impacts of Hurricanes Irma and Maria on Urban Tree Cover and Ecosystem Services

Municipality	Current Tree Cover (%)	Pollution Removal (t/yr)*	Carbon Storage (kt/yr)**	Carbon sequestration (kt/yr)
San Juan	25.7	320.3 ($1.10M)	1073.2 ($41.7M)	70.64 ($2.75M)
Ponce	67.6	170.3 ($846,000)	627.0 ($24.3M)	41.2 ($1.6M)
Mayaguez	61.1	93.5 ($467,000)	337.49 ($13.1M)	22.1 ($860,000)

* tonnes (t) = 1000 kg; ** kt = 1 M kg; Source: (Melendez and Ackerman, 2018)

Preliminary assessments of built structures in parks indicate structural damage to offices, gazebos, piers, restrooms, and lookouts. Trails were damaged, and significant amounts of debris blocked access to trails and facilities (Adams, 2018).[152] Further, tree nurseries sustained substantial structural and operational damage, and it is believed that they cannot support island-wide tree planting efforts with native tree species in the current state (Hernandez, 2018a).

After Hurricane Maria, vegetative debris caused road and trail closures in public areas and flooding hazards or barriers to aquatic species when caught in stream barriers. In state forests, natural reserves, ecological corridors, and wildlife refuges listed in the DNER Natural Area Response Needs, most locations note that access to some or all the sites were obstructed by vegetation or debris (Adams, 2018). In addition to vegetation, other categories of debris include marine, construction, and household waste (including hazardous materials).

Threatened and endangered species

Puerto Rico has many federally listed threatened and endangered species and other species in need of conservation. In addition, Hurricane Maria caused damage to species habitats, causing plant and animal mortalities, modifying microclimates, changing seeds and seedling bank dynamics, and exposing these endemic species to negative effects from opportunistic invasive species. For example, in bird population surveys based on comparisons before and after the hurricanes, two threatened and endangered species, the Sharp-shinned hawk and Puerto Rican plain pigeon, had population declines of over 50 percent (Vilella and Gallardo, 2018; Vilella and Weitzel, 2018). Extensive landslides, especially in some mountain areas, also destroyed forests and other habitats, including contributing to a 70 percent mortality rate in known populations of

[152] Please refer to "Forests and Other Natural Areas" section for specific trail closures.

Gesneria pauciflora, a threatened plant species (Perez and Melendez-Ackerman, 2018). Beach erosion directly and indirectly impacted sea turtle nests and nesting grounds: 53 percent of the hawksbill sea turtle nests at Humacao Nature Preserve were lost due to the storms. Some species and habitats suffered more than others and, unfortunately, there is a lack of information for many of the over 315 SGCN to determine the extent of these effects.

Other Natural Resource Impacts: Landslides and waste management

Background

Other hurricane impacts on the natural environment of Puerto Rico include landslides and waste management issues (including issues related to storm debris removal), and are discussed in this section. There are several distinct natural resource-related issues that result from resource management and conservation practices. For example, poor land-use planning and deforestation may contribute to excessive sedimentation and landslides. Resource use, as well as solid waste and landfill management, are inextricably linked to debris deposition and water quality, which in turn present risks to human health and built infrastructure due to flooding and pollution.

Pre-hurricane conditions

In Puerto Rico, previous studies have examined different categories of landslides that have occurred in the past, including rainfall-triggered debris flows, shallow soil slips, and slumps. Particular areas in Puerto Rico that are especially vulnerable to landslides include steep mountainous areas (>12° in gradient), high elevations (>300 m) associated with greater mean annual rainfall, areas exposed to intense storm tracks, and a legacy of human land use (Larsen and Torres-Sanchez, 1998).

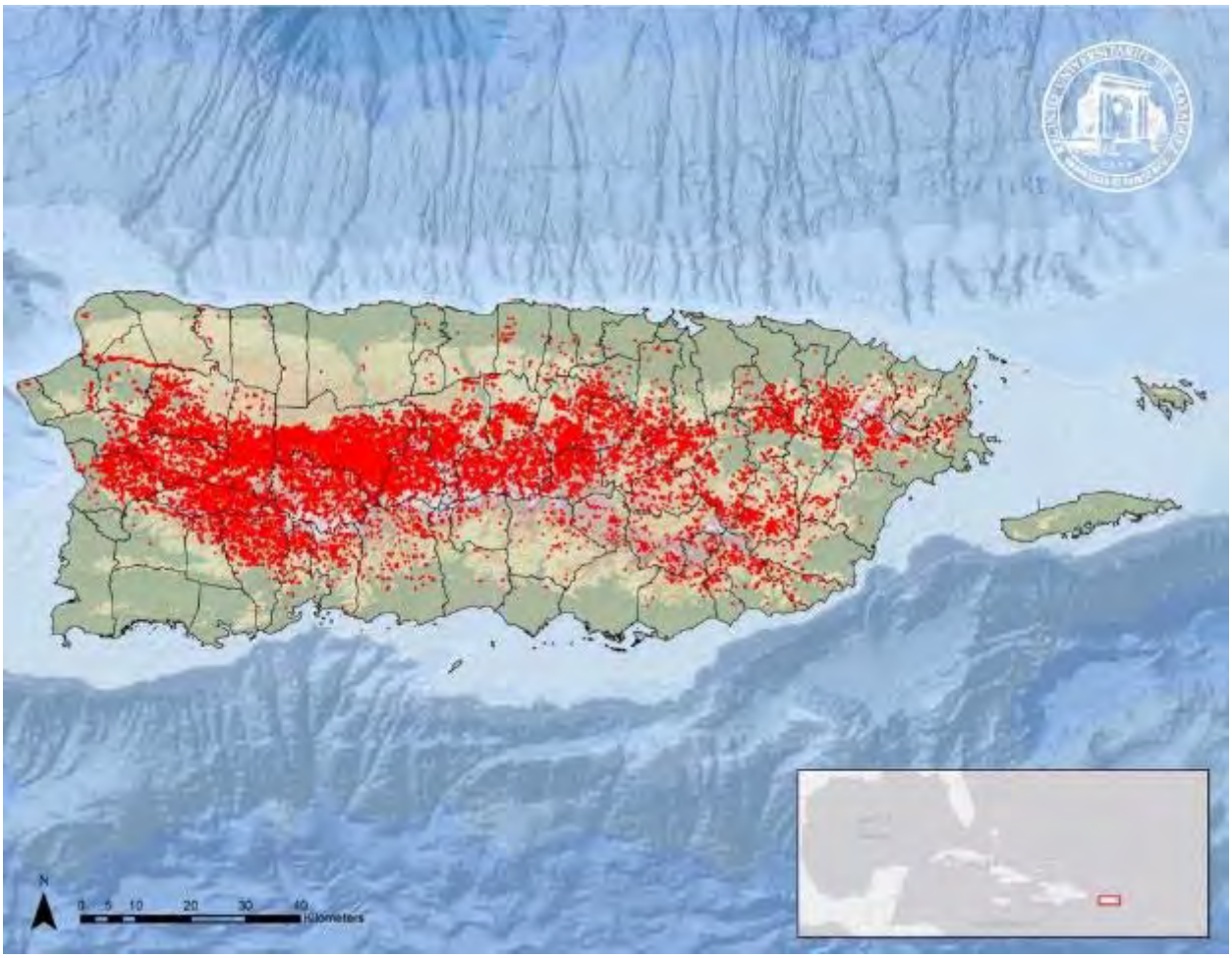
Solid waste management in general has been an ongoing issue in Puerto Rico. Since 2002, the EPA has been assisting Puerto Rico in implementing recycling programs, reducing greenhouse gas emissions at landfills, and improving landfill operations. Before Hurricane Maria, Puerto Rico had 29 operating landfills, most operating beyond capacity and only ten were operating disposal cells in compliance with EPA regulations (U.S. Environmental Protection Agency, 2016a). Pre-hurricane assessments of the landfills in Puerto Rico found that 15 were open with remaining capacity and 16 had limited to no capacity (one of which is closed and one is no longer operating) (Plossl, 2018a; Plossl, 2018b). Of these landfills, five are in karst landscapes (porous soils, putting aquifers at risk of chemical leaching), 14 could impact wetlands and waterways, four are in floodplains, nine could impact drinking water supply, five could impact natural reserves, 12 could impact federal endangered species, 21 had medium-to-high landfill gas potential, and eight were close to homes or schools (Plossl, 2018c).

Hurricane damage

Landslides are a persistent threat to human lives, property, tourism, agricultural and natural resource productivity, and natural habitats around the world. Irma and Maria led to landslides in the interior part of Puerto Rico, resulting in blocked roads, increased sedimentation in reservoirs and behind dams, disruptions to species habitats, and creation of debris. Areas in Puerto Rico that are especially vulnerable to landslides include steep mountainous areas and areas exposed to intense storm tracks as well as areas that have been heavily modified by human use, such as formerly forested areas that have been cleared for agriculture or roads (Larsen and Torres-Sanchez, 1998). The United States Geologic Survey (USGS) released a preliminary geospatial database of landslides associated with Hurricane Maria, based on analysis of high spatial resolution satellite imagery. This analysis found that the density of landslide events reached more than 64.7 per square mile in some parts of the main island. Most landslides were clustered in the steeper topography in the central part of the island, triggered by heavy rainfall during Hurricane Maria (Bessette-Kirton et al., 2017).

In addition to the preliminary damage assessments performed by USGS, researchers at the University of Puerto Rico completed more-detailed mapping assessments of landslide occurrence due to the hurricanes. They delineated more than 40,000 individual landslides across the island using high-resolution imagery from FEMA, NOAA, and Digital Globe (Figure 9.15) (Morales Valez and Hugher, 2018). An image of a landslide in Barranquitas is shown in Figure 9.16. The researchers also identified specific areas that were significantly impacted by landslides. For example, they estimated close to 15,000 landslides in the upper Rio Grande de Arecibo drainage basin, which supplies part of the drinking water supply to the San Juan metropolitan area (Morales Valez and Hugher, 2018). Although these reservoirs were filling with sediment before the hurricanes, landslides exacerbated this environmental issue and added an estimated 30 million cubic yards of sediment potential to the watershed, enough to fill 22 Empire State Buildings (U.S. Department of Agriculture, 2018). Landslides have been reported in areas such as the Maricao Forest, which likely damaged habitat for endangered species such as *Gesneria puaciflora*. Planned damage assessments with LiDAR data will be used to evaluate the impact of landslides on forest structure (Adams, 2018).

Figure 9.15. Concentration of landslides caused by Hurricane Maria



Source: (Morales Valez and Hugher, 2018)

Figure 9.16 Photograph from the Civil Air Patrol showing impacts of landslides on road networks in Barranquitas

Source: Images courtesy of Civil Air Patrol.

The hurricanes caused varying degrees of damage on the structural integrity of sanitary landfill systems (SRS) and open dumps, which includes erosion, water channeling, debris, slope instability, landslides, damaged roads, or structural damage ("Sanitary Landfill Systems (SRS) and Open Dumps in Operation in Puerto Rico,"). Puerto Rico's Solid Waste Authority estimated that the storms created 6.2 million cubic yards of waste and debris, enough to fill about 43 football stadiums with waste eight stories high (Kennedy and Migaki, 2017a). Not accounted for in these assessments is the potential demand for additional capacity as demolition proceeds of buildings and structures that were either severely damaged by the storms, or are located in floodways. Response operations have been focused on debris removal and composting of organic material. It is also possible that storm effects have destabilized landfill integrity, risking pollutant discharge through hazardous gas emissions, leaching of toxic chemicals into the soil and water, and unstable slope management. The HSOAC team still requires information on the extent of illegal open dumps across the island (estimated at 1,600-2,000 in number), as well as the environmental impacts that the hurricane had on the release of toxic or other dangerous materials from the landfills. Assessments of the remaining landfill capacity and potential hazards, including discharges into water features to surrounding areas from pollutant discharge, are ongoing.

Post-hurricane conditions

The U.S. Army Corp of Engineers has been tasked by FEMA with collecting 4.15 million cubic yards of debris, equivalent to 1,258 Olympic-sized swimming pools, from 55 participating municipalities in Puerto Rico (Carrasco, 2018). By May 15, 2018, USACE had collected four million cubic yards of debris. Vegetative debris is turned into mulch, and other materials are sent to recycling centers or landfills, preferably for use as cover material. There is also potential for agriculture to use this material. Precious woods are harvested and made available for future needs, such as commercial sale and for repairs to historic properties. This federal effort does not include 23 municipalities in the Commonwealth of Puerto Rico that opted out and are responsible for removal of an additional 2.3 million cubic yards of debris (Kornacki, 2018b).

The traditional method of vegetative debris removal used by the U.S. Army Corp of Engineers is Air Curtain Incineration (ACI), which burns debris from fallen trees and other vegetation. However, there are concerns in local communities that burning vegetation will emit harmful air pollutants that could have detrimental health impacts on people with respiratory or cardiovascular conditions. In addition, there is concern that burning vegetative debris removes nutrients from soils that plants need to naturally regenerate following a disturbance. Alternatives include composting, mulching, and recovering valuable hardwoods for wood crafts (Lichtenstein, 2017).

Remaining needs and recovery priorities

Given the damage sustained by Puerto Rico's natural resources from Hurricanes Irma and Maria, and the limited number of assessments and repairs conducted to date, there are significant critical needs and challenges will need to be addressed in the recovery process.

Short term

Over the next one to 12 months, priorities include:

- *Restored functionality for coastal resources near human-impacted areas and critical habitats near coasts.* Coastal resources near heavily urbanized or otherwise human-impacted areas could be some of the most fragile, as well as some of the most important, areas to get functioning again to restore coastal protection, tourism value, and other ecosystem services. Critical habitat areas in marine environments and near coasts should also be high priorities. For example, the San Juan Barrier Reef should be managed, priority wetlands restored, and sea turtle restoration projects should be completed before the upcoming nesting season.
- *Completed natural resources damage assessments, as well as assessments of cross-cutting and secondary impacts.* Many damage assessments are incomplete and, as data become available, it may be challenging to extrapolate from specific sites to Commonwealth-wide effects.

- *Identification of areas of focus for reforestation, and mitigation actions to aid threatened and endangered species recovery.* Establishing areas for reforestation, identifying the types of species that are best suited for forest recovery, and instituting conservation corridors will be important steps towards reforestation efforts. Mitigating effects of habitat disruption and impact of invasive species on threatened and endangered species will aid recovery.
- *Data collection to fill key information gaps that could have important environmental quality and human health impacts, such as information on open dumps and landfills or soils data.* Existing information does not include informal data, such as information on open dumps and landfills, which could have important environmental quality and human health impacts. Additionally, the influence of soils as a natural resource category is not fully captured by existing data, except as related to the forestry sector or sedimentation of reservoirs.

Longer term

Over the next one to ten years, Puerto Rico's natural resources require substantial attention in order to be resilient and sustainable over time.

- *New or updated forest and species conservation assessments.* Forest and species post-hurricane assessments face several critical needs. Many species are at risk, and it is not possible to assess and address all of them in the post-hurricane assessment and recovery activities. The number and scope of assessments are limited for several reasons, including the compressed scheduled, lack of funding, lack of baseline data, and gaps in scientific knowledge of how ecosystems and species respond to hurricane disturbances.
- *New strategies for landscape-scale conservation and habitat restoration to help restore, preserve, and increase the resiliency of entire ecosystems and as many species at risk as possible.* A remaining critical need is to integrate the damage assessments to create a focus on landscape-scale conservation and habitat restoration, building partner collaborations, and creating and enhancing conservation corridors to help restore and preserve entire ecosystems and as many species at risk as possible, not just individual threatened and endangered species.
- *Deploy agricultural practices and habitat restoration for interior areas of the main island affected by landslides, as well as restored site accessibility.* Landslides and sedimentation have presented a challenge to the interior part of the main island, resulting in blocked roads, increased sedimentation of reservoirs and behind dams, disruptions to species habitats, and creation of debris. Coastal wetlands and marine environments are also affected by sedimentation carried to the coast.

- *New approaches to address landfill overcapacity challenges.* Pre-existing overcapacity at landfills is an issue being made worse as debris caused by hurricane damage is disposed. The waste generation could quickly overwhelm landfills or create human health hazards.
- *Enhanced resilience of wetlands, mangroves, dunes, and beaches to serve as a natural buffer against future storm impacts.* As the first line of natural buffer against storm impacts, these resources were affected by physical damage, hydrological changes, and erosion activity caused by the storm in addition to being "primed" by human interference beforehand (e.g., building and recreational activities).
- *Invasive species management, especially habitats where invasive species impacts may have been exacerbated by storm damage.* During the peak of flooding during Hurricane Maria, many reservoirs were receiving and discharging more than 2,000 m^3/s of water. This may have altered the balance of aquatic communities and could facilitate the spread of invasive species (Adams, 2018).
- *Improved water quality and new investments to address high rates of sedimentation in freshwater reservoirs and the marine environment (also see Water sector below).* Water quality degradation from high rates of sedimentation and waste water treatment facility discharges likely impacted water quality in freshwater reservoirs, marine sites, and other important ecological areas. Sedimentation could also have impacts on aquatic species in reservoirs that are used for sport fishing (Adams, 2018). In addition, EPA is working to assess damage to toxic chemical sites, which may have released chemicals into the environment and water supply. (See Chapter 12 for additional information concerning Water.)

10. Cultural Resources

Overview

This chapter documents the information available on hurricane damage to Puerto Rico's cultural resources and the pre-hurricane and post-hurricane conditions for this sub-sector. For this assessment, we define the historic, cultural, and recreational sites as archeological sites, historic properties, museums, libraries (both public and school), collections and the landscapes maintained within these sites, performing arts centers, the Puerto Rican National Parks System, community parks, recreational fishing areas, and other publicly accessible wildlife access areas under federal, territorial, municipal, and private ownership. This category also includes the artists and performers themselves. For simplicity, this chapter is organized into four additional cultural resources subsector sections: (a) archaeological and historic sites, (b) museums, libraries, and archives, (c) performing arts, sports facilities, and parks and recreational facilities, and (d) artists and artisans. Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Natural and Cultural Resources" Sector Report.

Because of the breadth of these topics, the Cultural resources subsector intersects with several other sectors described in this report. Puerto Rico's parks and fisheries are important recreational assets and consist of a number of natural resources (e.g., forests, fish, and other animal species), which are discussed in Chapter 9. Additionally, public buildings that also serve cultural purposes (e.g., school libraries) are discussed in Chapter 15 and the economic implications of the 2017 hurricane season (including marine industries and tourism) are documented in Chapter 5.

Given Puerto Rico's rich human history and landscape, there are naturally many significant historic and cultural sites and practices. These span thousands of years, from prehistoric archaeological sites to present-day artists living and working in Puerto Rico. Historic, cultural, and recreational sites and individuals are located throughout the Commonwealth, are integral to the Puerto Rican sense of community, and are a significant draw for tourism.

The federal government, territorial government, municipal governments, and private non-profit organizations are all involved in managing Puerto Rico's cultural, historic, and recreational resources. Table 10.1 shows all the Commonwealth and Federal agencies responsible for cultural resources in Puerto Rico. The maintenance of even one site can require the coordination of several groups. At the federal level, the National Park Service (NPS) is of primary importance, managing the San Juan National Historic Site. The NPS holds the site by fee title, and the site is subject to the rules and protections of U.S.C. Title 54.

The National Register program is administered at the state, territorial, and tribal level by State Historic Preservation Offices (SHPOs). Each SHPO acts on behalf of the Department of the Interior to manage the nomination and review process and to maintain the relevant data and the ACHP's review process. Thus, Puerto Rico's SHPO, the Oficina Estatal de Conservacion Historica (OECH), is responsible for managing the approval process of any federal monies to be used for restoration and preservation, in compliance with both federal and territorial cultural preservation laws.

In 1955, the Government of Puerto Rico established its own organization for the preservation and promotion of cultural heritage: the Instituto de Cultura Puertorriqueña (Institute of Puerto Rican Culture, or ICP). The ICP manages dozens of sites and museums, including the Archivo General de Puerto Rico (General Archive of Puerto Rico) and the Biblioteca Nacional de Puerto Rico (Puerto Rican National Library).[153] The Department of Natural and Environmental Resources (DNER), Department of Sports and Recreation (DRD), the National Parks Company (NPC), and many of the 78 municipalities all maintain portfolios of park facilities. In general, DRD and the municipality portfolios tend to specialize in recreationally focused parks, while DNER maintains a more nature-centered portfolio. However, park ownership is unclear is some cases. Commonwealth agencies have attempted to devolve responsibility (and affiliated costs) for some sites to municipalities with unclear ownership results, and multiple entities may have ownership claims on some portion of the facilities and lands that compose some park complexes. In addition, DNER manages many sites that are not DNER-owned and that instead have some other set of public and/or private owners. For simplicity, we generally lump the National Parks system in with DNER parks in this chapter, even though National Park ownership is in transition, because the DNER nature parks and the National Parks have similar characteristics.

Table 10.1. Agencies Responsible for Cultural Resources

Agency	Role	Relevant Regulations
Federal Agencies		
NPS	Administers National Register; manages the San Juan National Historic Site	NHPA
Commonwealth Agencies		
OECH	Responsible for managing the approval process of any federal monies to be used for restoration and preservation, in compliance with both federal and territorial cultural preservation laws	National Historic Preservation Act (NHPA), 1966 as amended
ICP	Administers territorial-level historic site designation process; sets historic	Law 89 of 1955

[153]It also sponsors programs in all the visual and performing arts and has restored many buildings throughout the territory. It also manages several museums, some of which are located in historic homes, forts, and archaeological sites.

Agency	Role	Relevant Regulations
	preservation regulations; manages historic and cultural sites including museums, theaters, National Library, and General Archive	
DRD	Administers the Puerto Rican National Parks System and maintains roughly 700 community parks across the Commonwealth.	Law 26 of 1980
79 Municipalities of Puerto Rico	Each administers a portfolio of community parks	

Cultural resources play an important role in emergency response and recovery. In times of emergency, stabilization and preservation are the primary responsibilities of every institution concerned with cultural and historic resources. Even if a building is structurally intact, contents of the building may experience damage. Importantly, cultural and historic assets may be more damaged in the aftermath of a catastrophe than during the catastrophe itself. For example, loss of power may not cause problems *per se*, but the resulting loss of climate control can damage paintings and paper objects over the medium to long term. Thus, the immediate concern is always to stabilize the physical environment so that further damage does not occur, including by evacuating certain items.

A secondary cultural resource entities' responsibility is to resume normal operations with respect to the public. While this is ultimately the goal of every sector, cultural institutions can be especially important in maintaining a sense of hope and normalcy while other sectors recover. The reasons for this are twofold. First, because museums invest in the infrastructure necessary to protect their collections, they are often better prepared to resume basic functions after a catastrophe. Therefore, they can offer safe havens, respite, and activities for local citizens who may be dealing with power outages and other damage in the rest of their towns. Second, cultural sites, historic sites, and national parks are a cornerstone of the tourist economy, and the sooner they are able to reopen their doors, the sooner the economy as a whole can begin to recover.

Data Sources and Methods

Data sources

Cultural resources are important assets to the public, representing community, social, and economic value. Table 10.2 summarizes key damage assessment data sources for cultural resources, including historic properties, museums, and artisans.

Table 10.2 Summary of Key Damage Assessment Data Sources

Dataset	Source	Date of Last Update	Evaluation Notes
Historic properties damage assessment forms	In-person assessments	June 1, 2018	Details provided for each building, including monetary and qualitative damage descriptions
Museum damage assessment survey	Survey administered by NCR with aid of AAM	June 1, 2018	
ICP registry of artisans	ICP	March 23, 2018	
FEMA IA Registration Intake	FEMA	March 23, 2018	Lists funding levels by ZIP code and disaster number
Assessment of DNER and DRD-Owned Recreational Sites	TBD		

While Table 10.2 displays a summary of damage assessment data sources, Table 10.3 expands on the approaches that assessments take to better understand the health of cultural resources. The table also includes the expected results of those assessments.

Table 10.3 Summary of Cultural, Historic, and Sports and Recreational Assessment Approaches and Expected Results

NCR Asset/Function	Assessment Focus	Methodology and Sampling Strategy or Goal	Results expected
Historic Properties-SHPO	Historic Properties-SHPO Assessments	2,250 buildings assessed	497 buildings from San Juan, San German, and Aguirre historic districts
Historic Properties-ICP	Historic Properties-ICP Assessments	750 buildings assessed	20 assessments of ICP-administered buildings
Archeological Sites	Archeological Sites Assessment	Sites assessed as part of SHPO and ICP plans listed above	
Museums	Museums Assessment	378 museums received survey to self-report damage; 32 chosen for in-person assessment	32 museums and their collections assessed for damage
Libraries/Archives	Libraries/Archives Assessment	General Archives assessed as part of ICP survey; others received survey to self-report damage	
Arts Organizations	Arts Organizations Assessment	Survey of arts organizations conducted	
Artists	Artists Assessment	Artists surveyed in person, sample based on established registries and recruiting via social networking	
Parks and Recreational facilities	DNER and DRD-Owned Recreational Sites	Sites assessed using mobile app-based checklist; repair costs estimated	Overall damage to park amenities; ballpark cost estimates for repairs to parks

Methods

Damage assessment is ongoing across this subsector. This chapter summarizes the results available at the time of writing and obtained from publicly available reports and from partners. Detailed descriptions of on-the-ground damage assessment methods used are below.

Archaeological sites were assessed by a two-person team, with one representative of the NPS and one from the SHPO. They assessed archaeological sites on the National Register and those administered by ICP, for a total of 40 sites. Historic sites were assessed at multiple levels. A team of six people performed Class C analyses of buildings in the historic districts of San Juan, San German, and Aguirre. These assessments covered all National Register sites in these locations, including 2,250 individual buildings. At the territorial level, 750 ICP buildings were also assessed. As part of the assessment strategy, unlisted but eligible sites will also be identified for inclusion in either the National or Commonwealth Register.

For both historic and archaeological sites, on-site damage assessments of buildings were conducted using standardized methodologies. First, a Rapid Building and Site Condition Assessment provides an overview of damage, along with detailed photographic documentation. This assessment lists the primary characteristics of the structure, including any official historic designation, along with a checkbox-based summary of flooding and damage. This form is used by FEMA and was developed by the National Center for Preservation Technology and Training and the Heritage Emergency National Task Force.

The Rapid Assessment form is meant to be used for preliminary, first-stage assessments. It does not require inspectors to have detailed knowledge or skills in historic preservation and does not require access to the interior of buildings, which may be dangerous or infeasible shortly after a disaster. It also allows for follow-up inspections to be prioritized based on the results and recommendations of the first-stage rapid assessment (National Center for Preservation Technology and Training, undated). An important qualification of the rapid assessment is its focus on the built environment. This means that any art or artifact collection inside the buildings must be examined separately; similarly, for archaeological sites, the assessment will focus on the modern infrastructure, not on the ancient features of the site.

When necessary, second-stage damage assessments provide itemized estimates of the cost to repair physical damage to a building. These estimates, like insurance claims, report estimated labor hours and equipment hours and then add overhead, administrative, and other costs at fixed percentage rates. Finally, a historic preservation factor and design contingency are added at a fixed rate, resulting in an overall estimate.

Ten percent of Puerto Rico's museum collections were assessed in person. A web survey administered throughout Puerto Rico provided more information about damage and needs from a wider set of museums. In cases where museums are housed in National Register buildings, the structures themselves were assessed as part of the historic building assessment effort, but in other cases damage to buildings may have been recorded as part of the survey done for a museum's

application for FEMA public assistance grants. Assessments covered 10 percent of libraries and archives. The main focus was on the General Archives and National Library. The building itself was assessed as part of the ICP's historic building damage assessment.

Working in conjunction with DNER, DRD, and municipal officials, NCR RSF staff compiled a list of parks/ recreational sites, primarily those under DNER and DRD management. This required several rounds of list refinement, because a single site may consist of multiple park facilities with multiple owning and managing entities. Contractors then visited each site and completed a structured digital app to assess it. The app included forking question paths on individual amenity types and standard questions, including questions on the overall damage, usability, and additional park needs. A major focus of such assessments is the built structures in these parks: fences, trails, sporting facilities, recreational lodging. Debris is also a major consideration in assessments, because removal will be a key factor in enabling parks to reopen.

Data Gaps, Assumptions, and Uncertainties

For several categories of assets, comprehensive assessments are impossible for two reasons. First, the complete set of relevant assets may be unknown; this is particularly the case for individual artists and artisans, but it is also true of libraries, personal art collections, local museums, and local parks. For each category of site types, the damage assessments necessarily worked off a list of known sites. In some cases, such as National Register sites, the list is finite and known. But in other cases, such as private art collections or school libraries, there is no extant list. Even in cases when surveys were administered to gather information from a larger sample, there may be unidentified museums or libraries that did not receive the survey; it is impossible to know who these institutions are. A rough approximation of artists' and performers' lost income, supplies, and materials exists; however, the true loss cannot be known. Second, an item-by-item assessment of each museum or library collection was not feasible because of the time constraints. Online surveys have been implemented to fill in some data gaps, but the existence and state of these collections at some institutions may remain unknown.

In addition, randomized sampling was used when necessary for some subsectors. For assessments of individual artifacts, 10 percent of the objects in damaged areas were examined. This sampling strategy provides a feasible alternative to item-by-item inspection, ensuring that any given type of object —based on size, physical material, age, and other variables—will have the same likelihood of assessment.

As indicated in the introduction and throughout this chapter, planning and executing damage assessments in this sector can be challenging for a variety of reasons, including the vast geographic scope and range of assets, the need for extensive field work, and the lack of timely access in some cases to appropriate instruments and expertise.

Archaeological and Historic Sites

Background

Puerto Rico is home to historical archaeological sites, including pre-historic sites, examples of Spanish, neoclassical, and colonial architecture that date to the 16th century, and culturally significant buildings and artifacts. The San Juan historic site was one of the first to be legally recognized as such (in February 1949), under the Historic Sites Act of 1935.[154] The area later turned into the San Juan National Historic Site when the National Register of Historic Places (NRHP) was established in 1966. Recreational visits to this site grew from 1 million in 2005 to 1.5 million ten years later (NPS Stats, undated).

The NRHP has expanded to include a total of 347 sites in Puerto Rico, six of which are also listed as National Historic Landmarks, and several of which are grouped into a UNESCO World Heritage Site (National Park Service, undated; UNESCO, 2018).

Archaeological Sites

A complete list of Puerto Rican archaeological sites is impossible to produce, because some may still be undiscovered; recent applications of LiDAR technology have shown this to be true on nearby islands (Sonnemann, Hung and Hofman, 2016; Optiz et al., 2015). Of the numerous known sites, 10 are listed on the National Register, and two of them—Caguana Site and Caparra Archaeological Site—are also National Historic Landmarks. The National Register sites are of national and international significance, containing the remains of the earliest known European settlements in any U.S. Territory (National Register of Historic Places, 1984), prehistoric evidence of habitation at least 5,000 years ago (National Register of Historic Places, 1993), and some of the best-preserved prehistoric art and tribal sites in the Antilles (National Register of Historic Places, 2003; National Register of Historic Places, 2008; National Register of Historic Places, 1978).

Besides the National Register, a list of archaeological sites is maintained by the OECH, Puerto Rico's State Historic Preservation Office. The list includes sites that have been assessed to comply with various historic preservation grants and that, therefore, is not necessarily comprehensive. As of 2015, the list included 2,226 sites on both land and underwater (Puerto Rico State Historic Preservation Office, undated).

Colonial-era shipwrecks also constitute a valuable archeological resource. These are sometimes managed by the ICP through its Council for the Conservation and Study of Underwater Archaeological Sites and Resources. A recent survey of sites on the north coast, between San Juan and Loiza, verified 20 known sites and documented 80 more that were of "potential archaeological interest" (Castro et al., 2010).

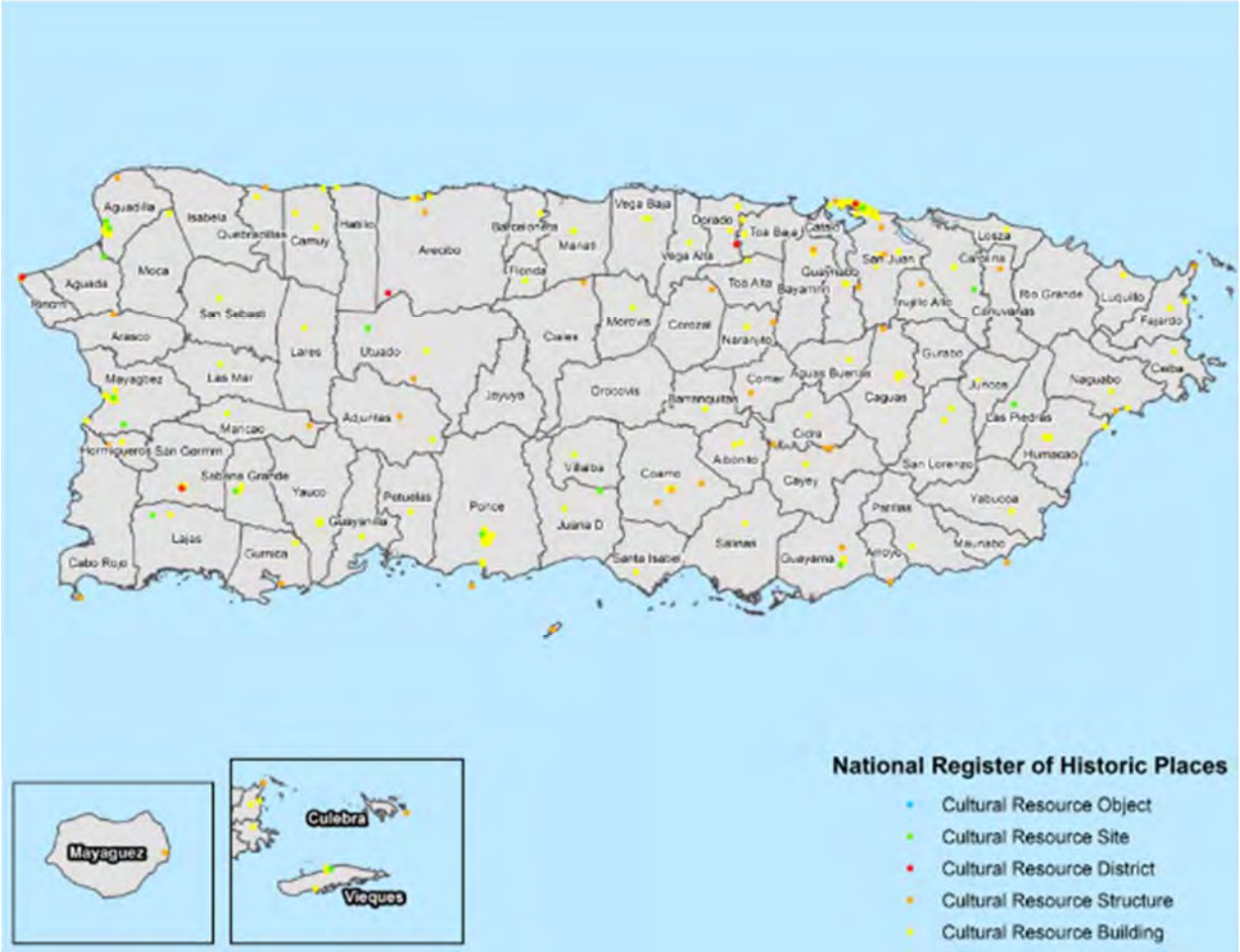
[154] This Act decreed the need to protect the fortifications and monuments of Old San Juan, including La Fortaleza, the governor's mansion.

Historic Sites

The National Register lists 347 individual sites in Puerto Rico (including the 10 archaeological sites mentioned above), with at least one in each of the 78 municipalities (Figure 10.1). Among those sites are 15 historic and archaeological districts, which collectively encompass around 1,750 properties.

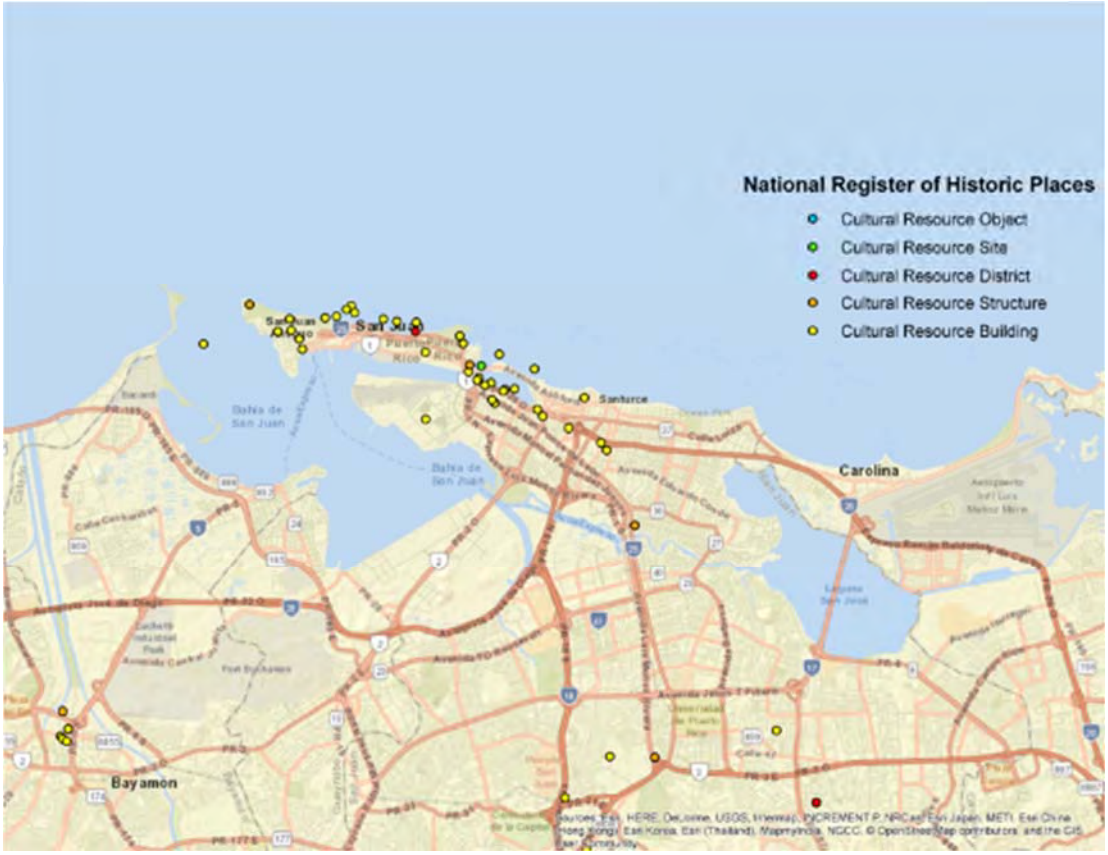
The densest concentration of registered historic sites is in Old San Juan Historic District, which contains 700 properties and some that are listed separately from the district itself (Figure 10.2) (Puerto Rico State Historic Preservation Office, undated). Three fortresses—San Felipe, San Cristobal, and Fortin San Juan de la Cruz (known locally as El Cañuelo)—make up the San Juan National Historic Site, and they are legally equivalent to a national park. And collectively, La Fortaleza, San Juan Historic Site, and parts of the old city walls comprise La Fortaleza and San Juan Historic Site, the only UNESCO World Heritage Site in any United States territory. Other high-density areas of National Register sites include Ponce and Mayaguez.

Figure 10.1. National Historic Register Sites in Puerto Rico



SOURCE: National Park Service Cultural Resources GIS Program

Figure 10.2. National Historic Register Sites in Greater San Juan



Source: National Park Service Cultural Resources GIS Program

Pre-Hurricane Conditions

Pre-storm assessments and emergency plans exist for some of Puerto Rico's significant cultural and historic sites. However, a 2014 UNESCO assessment of La Fortaleza and San Juan Historic Site found that several aspects of the site were unacceptable (UNESCO, 2014) or in need of improvement, according to the UNESCO rating system. Specific issues cited included the detrimental impact of tourism, invasive species (particularly feral cats), and wind/water erosion (UNESCO, 2014).

For the San Juan Historic Site more generally, the National Park Service noted in a report to UNESCO that wind erosion has been a constant problem for the fortresses, given their high and exposed walls. Wave erosion at the base of the fortresses has been exacerbated by ships exiting and entering the port, which required the construction of a breakwater near Castillo de San Felipe del Morro. The report also noted that San Juan's old city and fortification wall were endangered by several factors, including the density of housing near the wall in the La Perla neighborhood, graffiti and vandalism, heavy traffic, and issues associated with bird nests and rats (National Park Service and Puerto Rico State Historic Preservation Office, 2013). However, the San Juan

National Historic Site has undergone regular maintenance and has had an emergency action plan prior to the hurricanes. The cyclic maintenance program at the park has mitigated much of the ongoing damage to walls. The six-step emergency action plan begins at least one month before May 1 every year, at the start of hurricane season. The plan has included protocols for alerts, evacuations, recovery, and post-incident assessment (National Park Service Department of Interpretive Planning, 2006).

Findings of other reviews of emergency preparedness are mixed. The Tourism Company of Puerto Rico cited two components of San Juan National Historic Site (Fortin San Juan de la Cruz and the fortification walls) as being in "poor" condition, with the rest being in "fair" condition; four of the five requiring urgent attention for emergency planning (Puerto Rico Tourism Company, 2018). Of the 49 other structures most at risk of damage because of sea rise, only two were in poor condition (both abandoned) but 18 were in urgent need of emergency planning (Puerto Rico Tourism Company, 2018).

Hurricane Damage

Hurricanes Irma and Maria caused damage to the physical structures of historic and cultural sites and to their collections of artifacts. Wind and water have resulted in damage and have weakened the built structures of historic properties; debris has reduced access; and the presence of water has led to mold (Bajandas, 2018; Shepard, 2017).

Assessments were conducted for buildings in three National Register Historic Districts: San Juan, Aguirre, and San German. Table 10.4 shows the number of buildings examined at each district, the total percent that underwent any damage, and the total estimated Class C costs for the district. The majority of buildings were damaged in each district, with cost per building in the tens of thousands of dollars. Old San Juan sustained the highest per-building cost, at nearly $31,000 for each damaged building; San German was the lowest at nearly $12,000 per building. In addition, SHPO assessments were scheduled to reach 1,000 buildings and sites outside of historic districts. As of 1 June 2018, 348 of these assessments had been conducted, but information is not available for this report. However, even within the same district, the extent of damage varied; for example, the assessment of the Aguirre National Historic District evaluated 257 buildings and found that 98 sustained no damage, one was destroyed, while others were somewhere in between (HSOAC, 2018).

Table 10.4. List of Damage Estimates for National Register Historic Sites

National Register Historic District	Total Buildings Assessed	Buildings with any Damage	Total Class C Construction Cost Estimate
Old San Juan	70	77%	$1,669,035.67
San German	158	78%	$1,439,891.84
Aguirre	269	61%	$3,360,712.80

Source: (HSOAC, 2018).

Assessments of 20 ICP-administered properties in San Juan and Vieques estimated total damage at $26,964,921. Four of the sites were identified by ICP as highest priority among its holdings: Casa Blanca, Fortin San Geronimo, Fortin Conde de Mirasol, and Arsenal de la Marina. For these four sites, project proposals were developed for writing an HSR/CLR for each site. The damage estimates for individual ICP properties, including the HSR/CLR project proposal costs where applicable, are listed in Table 10.5. There are National Register sites that were not administered by NPS or ICP, including individual buildings that were part of historic districts.

Table 10.5. List of Damage Estimates for ICP Sites

Site	Description	Damage Estimate	Notes
General Archive	Building housing National Library and General Archive	$5,827,992	Damage to building only; collections damage estimated at $767,666
Arsenal de la Marina	Art gallery housed in former arsenal for Spanish Armada	$2,573,755	Estimate including HSR/CLR
Caguana Indigenous Ceremonial Center	Park and museum on Taino archaeological site	$752,352	Damage to modern infrastructure, not to ancient archaeological site
Casa Blanca	Museum in original governor's residence from 1521	$5,136,541	Damage to structure only, not to museum collections; estimate includes HSR/CLR
Casa de los dos Zaguanes	Historic site converted into theater space	$587,938	
Casa del Libro	Museum of print- and bookmaking with collection of rare books	$639,868	Damage to structure only, not to museum collections
Casa Opis	Houses the Centro Nacional de Artes Populares y Artesanias (Folk Art and Craft Center)	$245,244	
Teatro Francisco Arrivi	Performing arts venue	$915,300	
Fortin de San Jeronimo	18th Century fortress	$1,546,171	Estimate including HSR/CLR
ICP Headquarters	Colonial Spanish welfare house	$5,101,301	
Fortin Conde de Mirasol	19th Century fort housing Vieques Museum of Art and History and Vieques Historic Archives	$1,740,671	Estimate including HSR/CLR

Site	Description	Damage Estimate	Notes
Hatillo Cultural Center	Center in Hatillo municipality	$111,366	
Convento Domingo	Convent in San Juan	$964,330	
Casa Jesus T Pinero	Home of former PR governor	$160,319	
Santa Isabel Museo des Artes	Art museum	$42,809	
Casilla de Caminero	Colonial government-worker home	$82,561	
Casa Cautino	Museum in Guayama	$230,101	
Porta Coeli	Convent in San German	$178,613	
Casa Pietri	House in Sabana Grande	$127,689	

Source: Class C construction cost estimates conducted by National Park Service architects and other contractors on behalf of FEMA.

Post-Hurricane Conditions

In many cases, institutions have reopened to the public, but sometimes with temporary fixes for structural damage or with diesel generators to provide power. After a disaster, funding for the cultural sector becomes available through a patchwork of government relief programs, foundations, other arts organizations, and charitable groups. However, navigating the eligibility requirements for the various funding sources is not easy, and there is no centralized mechanism to match those who need funding with those who can provide it.

In the case of Hurricane Maria, most cultural and historic private non-profits may apply for public assistance grants through FEMA, but most are categorized as non-critical and therefore need to apply first for an SBA loan. Lack of awareness and information is a major issue here, and many arts organizations may forgo any funding because they end up not applying at all.

The recovery process for Puerto Rico's cultural institutions can also be hindered by the legal status of those institutions, which determines access to various sources of funding. These institutions may be registered as not-for-profits at the territorial level, but not as a Federal 501(c)3. This limits their ability to procure funds from federally funded agencies such as the National Endowment for the Arts (NEA); recognizing the needs faced in the community, the NEA did eventually change its eligibility requirements.

Museums, Libraries, and Archives

Background

Puerto Rico is home to a number of facilities dedicated to preserving and displaying items of cultural, intellectual, and historic importance, namely its museums, libraries, and archives.

Libraries and Archives

The largest archival institutions are the official territorial library and archives, both run under the auspices of ICP. The General Archives of Puerto Rico and the Puerto Rico National Library are housed together in a converted 19th-century building that was originally a hospital and later a Bacardi factory; thus, the building itself is of historic significance, as well as the collections inside. Together, the two institutions maintain records and manuscripts documenting the entire history of Puerto Rico, from 16th-century religious texts to modern multimedia materials, including records that are vital to the functioning and continuity of the government. The National Library is a repository for rare books and special collections related to eminent Puerto Rican writers; the Archives include 70,000 cubic feet of documents spanning over 200 years, including several collections dedicated to Puerto Rican film, music, and photography, as well as the Fondo de Obras Publicas (Records of Public Works). There are hundreds of other libraries in universities, colleges, schools, and municipalities; these are discussed in Chapter 15 of this report (Public Buildings).

Museums

Puerto Rico has a large number of museums, including those run by the government through the ICP and those run by private nonprofits. ICP administers several museums, some housed in historic buildings and dedicated to the preservation of the buildings and related works. For instance, the Museo de Arte Religioso Santo Domingo de Porta Coeli is a museum of religious paintings housed in a historic convent in San German (Zee Puerto Rico, 2018). Others have broader mandates, such as the Museo de la Música Puertorriqueña (Museum of Puerto Rican Music) or the Centro Cultural de Ponce Carmen Solá de Pereira (Carmen Sola de Pereira Ponce Cultural Center), both in Ponce.

Three large art museums provide examples of institutions whose collections are important for the tourist economy and also for Puerto Rican and Caribbean cultural heritage: the Museo de Arte de Ponce (MAP), the Museo de Arte de Puerto Rico (MAPR), and the Museo de Arte de Contemporaneo de Puerto Rico (MAC-PR). The MAPR is dedicated to Puerto Rican art, with a collection spanning over 150 years. The building itself is also historic, because it is the only remaining structure of the original San Juan Municipal Hospital (Musea de Arte de Puerto Rico (MAPR), 2018). The MAC-PR shows late 20th-century and contemporary art, focusing on Latin American, Caribbean, and Puerto Rican artists.

Pre-Hurricane Conditions

Because of their ownership structure and status as not-for-profit organizations, museums have often relied on subsidies or private donations to operate.[155] Libraries and archives have also provided many free services and subsist off combinations of government subsidies or support

[155] Personal communication with Pablo Guardiola, March 15, 2018.

from their respective universities or other parent institutions. Even accounting for admission fees, museums and performing arts organizations have covered an average of 5 percent of their costs through ticket sales; all forms of earned income (from gift shops, cafes, and rentals) have historically accounted for an average of 27 percent of their operating budgets (Association of Art Museum Directors, 2015; Bell, 2012).

The Puerto Rican General Archive and National Library are housed together in a converted 19th-century building that was originally a hospital and later a Bacardi Rum factory. Together, the two institutions maintain records (many required by statute) and manuscripts documenting the entire history of Puerto Rico, from 16th-century religious texts to modern multimedia materials. Thus, both the building itself and the collections inside hold historic and governance significance for the people of Puerto Rico. A major concern before Hurricane Maria was the location and aspects of the building's retrofitting, which leave the structure inadequate to meet the Archive's legal mandate to house collections of records that are vital to the continuity of the Puerto Rican government.

Hurricane Damage

Initial damage assessments showed that the degree of buildings' functional impairment ranged from negligible to severe. Smaller museums, libraries, and arts organizations have seen more damage from mold and flooding because they did not have the resources to plan ahead (and have lower capacity to recover). One particular institution received a singularly in-depth assessment: Archivo General (General Archive). The building itself was assessed as part of the ICP's historic building damage assessment, while damage to its collections were assessed by a team of curators in February and March 2018. Both reports note damage to the roof and to windows. The collections damage assessment from March 2018 notes that "the building is not in an ideal location for storing irreplaceable documents; it sits in a tsunami zone, near toxic chemical and military sites[,] and the building suffered from issues with the roof, windows, and generator power that caused collection damage to accrue up to five months after the hurricane" (Archivo, 2018) Damage to the building (not to the collections inside) was estimated at $5,827,992 (Archivo, 2018).

Assessments of other museums, libraries, and archives varied by ownership type. In cases where the institutions were housed in National Register buildings or administered by the ICP, the buildings themselves were assessed as part of the historic building assessment effort. However, resource constraints prohibited a full assessment of every privately run institution. 378 institutions received a survey to self-report damage to their buildings and material collections, but response was minimal. Of those 378 institutions, 32 returned the survey(FEMA Cultural Resources, 2018).

A consultant to the Smithsonian Cultural Rescue Initiative aggregated the survey responses and analyzed them. 69 percent reported damage to the building only, while 31 percent reported damage to the building and collections or records. The lower frequency of collection damage is

largely attributable to actions taken by curators and other staff members immediately after the hurricane.[156] However, the lack of repairs to buildings, electricity, and HVAC pose problems for the future. In terms of collections damage, the 32 institutions reported damage to collections ranging from 0 percent of objects to 100 percent, with an average of approximately 25 percent; two museums did not report numbers because they had not yet inspected their collections in depth. The most commonly damaged collection objects were paper, including books, drawings, archival photographs, and maps. Among the libraries responding to the survey, the number of books damaged was as high as 60,000.

Mold is a major ongoing issue affecting collections, and one-third of institutions reported problems with pests (particularly termites) that have damaged or could damage collections and records in the future.[157] 80 percent of the institutions have damage to buildings that could further damage collections in future storms; 20 percent of collections have been moved to other locations because their facilities are not sufficiently safe; 20 percent are in temporary or unsustainable storage (e.g., covered by plastic for the time being); and 25 percent of institutions now lack the required furniture or shelving for storage, often because of corroded metal or high levels of mold. In addition, some institutions lacked climate control in the first place, and every institution with HVAC or dehumidifiers suffered a failure of those systems. Finally, all 32 of the institutions lost power, some did not have backup generators, and some still have unreliable power; these issues are particularly relevant outside of San Juan.[158]

To better quantify the damage to museum, library, and archives collections, 37 institutions received in-person assessments, chosen based on those who reported any damage; thus, it is a select sample, but it does offer insight into how well cultural organizations were able to mitigate existing damage after the storm. Some sites were chosen based on their survey responses; others were cold-called or referred by other institutions to achieve as broad a sample of institutions types as possible.

In site visits, conservators inspected both the building and the collections stored inside. For each site, conservators roughly estimated what portion of the collection is in areas that sustained damage. They then inspected a random sample of 10 percent of the items in the areas sustaining damage. This is a departure from typical assessment methodology in which conservators examine every damaged item and develop a detailed treatment proposal and cost estimate. Time and resource constraints prohibited such thorough inspection in this case, meaning that these assessments are preliminary and cannot be used for treatment estimates.

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[156]Conclusion by Elke Selter of Smithsonian Cultural Rescue Initiative based on analysis of damage assessments.

[157]Conclusion by Elke Selter for the Smithsonian Cultural Rescue Initiative based on analysis of damage assessments.

[158]Conclusion by Elke Selter for the Smithsonian Cultural Rescue Initiative based on analysis of damage assessments.

Total damage estimates for these institutions range from $275 to $767,666, with a mean estimate of $70,556, reflecting the wide variety of institution collection sizes, extents of damage, and materials or expertise needed to treat artworks and archival records. In terms of storage equipment and supplies, the average institution requires an average of $9,630. The needs are often for generators, computer equipment to monitor humidity and temperature, new shelving, and pest or rodent traps. In terms of conservation supplies and labor costs, the average assessment was $63,223. The objects inspected ranged from large public sculptures and murals to individual drawings, with conservation of any individual work of art potentially requiring hundreds of hours of labor and specialized materials or tools. Total costs for one artwork can be in the tens of thousands of dollars.

Post-Hurricane Conditions

As described previously, emergency response is critical for museums, libraries, and archives to protect the assets they house. The larger museums are housed in modern buildings and often have their own emergency and recovery plans. In some cases, the buildings themselves, as well as the curatorial staff, proved after Hurricane Maria to be a source of expertise, emergency housing for other museums' objects, and a haven for residents seeking respite (see Box 10.1).

Box 10.1 A TALE OF TWO MUSEUMS

Two museums provide examples of how cultural institutions can become leaders in the community and help other organizations with their own recovery process and also illustrate how museum collections can be more at risk from the aftermath of a disaster than the disaster itself.

Before Hurricane Maria made landfall, the Museo de Arte de Puerto Rico (MAPR) enacted its emergency plan. While the building was structurally damaged, a $75,000 grant from the Smithsonian Institution, of which the MAPR is an affiliate, provided the means to keep power running with a diesel generator to ensure the stability of the collection inside. The museum stayed closed to the public, but it became a repository for cultural items from seven other institutions: La Fortaleza, Sacred Heart University, Jose M. Lazaro Library at University of Puerto Rico, Caguas Art Museum, Luis Munoz Marin Foundation, Ateneo Puertorriqueno, and Casa Roig Museum.

However, while the MAPR survived Hurricane Maria intact, approximately 50 days later a large amount of rain on top of already-overburdened drainage systems caused major flooding in parts of the museum, destroying its library and education department.

Meanwhile, the Museo de Arte de Ponce (MAP) sustained no damage to the building or collections. After clearing debris from the entrance to provide access, the museum reopened within a week, free of charge, providing air conditioning and plumbing to members of the community thanks to its own diesel generator.

In addition to serving as a physical repository for other museums' work, the MAPR has hosted resiliency and preparedness trainings offered by the Smithsonian Institution in the aftermath of the hurricanes. Heritage Emergency National Task Force, co-sponsored by FEMA and the Smithsonian, led a one-week training program (March 19 to 23, 2018) for museum professionals at the MAPR. Called the Heritage Emergency and Response Training (HEART), the program discussed risk assessment, occupational safety, disaster planning, conservation, emergency documentation, handling of damaged materials, evacuation of collection materials, online resources, PA forms, and other topics. A similar program for individuals was also held at the MAPR on March 24. This program taught how to salvage family possessions, offered advice to artists, and provided information from representatives of the IA, Hazard Mitigation, and SBA programs.

Months after the storm, damage from the hurricane is ongoing as a result of revenue impacts. No information is available on the loss of revenue for museums, libraries, and archives. While no institutions reported problems paying staff, not all of them have reopened to the public. In addition, no institution reported hiring additional staff or security, but many reported the need for skilled technical specialists who can aid with conservation and treatment of collections and records.

Parks, Recreational, and Sports Facilities

Background

Puerto Rico's parks, recreational, and sports facilities also provide recreational opportunities critical to the cultural fabric of the Commonwealth and to supporting a good quality of life for Puerto Ricans.

Sports and Recreational Facilities and Parks

Puerto Rico's sports and recreation sites include community-level parks, as well as the Puerto Rico National Park system. Parks may be described as "nature-centered" or "recreation-centered," depending on their intended purpose and typical uses. The Department of Sports and Recreation (DRD) owns the National Park system and over 400 other parks, mostly "nature-centered." The National Park system is a major source of revenue for DRD, including vacation facilities like rentable beach cabins. National parks are often also key drivers of the local economy. Parks, sports, and recreation sites also include areas where wildlife is the primary draw. This includes the national zoo, recreational fishing areas, commercial fisheries, and other areas that provide unique opportunities to encounter wildlife. Other local parks are municipality-owned, privately owned, jointly owned, or have undocumented ownership status and may include both "nature-centered" uses and "recreation-centered" uses, such as basketball courts and baseball stadiums.

Parks provide important services to the community, including access to infrastructure to support active living, stormwater management capabilities through green infrastructure, reduction of the urban heat island effect, economic benefits by increasing area attractiveness (Kaczynski and Henderson, 2007; Sandstrom, 2002; Crompton, 2005; Peters, Elands and Buijs, 2010), and community cohesion benefits by providing places for residents to gather.

Below is a summary of the categories of parks located in Puerto Rico:

- **National Parks, Public Beaches, and Rental Cabins**, There are 18–27 Puerto Rican National Park sites, excluding the U.S. National Forest of El Yunque, and depending on whether one counts adjacent facilities separately. The National Park system is heavily concentrated near San Juan, with at least eight parks falling within a 15-mile radius of the capital, and virtually none south of the Cupey outskirt of the city. Most National Parks also contain public beaches, but many public beaches ("balnearios") are not National Parks. The non-National Park beaches mostly line the east and west coasts. In addition, some sites also contain vacation centers—collections of rentable cabins and surrounding park facilities in scenic, natural settings.
- **State Forests, Nature Reserves, Wildlife Reserves**. Many of Puerto Rico's nature-focused regional parks are State Forests, Nature Reserves, or Wildlife Reserves. There are roughly 20 state forests under DNER management, of which about half are situated in the sparsely populated, mountainous center of the island. There are roughly 5–10 wildlife refuges under DNER or U.S. Fish and Wildlife Service management, including the National Zoo in Mayagüez. There are approximately 30–34 nature reserves depending on whether one counts adjacent sites separately and on whether one counts former plantations ("finca") as recreational or historic sites. All but two are located near the coast. One (Maricao State Forest) offers rentable cabins.
- **Lakes**. Puerto Rico has at least 17 large lakes, and at least two of every three are the result of a dammed stream. They serve as water reservoirs and/or hydro-power stations. However, most of them have thriving ecosystems, and many draw in visitors, especially fishermen. Lago Caonillas, a dammed river near Utuado, offers rentable cabins. Lagos La Plata and Luchetti are designated DNER wildlife refuges.
- **Total Number of DRD Parks**. Depending on whether one counts adjacent parks separately, the DRD manages between 320–424 recreation-centered park complexes in 51 municipalities. The municipality of Ponce holds the most DRD sites, but municipalities in the San Juan area likely contain more parks when municipality-managed sites are taken into account.
- **Concrete park amenities**. The most common DRD park amenity is a basketball court, which can be enjoyed in 78 percent of all DRD parks. Basketball courts require relatively little space and are typically made of long-lasting materials like concrete and steel. Basketball courts in Puerto Rico are often covered with a corrugated roof on steel I-beams. This makes the courts usable in the often-wet weather and extends

the lifespan of the court. In addition, some courts double as space for community aerobics classes. Basketball parks often contain other compact, hard-material amenities, such as tennis courts or playgrounds.

- **Baseball stadiums**. The next most common amenity is the baseball field, which can be enjoyed in 38 percent of parks. Baseball has a very long history in Puerto Rico, including strong performances in regional and global baseball competitions. The baseball parks in Puerto tend to be competition-ready and designed to handle spectator crowds.
- **Other parks**. 90 percent of parks have either a basketball court or a baseball field, and 30 percent have both. The remaining parks tend to have amenities, such as gazebos (40 percent of remaining parks), community centers (38 percent of remaining parks), and fitness tracks (33 percent of remaining parks), as well as the typical high prevalence of playgrounds (50 percent) (Department of Sports and Recreation (DRD), undated).
- **Linear parks**. There are at least eight linear parks in Puerto Rico, of which most are municipally-owned. The typical linear park in Puerto Rico follows a waterline. This provides a natural right-of-way for pedestrian/bike paths and creates a green buffer between flood waters and urban development.

Pre-Hurricane Conditions

Pre-hurricane conditions were largely dictated by the funding environment and ownership structure of Puerto Rico's parks. The ownership of park assets in Puerto Rico is not straightforward. DNER holds many nature-centered parks. DRD and many of the 78 municipalities own many recreation-centered parks, and DNER owns a handful. The National Parks Company, a subsidiary of DRD, holds many sites that straddle the dividing line between nature-centered and recreation-centered. The electrical utility (PREPA) and water utility (PRASA) have some holdings related to natural recreational areas, primarily related to reservoir lakes. The private, non-profit Conservation Trust of Puerto Rico and its Para La Naturaleza unit have some holdings related to their conservation mission, as do other similar organizations. However, these sites are not wholly separate. Different entities may own adjacent parcels of park land or one may manage facilities that are on the land of another. Some sites were devolved to municipalities as part of Commonwealth cost-cutting measures, but without any transfer of funding to upkeep them. Communities informally maintain some sites, as a grassroots reaction to lack of maintenance from the official maintaining entity. While local managers generally understand the assets in their community portfolio, that information is not necessarily compiled at the Commonwealth level. This can impede efforts to take remedial action after a disaster, especially since FEMA aid needs to be tied to a specific eligible applicant.

As described in other chapters of this report, starting with the phasing out of key tax incentives a decade ago, Puerto Rico has experienced long-term economic decline. This resulted

in a government debt crisis and dramatic changes in Commonwealth and municipal fiscal policy. Parks have consistently had diminished budgets, diminished staff, and diminished investment since then. Some park assets that reached the end of their lifecycle have not been replaced. Some park assets have not received needed maintenance. Some opportunities to build new assets to meet the changing needs of the population have not been actualized.

Access to parks in Puerto Rico is generally good, though many are not accessible for pedestrians. 97 percent of the population live within 5 miles of at least one park, usually a DRD recreation-focused park (90 percent). While nature-centered parks are less common and usually more remote, 97 percent of the population lives within 11 miles of one. However, pedestrian access to parks remains constrained. Only 47 percent live within a 30-minute walk of a park (1.5 miless), and 23 percent live more than an hour's walk from a park (3 miles). Moreover, traffic on neighborhood streets has increased over the past couple of decades, making it more difficult for pedestrians to access nearby sites.

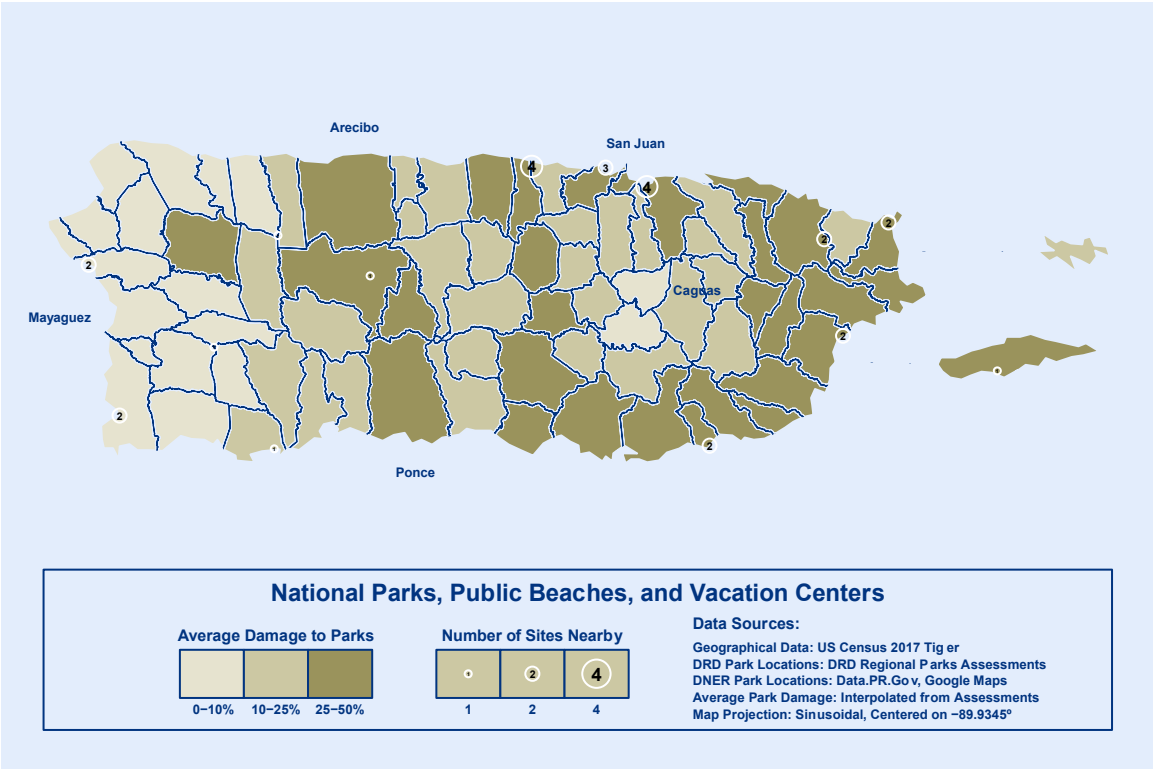
Hurricane Damage

Hurricanes Irma and Maria caused damage to the physical structures of recreation sites and park facilities, whereas debris reduces access to these sites. The presence of water contributes to mold and mildew, which negatively affects the structures and their contents. Excessive debris can compound this problem by reducing access (Bajandas, 2018; Shepard, 2017). The disruption of public services can create additional opportunities for damage to occur, such as when disruptions in law enforcement services enable theft of valuable park building components.

The extent of the damage to parks closely mirrors the path of hurricanes. In areas along the direct paths, assessment teams rated 30 percent of parks as having received “Severe” or “Near Complete” damage. For example, DRD parks on the eastern coast (where the hurricanes made landfall) incurred more damage than parks on the western coast. In the southwest, no park received a “Severe” or “Near Complete” damage rating, although many still experienced light damage. Within a given area, parks were more likely to receive a “Severe” rating or above if they had “softer” park amenities. For example, parks with basketball courts, playgrounds, or tennis courts were 30–70 percent less likely to be severely damaged, but parks with basketball fields were 25 percent more likely. However, the extent of damage was not necessarily proportional to damage costs, because “harder” assets are more expensive to repair.

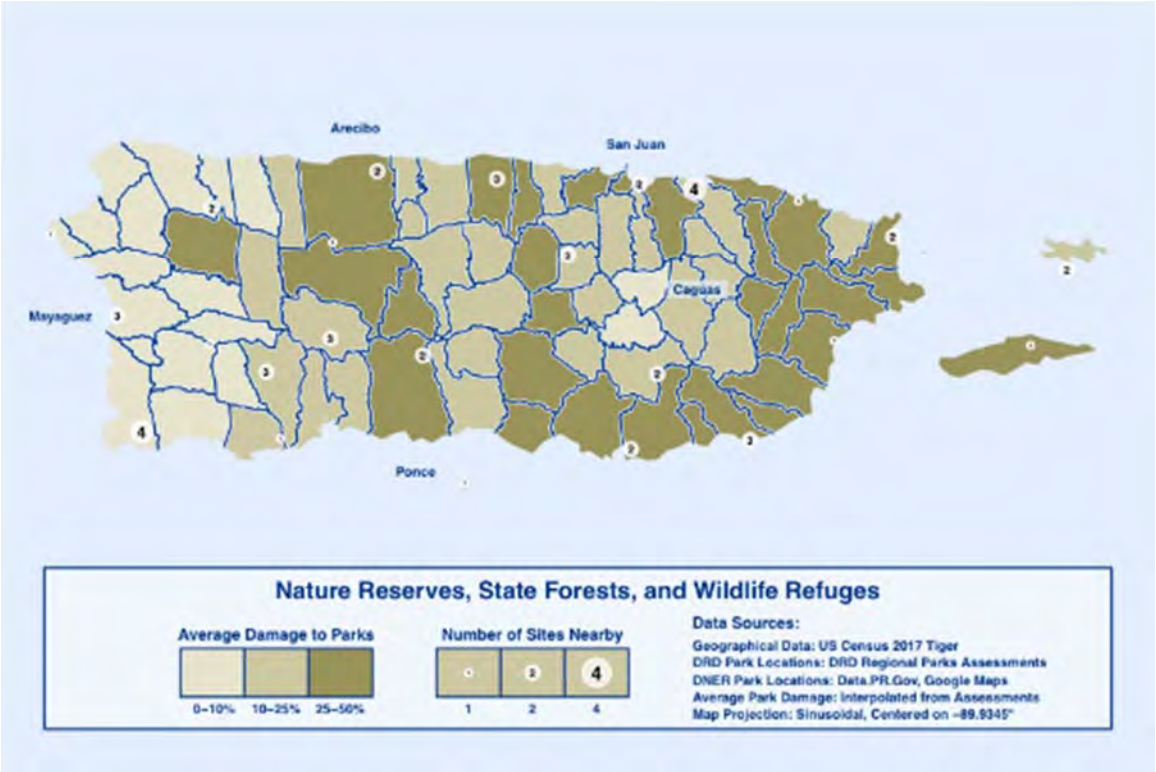
Figures 10.3–10.5 show various types of parks and recreation areas and facilities overlaid on a map of estimated average damage to parks (of any kind) for each municipality. Figure 10.3 maps the locations of various clusters of National Parks, Public Beaches, and Vacation Centers (i.e., rental cabins and associated facilities). Figure 10.4 shows the locations of Nature Reserves, State Forests, and Wildlife Refugees. For reference, they are overlaid on a map of estimated average damage to parks (of any kind) for each municipality. Figure 10.5 displays the Regional Parks under the management of the Department of Sports and Recreation.

Figure 10.3. Location of National Parks, Public Beaches, and Vacation Centers Overlaid on a Map of Estimated Average Damage to Parks in Each Municipality



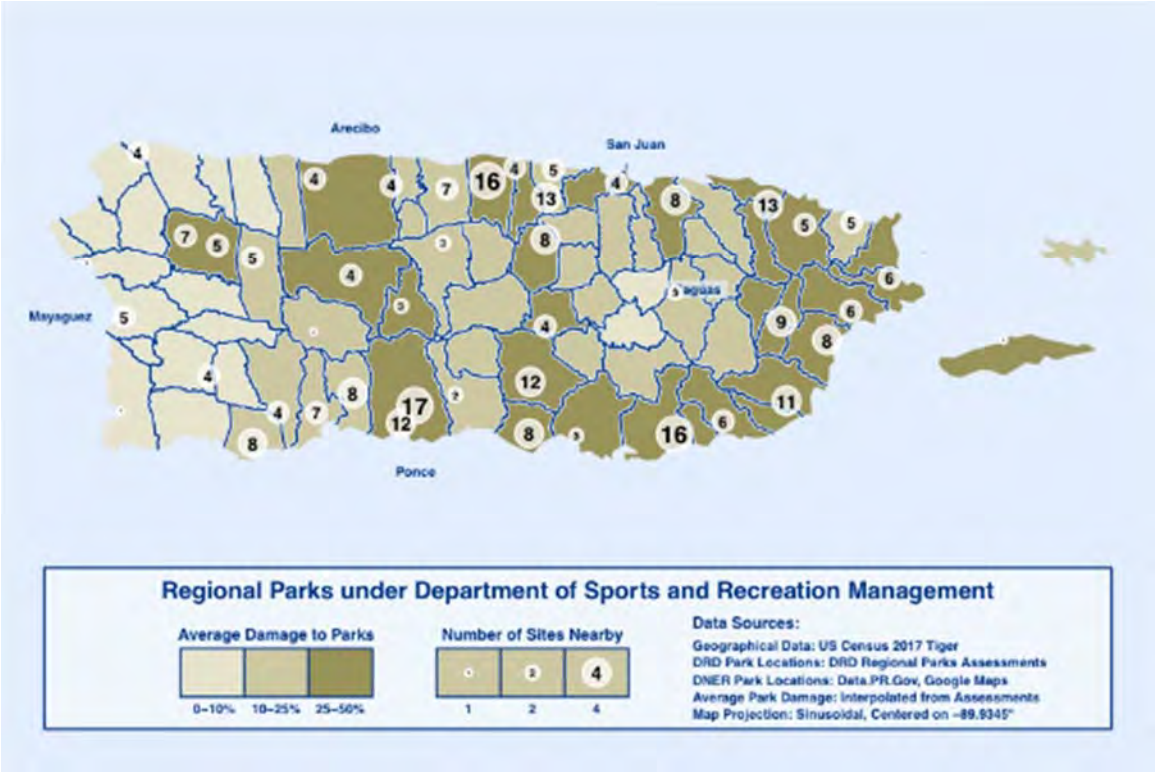
This figure displays the Commonwealth of Puerto Rico, with borders denoting its 78 municipalities. Each municipality is colored according to the estimated average percent damage of parks, as interpolated from all park damage assessments available. These assessments rated parks on a scale from minimally damaged (0–20 percent damage) to completely damaged (80–100 percent damage). The white dots with numbers in the center indicate the total number of relevant sites in that area. To cluster sites into dots, we used Ward's Minimum Distance Hierarchical Clustering to cluster sites that fall within 10 miles of each other.

Figure 10.4. Location of Nature Reserves, State Forests, and Wildlife Refuges Overlaid on a Map of Estimated Average Damage to Parks in Each Municipality



This figure displays the Commonwealth of Puerto Rico, with borders denoting its 78 municipalities. Each municipality is colored according to the estimated average percent damage of parks, as interpolated from all park damage assessments available. These assessments rated parks on a scale from minimally damaged (0–20 percent damage) to completely damaged (80–100 percent damage). The white dots with numbers in the center indicate the total number of relevant sites in that area. To cluster sites into dots, we used Ward's Minimum Distance Hierarchical Clustering to cluster sites that fall within 10 miles of each other.

Figure 10.5. Location of Regional Parks under Department of Sports and Recreation Management, Overlaid on a Map of Estimated Average Damage to Parks in Each Municipality



This figure displays the Commonwealth of Puerto Rico, with borders denoting its 78 municipalities. Each municipality is colored according to the estimated average percent damage of parks, as interpolated from all park damage assessments available. These assessments rated parks on a scale from minimally damaged (0–20 percent damage) to completely damaged (80–100 percent damage). The white dots with numbers in the center indicate the total number of relevant sites in that area. To cluster sites into dots, we used Ward's Minimum Distance Hierarchical Clustering to cluster sites that fall within 10 miles of each other.

Combining all categories of parks, it may require roughly $316 million to repair all DNER and DRD parks to an undamaged condition. In addition to park amenities, the assessed cost to repair parks also corresponds the size of the park and the density of built versus natural amenities. Approximate number of parks, average repair costs, and estimated total repair costs appear in Table 10.6. While the natural environments of Puerto Rico sustained significant damage, nature-focused parks tend to have fewer built structures on them and less closely manicured landscapes. Consequently, while these parks sustained significant natural damage, they had fewer critical park structures that could be damaged. DNER applied for 4.05 million cubic feet of debris removal, primarily from its highly manicured portfolio of vacation centers and public beaches.

Table 10.6 List of Damage Estimates for All Categories of Parks

	Approximate Number of Parks	Average Repair Cost Estimate Per Park	Projected Total Repair Costs
DNER Park	20 State Forests + 34 Nature Reserves + 5 Wildlife Refuges = 59 parks	$2.7 million	$159.8 million
National Parks	18 National Parks	$982,000	$17.7 million
DRD Park	424 Regional Parks	$328,000	$139.0 million
Total	501 Parks		$316.5 million

Post-Hurricane Conditions

Parks and recreation sites have reopened as debris and other obstacles have been cleared. As stated previously, some sites have been unable to reopen because of damage from the storms. Parks vary widely in attention received, both before and after the hurricanes. National Parks are often also key drivers of the local economy. Consequently, these sites receive regular maintenance and have been prioritized for debris removal ("Category A") FEMA PA. A few even saw informal, local debris removal efforts soon after the hurricane.

However, there are significant opportunities to redesign the park system so that it is more effective at providing community and infrastructure services. If repair funds are diverted from low potential sites to higher potential sites, this may not result in costs being higher than the $316 million needed for a straightforward repair effort. However, it may be advantageous to build in additional margin for redesign opportunities.

Performing Arts, Artists, and Artisans

Background

Puerto Rico's performing arts naturally intersect with its population of working artists. Performing arts organizations are composed of individual artists, some of whom may also work, perform, teach, exhibit, and sell their work separately from the organization. This section reviews what is known about those who work cultural industries and the aggregate economic contribution of those industries.

The activities of performing arts organizations and individual artists are not necessarily tied to any one property or building. Yet it should be noted that the list of dedicated performance spaces intersects with lists of historic properties. For example, the Teatro la Perla in Ponce is a historic venue offering performances in a variety of art forms. In Mayaguez, the Teatro Yaguez is a historic and still-functioning opera house on the National Register.[159]

[159] NPS, "Teatro Yaguez", NRHP Reference #85003086: https://www.nps.gov/nr/travel/prvi/pr24.htm

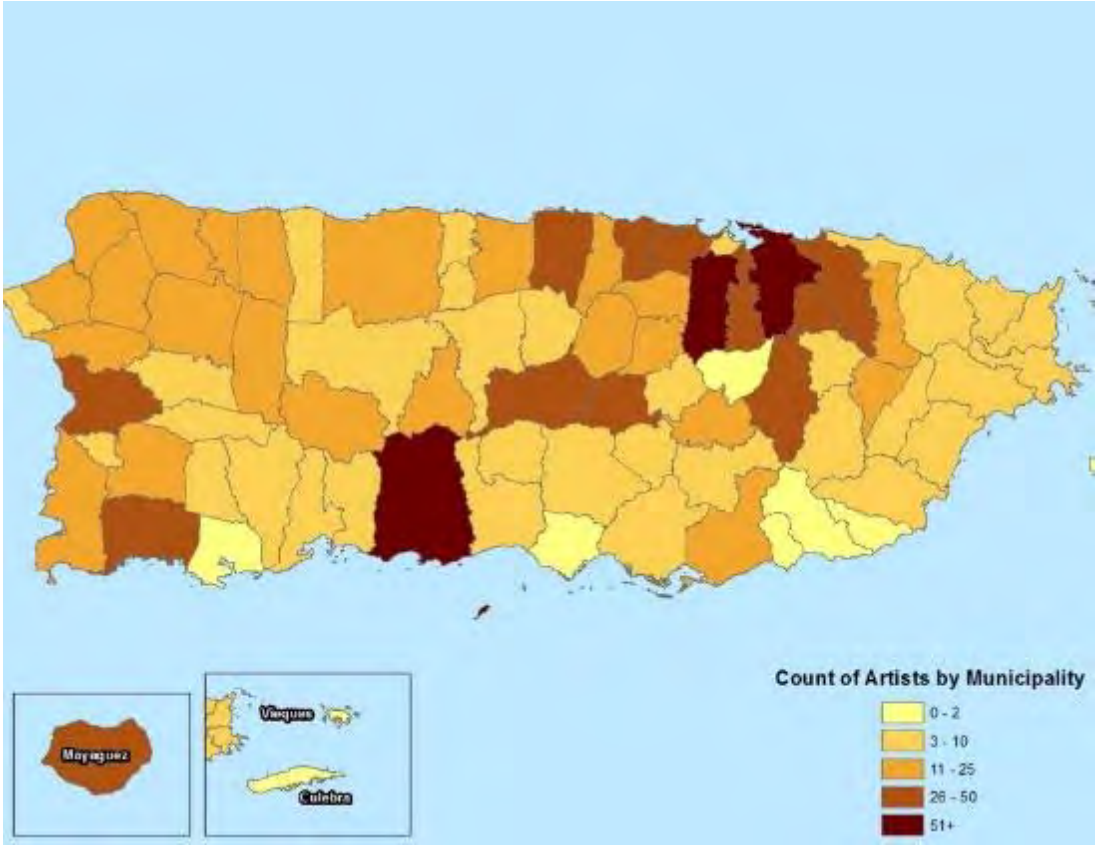
In terms of activity, the cultural industries in Puerto Rico are significant. A 2013 study estimated that as of 2011 there were 1,889 Puerto Rican companies in the cultural and creative industries, comprising 14,715 jobs with a payroll totaling $436 million and business volume totaling $1.74 billion (Hernandez 2013). 48 percent of that volume was attributable to cinema and media industries, 19 percent to books, 13 percent to visuals arts, 12 percent to design, 7 percent to performing arts, and 1 percent to museums. In addition, creative activity is spread all over the island. A recent study by the Puerto Rican Commission for Cultural Development (CODECU) used several data sources to account for measurement issues (Hernandez & Quintero, 2015). The report concluded that those involved in the creative industries are spread around the island, with large clusters in San Juan, Ponce, Bayamon, Mayaguez, and Caguas.

Artists practice many different forms, from visual arts to performance and theater to music. Artisans create skilled crafts and handiwork, such as weaving, basket-making, and woodworking. It is difficult to quantify who exactly "counts" as an artist. Artists and artisans may earn all or most of their income through their work, or they may have another primary source of income; this means that surveys collecting data on primary occupation may undercount artists. Hernandez & Quintero, 2015 note that "activity is concentrated in small and medium enterprises with some degree of formality. However, in the areas of creation, including arts and design, self-employment represents a large proportion of cultural activity" (p. 21).

Two databases provide information about artists in Puerto Rico. Survey-weighted calculations based on occupational data from the 2012–2016 waves of the Puerto Rico Community Survey (PRCS) show 10,815 individuals had their primary employment in one of 11 arts-related fields, including artists, actors, designers, musicians, writers, and dancers. In addition, the PRCS indicates those in creative industries earned an average of $25,205 per year (95 percent confidence interval: $22,221 to $28,188)—higher than the average for the population as a whole. However, those producing art (e.g. visual artists, dancers, and musicians) earned less than the population average, while those on the business end (e.g. broadcasting announcers, film producers) earned more. These patterns agree with those found by Hernandez & Quintero (2015) using data from the Puerto Rico Department of Labor and Human Resources and the PRCS (Hernandez and Quintero, 2015); the PRCS only records primary occupation, so the data do not record hobbyists or those who earn less than half their money from artistic endeavors. In fact, Hernandez Acosta (2013) estimates there are 80,000 cultural workers in Puerto Rico and that at least 10 percent earn no income from their art practice.

In addition to the PRCS, the ICP maintains a registry of artists and artisans that, while not necessarily comprehensive, lists 1,754 individuals. The list shows that the vicinities of San Juan, Mayaguez, and Ponce are centers of artistic activity (Figure 10.6). The ICP registry largely agrees with the densities of creative industries as outlined in Hernandez & Quintero (2015).

Figure 10.6. ICP-Registered Artists by Municipality



SOURCE: ICP

Pre-Hurricane Conditions

As in many communities, artists and artisans in Puerto Rico have faced challenges related to informal production spaces and piecemeal income streams. Information on the physical assets used by Puerto Rico's artist community is limited, but anecdotally there is evidence that artists sometimes work in studios that are converted from unused residences owned by relatives.[160] Such conditions can make it difficult to qualify for funding from public and not-for-profit sources following a disaster. When artists do not own their workspace or when income from producing art is just one of several streams of income impacted by the hurricane, it can be difficult to qualify for funding from public and not-for-profit sources. In addition, artists and artisans not listed on a registry can be difficult to find and target for recovery funding; word of mouth or advertising campaigns may be the only way for artists to learn about ways to access recovery funds.

[160] Personal correspondence with Pablo Guardiola of Beta-Local, 15 March 2018.

Hurricane Damage

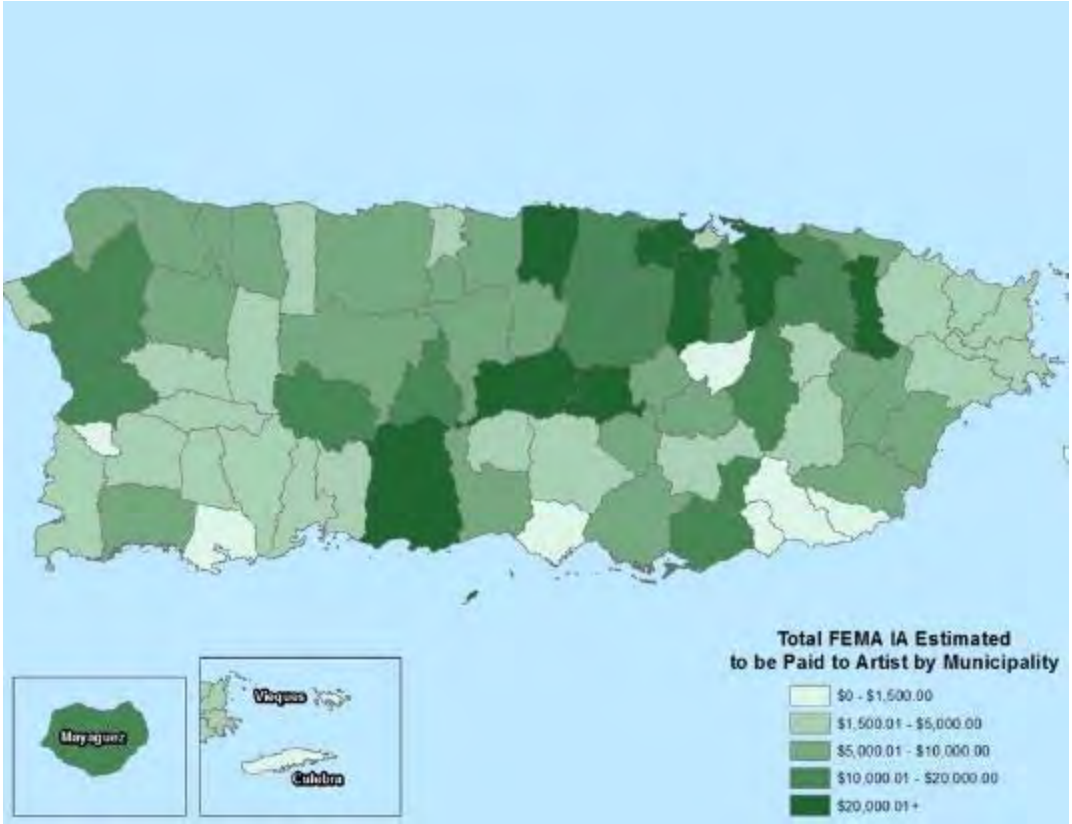
Damage to performing arts venues that are also ICP sites was assessed as a part of the ICP assessments of historic properties. These include Casa de los dos Zaguanes, a historic site converted into theater space, which was found to have sustained an estimated $588,000 worth of damage, and Teatro Francisco Arrivi, a performing arts venue that had an estimated $915,300 worth of damage.

Several different data sources provide a broad picture of damage to artists and creative practices. These sources include grant information from arts-focused foundations; statistics imputed from ICP and FEMA data; reports from interviews; and survey data collected by arts recovery experts. Collectively, these reports indicate that most artists and arts organizations earned zero income from their art practice for 3–6 months after the storm. Many sources project continuing losses well into 2018, if not after.[161] CERF+, an organization dedicated to supporting artists, found that among their grantees, 61 percent expected to be able to work near full capacity by 6 months, with 10 percent expecting recovery to take more than one year (CERF+, 2018).

The ICP registry of artists and artisans provides information on the geographic distribution of artists. These data were linked to the FEMA Registration Intake and Individuals Household Program data, which list the amount of IA funding at the ZIP-code level for each declared emergency (FEMA, 2015). These data distinguish funding through the Individual and Household Program (IHP), Household Assistance (HA), and Other Needs Assistance (ONA). The calculations indicate that total FEMA registrations from artists would average 4.9 per municipality, ranging from 0 to 58 (Figure 10.7). Municipality-wide damage to artists averaged $5,011 for IHP, $2,727 for HA, and $2,283 for ONA. But because of the uneven distribution of artists throughout Puerto Rico, the range is large: up to $25,867 for IHP, $11,427 for HA, and $14,440 for ONA.

[161]Discussion with Amy Schwartzman based on her data and research conducted in April–May 2018.

Figure 10.7. Predicted Total FEMA IA Damage Paid to Artists by Municipality



SOURCE: ICP registry, FEMA Registration Intake, and U.S. Census.

Post-Hurricane Conditions

For artists and artisans, property ownership has been a logistical roadblock to procuring funding. Artists who do not own their studios or workspaces may not qualify for funds to rebuild the physical structures. The uncertainty of artists' income streams poses another issue. Revenue from artistic ventures is inherently uncertain on a month-to-month basis; when that revenue is just one of several sources of income, the post-hurricane outlook for artists can be particularly difficult to predict. Thus, when artists are offered recovery loans from federal programs (even with very good terms), they sometimes turn them down. In some cases, other organizations can fill in the gaps with grants that do not need to be repaid.[162]

Remaining Needs and Recovery Priorities

Overall, the impact of the damage on cultural resources on a broader scale presents challenges to resiliency and the well-being of certain populations. Many artists lost everything and do not

[162] Personal communication with Pablo Guardiola, March 15, 2018.

qualify for PA because they are not a company or non-profit. As a result, it may take longer for this population to recover financially from the damage of the storm. Lack of access to parks, sports and recreational facilities, and cultural institutions may present a challenge to the mental and physical well-being of Puerto Ricans, especially if access to these resources is limited over a prolonged period of time. Additionally, the continued period of closure of these institutions will impact the economic well-being of those employed within each industry.

Short Term

Over the next one to 12 months, priorities include:

- *Completed cultural resources damage assessments.* Efforts are proceeding to assess damage to Puerto Rico's cultural resources from the 2017 hurricane season, but many information gaps remain, as documented in this report.
- *Data collection to fill remaining information gaps on cultural resources, including information on artists and artisans.* ICP currently maintains a list of artists in Puerto Rico, though it is thought to be incomplete. A list of local artists would improve access to recovery resources and assist with future resiliency in this sector.
- *Improved emergency preparedness for cultural heritage sites, cultural institutions, and artists.* Emergency plans should be created for all major cultural and historic resources and need to be tailored to the idiosyncratic needs and resources of each institution or individual. There is currently no regulatory or legal requirement that all institutions provide proof that they have indeed created emergency plans.[163]

Longer Term

Resiliency and future preparedness are key challenges for cultural and historic resources. Over the next one to ten years, Puerto Rico's priorities include:

- *New information and datasets describing historical and cultural heritage sites.* The Historic Structure Report (HSR) and Cultural Landscape Report (CLR) would be useful to guide restoration for each structure damaged in Puerto Rico; account for proper treatment and conservation of historic materials, archaeological surveys of the site, and curation of any museum collections generated by the project; improve documentation of the site's significance; and aid educational programming, site maintenance, and future disaster resilience.
- *Repairs and future resilience of parks and recreation sites.* The hurricanes inflicted significant damage to facilities in the eastern two-thirds of the island, many of which were already at end of lifecycle and pre-dated modern hurricane-resistant building codes. Park resiliency was significantly impacted by resource shortages for upkeep and complex under-documented ownership structures.
- *Additional funding sources to support recovery in the cultural sector.* Once cultural resources are identified and damage are quantified, funding sources may be applied to

[163] Personal conversations with CRAC (Cultural Resources Advisory Committee), which includes ICP, SHPO, and NPS employees who expressed concerns about this lack of regulation.

help this sector recover. However, a number of challenges remain. For example, smaller museums, libraries, and arts organizations that suffer from problems like mold and flooding and that did not have the pre-storm resources to plan ahead currently have lower capacity to recover. Artists and artisan communities, the majority of whom do not qualify for PA, have lost their entire inventories and sources of income. This population will require long-term support to bounce back (Beta-Local, 2018).[164]

[164] Personal communications with Amy Schwartzman.

11. Energy Systems

Overview

Hurricanes Irma and Maria inflicted extensive damage to Puerto Rico's electrical and fuel systems. The damage to the energy sector and the protracted restoration and recovery efforts had significant and extended effects on many other sectors as documented elsewhere in this report, including health and human services, transportation, communications, and water. In turn, Puerto Rico's pre-existing infrastructure and economic challenges, coupled with the scale and extent of the hurricane damage on the electricity grid, further challenges Puerto Rico's ability to restore its energy sector and enable it to meet the evolving demands of its people.

This chapter describes background, pre-hurricane conditions, and the effects of Hurricanes Irma and Maria on Puerto Rico's energy systems. As authorized in congressional mandate (*H.R.1892 - Bipartisan Budget Act of 2018*, 2018), the electricity subsector is specifically identified as "electric power systems and grid restoration." The other two energy subcomponents—oil and natural gas—are not specifically listed; they may fall within "other infrastructure systems, including repair, restoration, replacement, and improvement of public infrastructure such as water and wastewater treatment facilities, communications networks, and transportation infrastructure." Therefore, this chapter is organized into two sections, for the following subsectors: (a) Electricity and (b) Fuels (petroleum, natural gas, etc.).

A number of local and federal agencies have jurisdiction over different components of Puerto Rico's energy sector. A summary of agencies responsible for the electricity subsector in Puerto Rico is given in Table 11.1, along with their respective roles and relevant legislation and regulations. Key agencies in the fuel subsector are not included in the summary table, but are described in the Fuels section below. Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Energy Systems" Sector Report.

Table 11.1. Agencies Responsible for the Electricity Subsector

Agency	Role	Authorizing Legislation and Relevant Regulations
Puerto Rico Electric Power Authority (PREPA)	Publicly owned, vertically integrated utility that has been sole provider of electricity to Puerto Rico since 1941	PR Electric Power Authority Act of 1941; Puerto Rico Energy Transformation and RELIEF Act of 2014; Electric Power Authority Revitalization Act of 2016
Puerto Rico Energy Commission (PREC)	Oversees and regulates PREPA and energy companies since 2014	Puerto Rico Energy Transformation and RELIEF Act of 2014; Regulation on Integrated Resource Plan for the Puerto Rico Electric Power Authority; Microgrid regulations
State Office of Energy Public Policy	Develops the energy public policy for PR; liaises with federal entities such as US Department of Energy (DOE) and Federal Energy Regulatory Commission (FERC); Implementing agency for federally funded energy programs, including Weatherization Assistance Program (WAP) and State Energy Program (SEP)	Puerto Rico Energy Transformation and RELIEF Act of 2014
Federal Energy Regulatory Commission (FERC)	Limited oversight of environmental and health and safety matters	Federal Power Act of 1920
Financial Management and Oversight Board (FOMB)	Sole power to approve fiscal plans, budgets, debt restructuring agreements (both in court and through voluntary accord with bondholders), and critical projects (including energy sector efforts)	PROMESA Act (P.L. 114-187 (2016))
US Army Corps of Engineers (USACE)	Grid restoration and emergency assistance, including temporary power and microgrids	Stafford Act, P.L. 93-288, as amended; National Disaster Recovery Framework
US Department of Energy (DOE)[a]	Infrastructure Recovery Support Function (RSF): Facilitates the restoration of energy infrastructure systems and services to support a viable, sustainable community and improve resilience to and protection from future hazards	National Disaster Recovery Framework
US Environmental Protection Agency (EPA)	Ensures environmental regulations are followed (e.g., Mercury and Air Toxics Standards, MATS, under the Clean Air Act)	National Disaster Recovery Framework
Federal Emergency Management Agency (FEMA)	Grid restoration and emergency assistance	Stafford Act, P.L. 93-288, as amended; National Disaster Recovery Framework

[a] Note: DOE serves as the coordinating agency for Emergency Support Function #12 - Energy (ESF-12) under the National Response Framework and as the Sector Specific Agency (SSA) for Energy under Presidential Policy Directive 21.

Data sources and methods

Data sources

Most of the initial energy sector damage assessments (for both electricity and fuels) were completed in fall 2017. Several damage assessments were conducted, with varying degrees of granularity, scope, and geographic coverage. These assessments and other data sources used in this chapter are summarized in Table 11.2.

Table 11.2. Selection of Existing Damage Assessments

Dataset	Source	Date Range	Pre-Storm	Post-Storm	Recovery	Acquisition Status	Evaluation Notes
Feeder Lines and Poles	Restoration Contractors	Jan. sample	--	Y	Y	Subsample Acquired, further data available upon request	Mixed quality – One contractor (Cobra) provided granular and detailed data, but covers only 2 regions in the southeast; 14 other contractors did not use same level of documentation
Sub-transmission and Distribution Damage and Restoration Progress	PREPA, USACE	Multiple, including 3/19	--	Y	Y	Acquired	Mid-range quality – damage description varies; Includes both damage assessment and restoration data
Substation Flooding	NYPA	10/17	--	Y	N	Acquired	Detailed inspection reports on 18 flooded substations
Transmission Damage and Restoration Progress	PREPA, USACE	Multiple, including 3/19	--	Y	Y	Acquired	Mid-range quality – damage description varies; Includes both damage assessment and restoration data
KPI Daily Update	PREPA	Daily Updates	--	Y	Y	Acquired	Data back to beginning of response available 'with project'; daily update including electrification, substations, feeders, supplies, load
Nighttime Lights	University of Michigan	9/17 – 1/18	Y	Y	Y	--	Proxy/back-up for on-the-ground assessment
Nighttime Lights	NASA	9/17 – 1/18	Y	Y	Y	--	Proxy/back-up for on-the-ground assessment
HIFLD Open	DHS	2017	Y	N	N	Acquired	Open data have moderate accuracy on location and structural detail.
IP Network Response Rate	MIT	9/17 – 1/18	Y	Y	Y	Acquired	Mixture of both power and network (communications) availability

Methods

The HSOAC team collated data and developed maps and counts to assess damage and needs for the Energy sector. Where inconsistencies are found in the data, the team worked through a process to either (a) resolve the difference, or (b) present both sets of information. In select instances when systematic data were not available, HSOAC conducted analysis of aerial photographs; therefore, some damage percentages are estimates based on visual inspection.

Data gaps, assumptions, and uncertainties

Much of the information provided by partners in the Energy sector is either (1) marked as For Official Use Only (FOUO), or (2) developed or adapted from proprietary (private) sources; thus, this information is sensitive. Obtaining non-sensitive data is difficult. Data available on infrastructure locations are also currently incomplete.

This version of the damage assessment concentrates on the current state of the energy sector and offers a snapshot, including information up to March 19, 2018; HSOAC continues to receive new information daily. Consequently, some emergency management data sections are sparse. In particular, data on the fuels subsector are very incomplete. Information on the prior state of the system is incomplete (e.g., location of assets, power requirement, and criticality of priority facilities are unknown; maintenance level of assets is often unknown). Finally, the governance structure in the electricity subsector is in flux as of this report writing.

Electricity

Background

Electricity use per capita in Puerto Rico is only about 40 percent of the average for all 50 states (U.S. Energy Information Administration, 2017). According to the U.S. Energy Information Administration, Puerto Rico does not have proven stores of coal, natural gas, or oil reserves (U.S. Energy Information Administration, 2017);[165] therefore, it imports all its fossil fuels in order to produce energy. This places Puerto Rico at a disadvantage compared with U.S. states, which produce electric power at an average of less than half of Puerto Rico's costs.

However, while more expensive than the U.S. average, the price of electricity for consumers in Puerto Rico is comparable to that on other islands. For example, electricity prices in Puerto Rico are lower than those in Hawaii. Table 11.3 shows a comparison of electricity prices for different sectors for Puerto Rico, the U.S. average, and Hawaii.

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Table 11.3. Price of Electricity in Cents/kWh

Sector	Puerto Rico	US Overall	Hawaii
Residential	20.47	13.19	28.76
Commercial	22.39	11.04	26.22
Industrial	18.64	7.25	22.41
Transportation	[unknown]	10.07	[unknown]
Total	21.16	10.98	25.49

SOURCE: U.S. Energy Information Administration, "Territory Energy Profile Data." 2018. Accessed April 3. https://www.eia.gov/state/data.php?sid=RQ.

History and structure of the electricity subsector

In 1941, the Government of Puerto Rico began to consolidate control and governance of public electric power generation. Previous generation efforts were locally controlled or relied on private power generation. Since 1979, this consolidated publicly owned utility has been known as the Puerto Rico Electric Power Authority (PREPA). In 1981, PREPA assumed control of all Commonwealth-owned electric power systems in Puerto Rico (PREPA, 2018b). PREPA is one of the largest publicly owned utility companies in the United States; most utilities in the United States are privately owned. In 2014, it ranked first among U.S. publicly owned utilities in terms of both customers served (1.5 million) and electricity revenues ($4.6 billion) and ranked ninth in terms of power generation (12.7 million mWh) (American Public Power Association, 2016).

PREPA is governed by a nine-seat board: Six seats are appointed by the Governor of Puerto Rico, two seats are elected by power consumers, and one seat is reserved for the Secretary of the Department of Transportation and Public Works (PREPA, 2006). For daily operations, the Board selects an executive committee, which is led by the Executive Director. From 1941 until 2014, PREPA operated independently of any regulatory oversight other than direct legislative control. This arrangement is common among municipal utilities. The government of Puerto Rico occasionally made legislative efforts to augment PREPA's functions, including efforts to move toward greater use of renewable energy sources.

In 2014, following a series of complaints about management and electricity service, the Government of Puerto Rico passed the Energy Transformation and RELIEF Act (Government of Puerto Rico, 2014), which created the Puerto Rico Energy Commission (PREC). PREC is an independent oversight board and regulatory authority that is managed by a commission president and two associated commissioners and charged with implementing Commonwealth public policy as it relates to energy (Puerto Rico Energy Commission, undated). PREC was given powers to oversee PREPA's energy rates, power generation, and interconnection matters, as well as implementation of the standards for renewable energy production (as adopted in 2010). In mid-2017, due to the inability to service approximately $9 billion of outstanding debt, PREPA began a judicial debt restructuring process pursuant to Title III of the Puerto Rico Oversight, Management, and Economic Stability Act of 2016 (PROMESA).

Key assets

The electricity subsector comprises generation, transmission, and distribution. The generating capacity of the Puerto Rico Electricity grid has been stable at approximately 6 GW over the past five years (PREPA, 2018b). Selected major generation assets are summarized in Table 11.4. Approximately 57 percent of Puerto Rico's electricity is produced from petroleum (fuel oil), 31 percent from natural gas, 18 percent from coal, and 3 percent from renewable energy (wind, solar, biomass, and hydroelectricity) sources (U.S. Energy Information Administration, 2018a).

In 2010, Puerto Rico enacted legislation that set a target of producing 12 percent of its electricity from renewable sources starting in 2015 and scaling up to 15 and 20 percent by 2020 and 2035, respectively (U.S. Energy Information Administration, 2018a). The 2015 goal was not met. As of June 2017, 2.4 percent of PREPA's electricity came from renewable sources (approximately 1 percent wind, 1 percent solar, 0.35 percent hydroelectric from 21 units, and 0.05 percent biomass via landfill gas facilities) (U.S. Energy Information Administration, 2018a). The largest solar farm on the main island (Isabela, 45MW) came online only between September 2016 and May 2017 (U.S. Energy Information Administration, 2018a).

The transmission network includes high voltage lines (115 and 230 kV) and a sub-transmission network (38 kV) (PREPA, 2014). According to PREPA documentation, in 2013, Puerto Rico had 2,478 miles of transmission lines and 279 38 kV substations. However, informal communications with government officials suggest somewhat different estimates in 2017: 2,588 miles of transmission lines, supported by a total of 42,262 poles.[166]

The power distribution network in Puerto Rico predominantly has voltage classes of 4.16, 8.32, and 13.2 kV.[2] PREPA estimated a total of 31,485 miles of distribution lines in 2013 (PREPA, 2018b). However, a 2017 estimate (based on informal interviews) suggests a much smaller total of about 16,000 miles, supported by nearly 335,000 distribution poles.[167]

Figure 11.1 gives a general sense of the major elements of the Puerto Rican electric grid as reported by publicly available sources, including major power plants and transmission lines. These sources include the DHS HIFLD Open dataset, which shows transmission lines, and publicly available PREPA system maps, which show generating stations.

[166] Email correspondence from Alex Breckel (Energy Recovery Support Function Lead, DOE) to Martha Merrill on February 27, 2018. The main source of this information comes from PREPA's E-GIS system

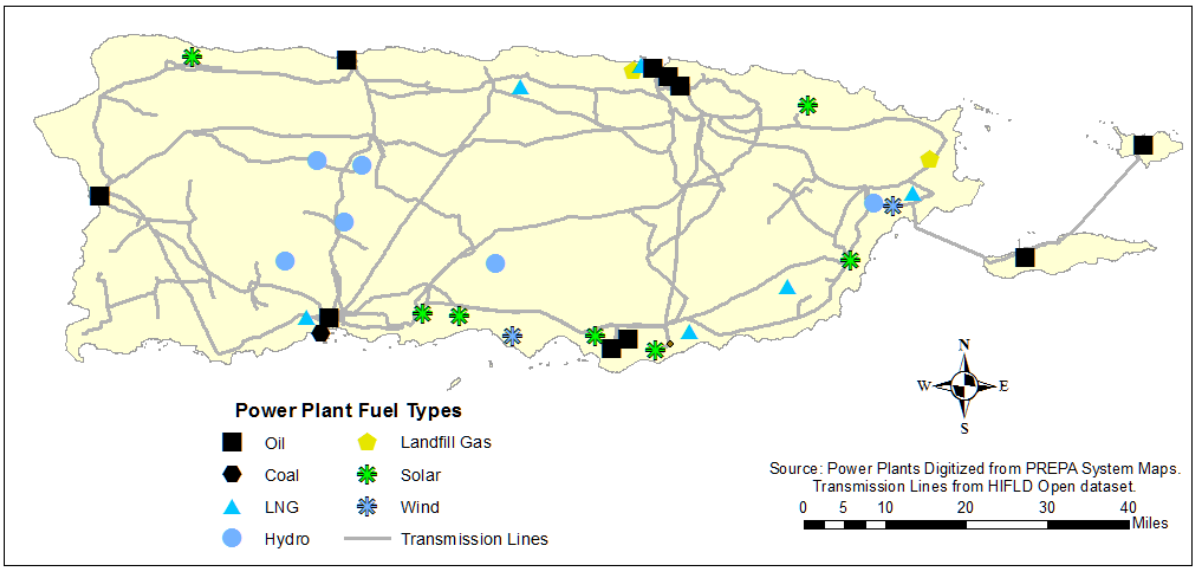
[167] Email correspondence from Alex Breckel (Energy Recovery Support Function Lead, DOE) to Martha Merrill on February 28, 2018

Table 11.4. Major Power Plants in Puerto Rico

Plant	Capacity (MW)	Site	Construction Year	Fuel
PREPA				
San Juan Generation Plant	400	San Juan Site	1965-1969	OIL #6 Fuel
Costa Sur Generation Plant	990	Guayanilla Site	1962-1973	NG / OIL #6 Combination Fuel
Palo Seco Generation Plant	602	Cataño Site	1960-1970	OIL #6 Fuel
Aguirre Generation Plant	900	Salinas Site	1975	OIL #6 Fuel
Aguirre Combined Cycle Generation Plant	592	Salinas Site	1977	OIL #2 Fuel
Cambalache Generation Plant	247	Arecibo Site	1997	OIL #2 Fuel
San Juan Combine Generation Plant	440	Arecibo Site	2008-2009	OIL #2 Fuel
Mayaguez Generation Plant	220	Mayaguez Site	2008	OIL #2 Fuel
Private				
EcoElectrica Generation Plant	507	Peñuelas Site	2000	LNG (Liquified Natural Gas)
A.E.S. Cogenerator Generation Plant	454	Guayama Site	2002	Coal Fuel

SOURCES: (1) (PREPA; Puerto Rico Energy Commission, 2015; U.S. Energy Information Administration, 2018a)

Figure 11.1. Select Elements of Puerto Rico Electric Grid



SOURCE: "HIFLD Open." 2018. Accessed April 3. https://hifld-geoplatform.opendata.arcgis.com/.

Pre-hurricane conditions

The financial and governance issues facing the electricity sector in Puerto Rico predate the September 2017 disasters caused by Hurricanes Irma and Maria. Those storms led to a catastrophic technical failure of an already aging and stressed system of electricity generation and distribution. The storms' aftermath further complicated the ability of the Commonwealth to restructure its debt obligations while providing necessary electricity services to its residents. The storms also triggered federal assistance programs designed to respond to natural disasters. PREPA, as a public utility, is eligible for FEMA help under the PA Grant Program and the Stafford Act.

Declining economic and population trends in Puerto Rico prior to Hurricanes Irma and Maria led to major challenges in funding the maintenance, expansion, and improvement of Puerto Rico's energy sector. Ultimately, these challenges contributed to Puerto Rico's high level of debt—$73 billion, or approximately 68 percent of gross domestic product (GDP)—and PREPA's debt, which includes over $9 billion in outstanding bonds and an additional $3.6 billion in underfunded pension obligations (PREPA, 2017; Walsh, 2017; Bradford, 2017). Absent a restructuring of the obligations, the current levels of debt constrain spending of hurricane recovery funds and could make future debt financing expensive because of the high assessed risk of default (Federal Reserve Bank of New York, 2014a).

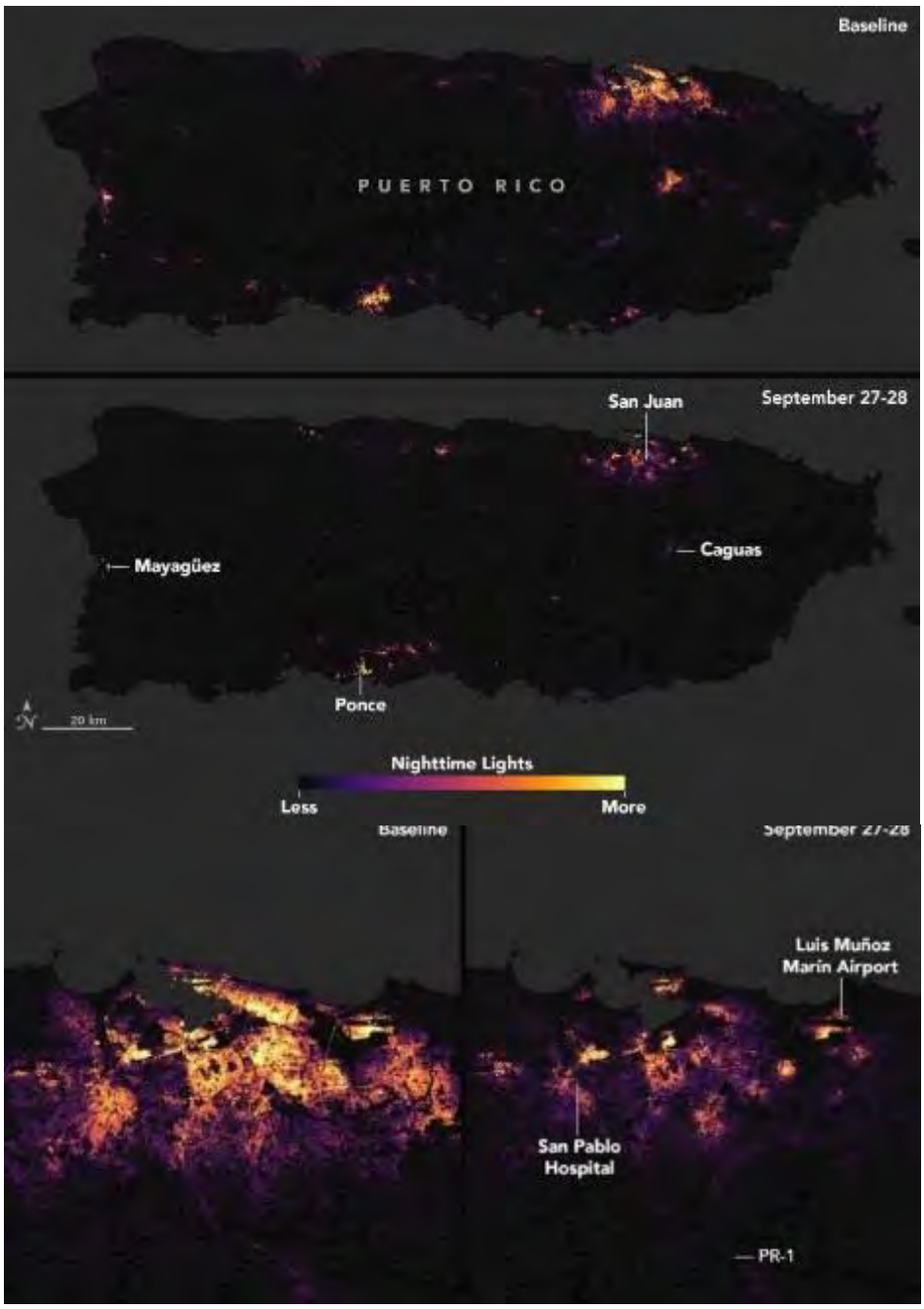
Puerto Rico's electricity sector also faced many functional and operational challenges prior to the hurricanes. In particular, five of PREPA's eight major power plants were constructed before 1980 (PREPA, 2018b), and consumers experienced blackout rates that were four to five times higher than those for other U.S. utilities (Synapse Energy, 2016). The majority of the electricity generation capacity was located on the southern coast of the island (see Table 11.4 and Figure 11.1), while the majority of the electricity use occurred in the more populous north. The connecting transmission system traversed the mountainous geography of the central island, with reduced accessibility, adding to the fragility of the system. Infrastructure maintenance has been challenging due to more-rapid degradation in a hot, humid, saline, and densely vegetated, environment—especially for remote assets. Combined with aging and inadequately maintained electricity infrastructure assets, this environmental challenge left the system brittle and highly vulnerable to storm damage from the hurricanes ("Be PREPA-ed: The story of Puerto Rico's power grid is the story of Puerto Rico," 2017). Repairs were also slowed by differences from CONUS systems in voltage and other technical specifications, making parts harder to obtain.

Hurricane damage

The damage to the electricity sector was catastrophic, causing the entire transmission system to fail. Immediately following Hurricane Maria, one hundred percent of the island lost power, and over 25 percent of PREPA's towers and poles were downed or damaged (Table 11.5). Nighttime

satellite images show a striking lack of power immediately after the storm (September 27-28, Figure 11.2). During the day, catastrophic failure of the electricity grid was evident from the air. Nearly five months after the hurricane, photographic evidence continued to show downed power lines, downed or restrung transmission lines, and significant new infrastructure (poles, lines) being brought in at locations across the island (Figure 11.3).

Figure 11.2. Nighttime Lights for the Main Island of Puerto Rico



NOTES: Top is a composite satellite image from prior to the storm. Middle: after the storm (evening of Sept 27-28). Bottom: close-up of San Juan for same time. Sources: (NASA Earth Observatory, 2017; Clifford, 2017).

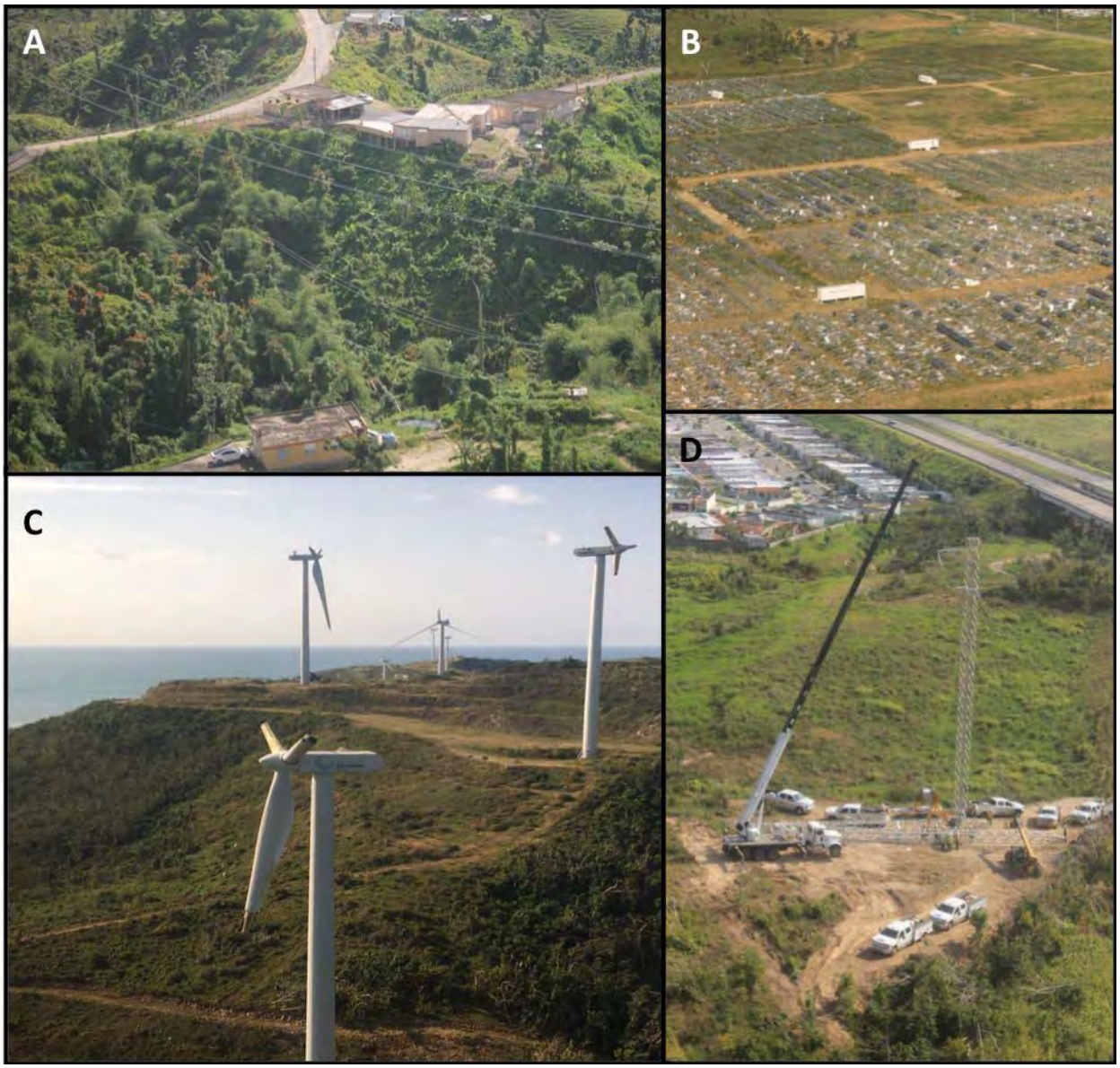
Damage to power production

The larger, fossil fuel-based power plants that generate most of Puerto Rico's electricity (approximately 96 percent) did not suffer major damage in the storm (Puerto Rico Electric Power Authority, 2017). However, renewable power installations suffered a wide range of damage depending on their locations.

No major damage was reported to Puerto Rico's many small hydroelectric installations. The main island's two major wind farms saw contrasting outcomes, with the Punta Lima wind farm experiencing heavy damage, while the Santa Isabel wind farm had no visible damage.

Damage to solar farms also varied. The HSOAC team analyzed post-storm aerial photographs (National Oceanic and Atmospheric Administration, undated-b), estimating damage percentages based on visual inspection of displaced solar array elements. The La Comita Solar Farm in the hard-hit southeastern sector of the island saw light to moderate damage (10 to 20 percent) to its Phase 1 arrays, and heavy damage (perhaps 80 percent) to its Phase 2 arrays (Figure 11.3, "C"). Other plants and solar farms, including the AES Illumina solar plant near Puerto de Jobos, Cotto Laura, Oriana solar farm near Isabela, and the San Fermin (Loiza Energy) solar farm near San Juan, saw light to moderate damage (between 5 and 20 percent). In general, solar arrays on the northern coast fared considerably better than those in other locations. Several extensive solar roof installations were also observed to have no visible damage, including the large installation on the roof of Honeywell Aerospace in Poblado San Antonio.

Figure 11.3. Example of Electricity Infrastructure Damage and Ongoing Repairs (March 7, 2018)



NOTES: A) downed power lines; B) damaged La Comita solar farm; C) damaged wind turbines; D) transmission tower under repair. Photo source: HSOAC Team (Jordan Fischbach; Joie Acosta)

Damage to transmission and distribution infrastructure

The total number of structures downed or damaged is continually being updated as more damage is identified. Table 11.5 provides PREPA's best estimate of transmission and sub-transmission pre-storm structures[168] and total damage (U.S. Army Corps of Engineers, 2018b). According to USACE, as of March 19, 2018, the entire restoration effort across transmission, sub-

[168] Email correspondence from Alex Breckel

transmission, and distribution required 170,000 insulators, 4,900 miles (26 million feet) of conductors, 780 towers, 50,000 USACE poles, and 10,000 transformers.[169] This lower-bound estimate of damage does not include counts of items repaired in place with existing/scavenged materials beyond the USACE restoration effort.

Table 11.5. Transmission Damage

	Transmission			
	115kV		230kV	
	Count	Percent Damaged	Count	Percent Damaged
Pre-storm structures	5,407		2,439	
Downed (towers/poles)	648	12	107	4
Damaged (insulators/other components)	834	15	404	17
Total downed or damaged	1,482	27	511	21

NOTE: These values were updated as of March 19, 2018.

Flooding was also a problem for portions of the transmission and distribution system. FEMA's Hazard Mitigation Group overlaid a map of substations with the new ABFEs, corresponding to a 1 percent and 0.2 percent chance of flooding per year (see Chapter 8, Housing). Of 345 substations in the system, 86 (25 percent) were in the 100-year floodplain, and 101 (29 percent) were in the 500-year floodplain.[170] Given that the flooding was at record levels throughout the island, it is almost certain that these substations were exposed to flooding that resulted in damage. Flooding can result in a number of types of damage, including (but not limited to) the potential for water damage to electrical lines and circuits, debris washed into the substation, and inundation with silt. The New York Power Authority (NYPA) has produced a damage verification report on PREPA substations which provides detailed flood damage assessments for 18 flooded substations (New York Power Authority, 2017).

Post-hurricane response

Emergency response operations

Emergency response operations began immediately following Hurricane Irma, intensified after Hurricane Maria, and are continuing. Immediately following the storm, aerial damage assessments began in Puerto Rico, and initial advance power restoration teams arrived to conduct

[169] USACE manages ordering the required materials for the restoration effort in coordination with PREPA, FEMA, and DOE. These estimates are based on materials ordered, assuming that all ordered materials are required.

[170] Substation Summary Analysis, FEMA Hazard Mitigation. Email correspondence from Alex Breckel (Energy Recovery Support Function Lead, DOE) to Martha Merrill on March 20, 2018.

power assessments and install emergency back-up power at critical sites. On October 4, 2017, President Trump tasked USACE to lead planning and coordination efforts for power restoration in Puerto Rico.

As the extent of damage to the power grid became clear, both the Government of Puerto Rico and FEMA took steps to mobilize power restoration crews. Initially, PREPA did not activate mutual assistance agreement mechanisms, which would have brought in crews from other large electricity agencies on the mainland. Instead, PREPA opted to contract out initial work to smaller companies for fear that it would not be able to repay larger mutual assistance providers (Bade, 2017).

By the end of October 2017, when it was clear that the scale and speed of power restoration efforts needed to increase, Governor Rosselló requested mutual aid assistance from power companies in the continental United States. On October 31, it was reported that "The electric power industry has deployed restoration crews and Incident Management teams in response to PREPA's formal request for mutual assistance (U.S. Department of Energy, 2018b)," and the first of 13 additional power restoration contracting teams arrived in early November. The extent of damage to the electricity infrastructure, due to both the age of the system and storm damage, severely hampered early efforts at power restoration. Crews arrived before necessary supplies, and the types of supplies required were often specific to Puerto Rico.[171] As a result, some restoration efforts relied on scavenging necessary parts for immediate restoration (Parraga, 2017b; Marex, 2017). Plants lacked "black start" capability (the capacity to restart without drawing power from the electricity transmission grid), making it extremely difficult to restart many power generation sources (Parraga, 2017b; Marex, 2017). Access to transmission lines was hampered by line locations in rugged terrain and large amounts of unmanaged vegetation.

While not providing direct measurement of power outages, MIT Lincoln Laboratory conducted a study that tracked Internet Protocol (IP) network response rate over time as a proxy for service restoration after both Hurricane Irma and Maria (Figure 11.4).[172] Of note is that Hurricane Irma caused decreased response rates, but these rates were almost back to pre-storm levels within a week. This kind of damage and recovery is what might be expected after a strong storm on the U.S. mainland. However, following Hurricane Maria, response rates recovered much more slowly, remaining decreased to 30 percent to 40 percent of pre-storm levels even after 3 months of recovery.

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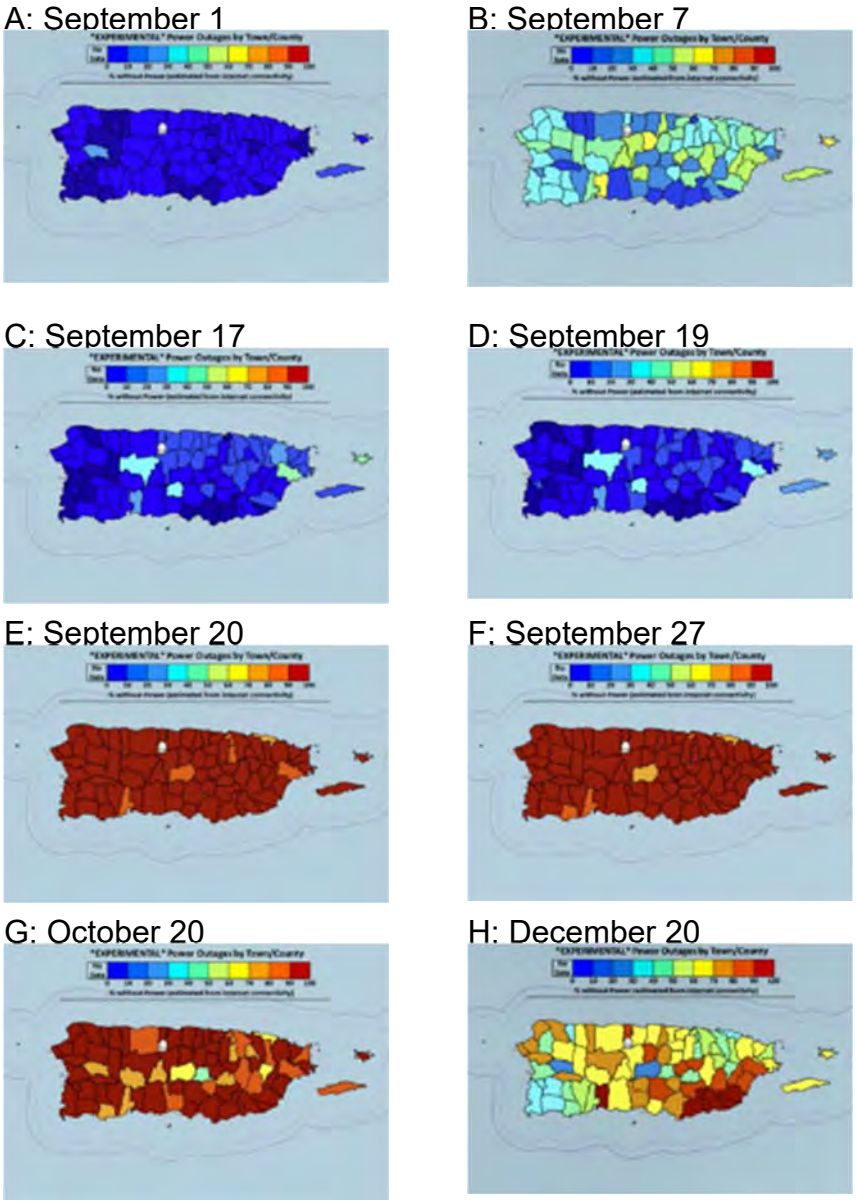
[171] SENSITIVE: Infrastructure Systems Recovery Support Function (IS-RSF): Fuels Subsector Listening Session Draft Notes, January 8, 2018.

Email correspondence from Patrick Massey (IS-RSF, DHS-NPPD) to federal partners, January 11, 2018.

[172] This study tracks the number of IP devices in Puerto Rico that are capable of responding to network traffic. Since IP devices require both electrical power and data connectivity, the indicator is not a perfect indication of power outages, but it can be expected to be closely correlated with power outages.

Figure 11.4. Power outage over time as a function of IP network response rate relative to pre-Irma



NOTES: A: Pre-Irma. B: September 7 (one day after Irma passed to northeast side of island). C: 9/17: (one week after Irma). D: September 19 (prior to Hurricane Maria Landfall). E: Sept 20 (day after Maria landfall). F: September 27 (1 week after Maria landfall). G: October 20 (1 month after Maria landfall). H: December 20 (3 months after Maria landfall). SOURCE: Puerto Rico Power Outages, Lincoln Laboratory, Massachusetts Institute of Technology (MIT-LL). Email correspondence from Jonathan Pitts of MIT-LL to Aimee Curtright and Martha Merrill, March 16, 2018.

Repairs and current conditions

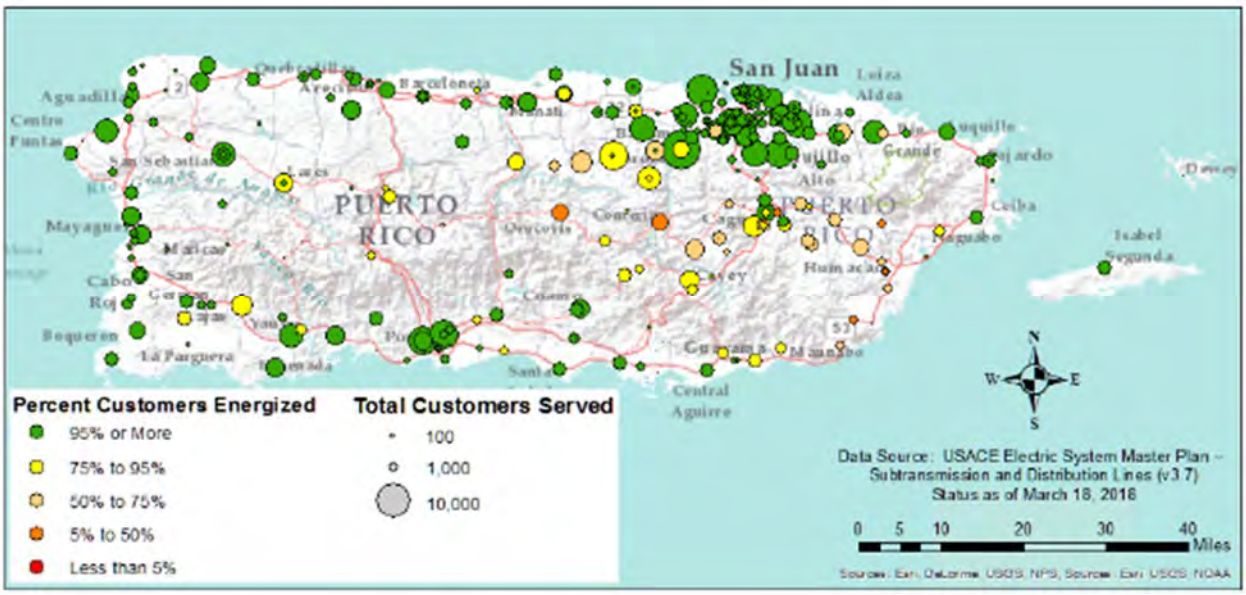
As of a March 18, 2018 snapshot, USACE data showed that power had been restored to 92.9 percent of customers. Figure 11.5 summarizes customer power delivery status by distribution substation on this date. However, this information does not indicate that the system was 92.9

percent repaired at that time, as transmission, sub-transmission, and distribution lines were in various states of repair.

Of the transmission lines, 73 percent were energized, and 27 percent were not (U.S. Army Corps of Engineers, 2018a).[173] These functional lines were enough to supply power to the vast majority of substations. However, this power was not as reliable as it would have been if all transmission lines were in service, thereby providing a degree of transmission redundancy. Of the sub-transmission lines, 59 percent were fully energized (with more than 95 percent of customers receiving power), 26 percent were partially energized (with 5 to 95 percent of customers receiving power), and 16 percent were not energized (with fewer than 5 percent of customers receiving power) (U.S. Army Corps of Engineers, 2018a).

Of distribution circuits, 77 percent were energized (i.e., greater than 95 percent energization; 930 circuits), 13 percent were in progress (155 circuits), and 10 percent were not in progress (117 circuits) (U.S. Army Corps of Engineers, 2018a).

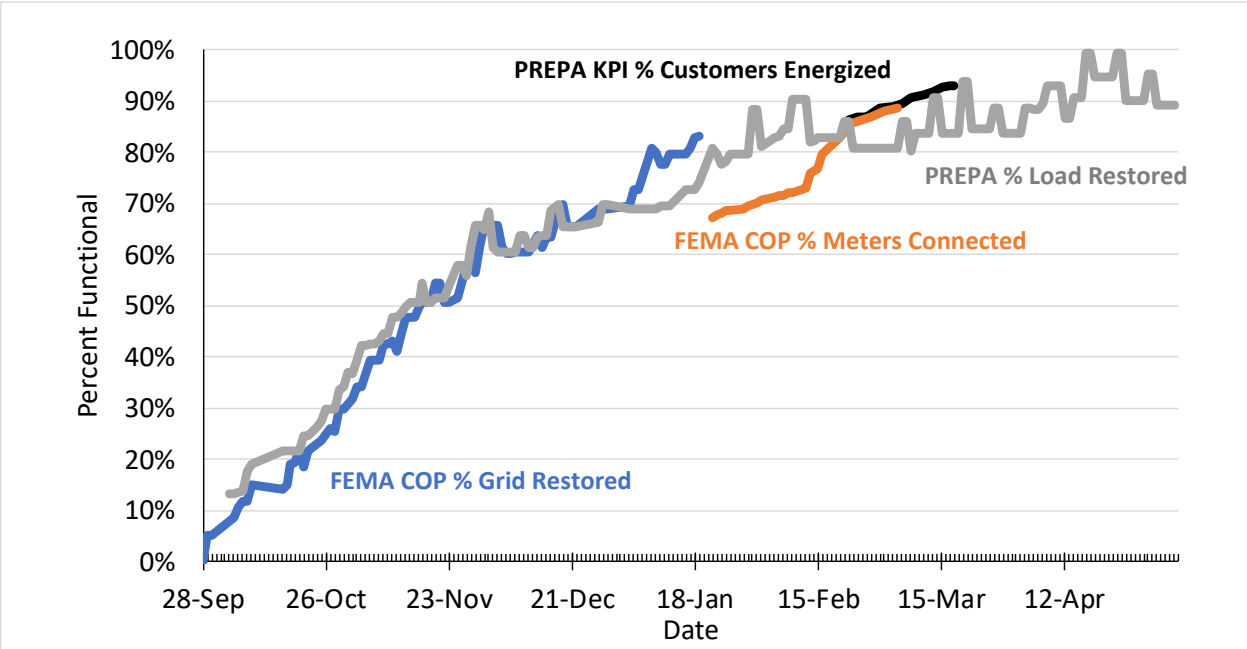
Figure 11.5. Status of Customer Power Delivery by Distribution Substation as of March 18, 2018



SOURCE: (PREPA, 2018a)

Figure 11.6 shows the history of the power restoration effort starting September 28, 2017—about one week after the storm—until May 8, 2018. Grid function data are presented in three series, two complied from FEMA Common Operating Picture (COP) documents, and one compiled from PREPA's Key Performance Index (KPI) daily updates. Although these indicators measure slightly different aspects of electric grid status, the figure makes clear the slow and steady nature of the power restoration effort.

Figure 11.6. Daily Overall Grid Status from Sept 28, 2017 to May 7, 2018



NOTE: Various measures indicate slightly different aspects of grid restoration. The discontinuity around January 20, 2018 reflects a change in FEMA's indicator of grid status from PREPA's "% of the power grid restored" (percentage of normal peak load) from September 28 to January 19, to "% of power meters connected" from January 22 to March 5. PREPA's Daily Updates resume on February 5, tracking "% of customers energized," which tracks well with the later FEMA COP indicator. SOURCE: (Puerto Rico Electric Power Authority, 2018)

While much progress has been made, it is expected that final steps will continue to be slow. Unofficial reports suggest that much of the remaining seven percent of distribution customers (as of March) were in the mountains and that these circuits will require helicopter work to repair, thus requiring several more months. These final circuits are the most difficult to repair and serve relatively few people per circuit. Attaining full reliability and 100 percent service is expected to require substantial additional time and effort.

Fuels

Background

In Puerto Rico, no fossil fuels are currently extracted or refined. Thus, key fuel subsector infrastructure consists of (a) ports and terminals to accept imported fuels, and (b) transportation of these fuels (typically via truck) to power plants, households, or gas stations (U.S. Energy Information Administration, 2017). The quantity of imported petroleum products is shown in Table 11.6, and a map of select petroleum and natural gas infrastructure assets is shown in Figure 11.7. Although Puerto Rico has multiple petroleum ports and terminals, natural gas is primarily delivered to a single location, the EcoEléctrica Guayanilla Bay Liquified Natural Gas (LNG)

Facility. This facility is capable of storing 160,000 cubic meters (1 million barrels) (Passut, 2017).

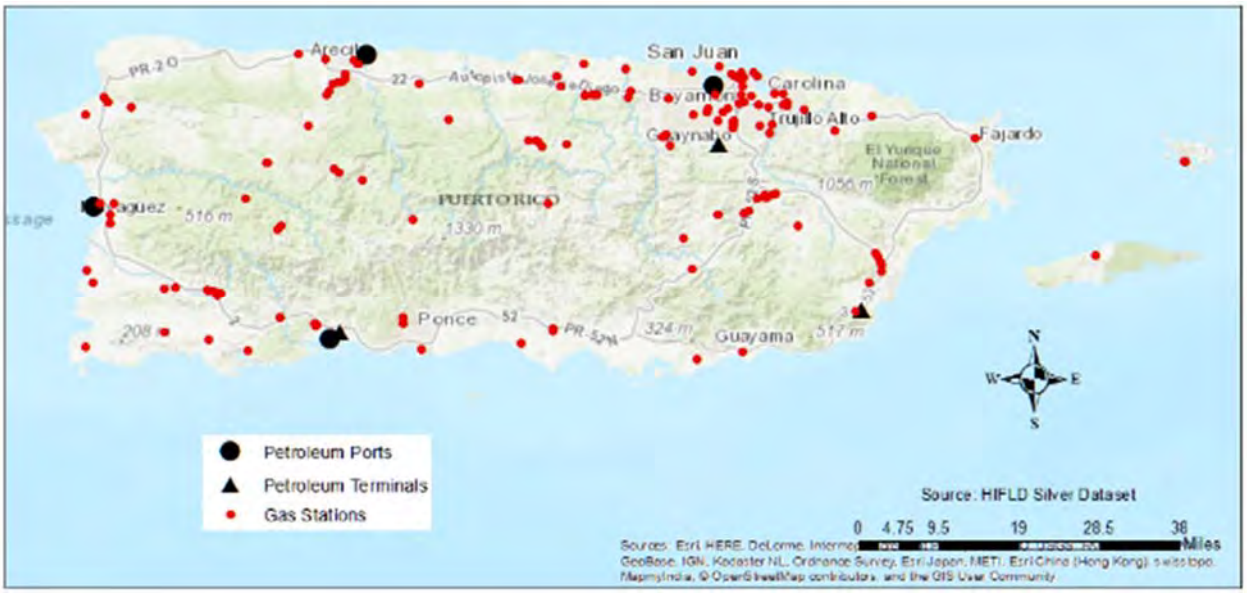
The power plants that supply electricity to the grid are powered by a mix of fuels. In the CONUS, the electricity fuel mix is mostly natural gas, coal, nuclear, and renewables (including hydroelectricity); petroleum is a very small component of the CONUS electricity generation system (U.S. Energy Information Administration). Conversely, Puerto Rico (like many islands) relies heavily on petroleum, with slightly less than half of the mix in 2017 coming from oil, approximately one-third coming from natural gas, and approximately one-sixth coming from coal (U.S. Energy Information Administration, 2018a; 2017). Because Puerto Rico neither produces nor refines these fuels (U.S. Energy Information Administration, 2018a), all fuel used on the island must be imported from the CONUS or other countries . Approximately one-third of imported petroleum is used for transportation in the form of gasoline or diesel to power automobiles and equipment (U.S. Energy Information Administration, 2018a), and approximately one-tenth is in the form of jet fuel, liquefied petroleum fuels, and/or kerosene (U.S. Energy Information Administration, 2018b) (U.S. Energy Information Administration, 2018a).

Table 11.6. Quantity of Fuels Imported into Puerto Rico in 2016 (thousand barrels)

Product Name	Port of Guayanilla	Port of Jobos	Port of Mayaquez	Port of Ponce	Port of San Juan	Total
Motor Fuels (For Road Use and Electricity Generation)	456	138	105	10,457	17,154	28,310
Jet Fuel	235				2,349	2,349
Propane	302			1,472	29	1,803
Butane					13	13
Kerosene					7	7
Asphalt and Road Oil	235					235
Total	993	138	105	11,929	19,552	32,717

Source: (U.S. Energy Information Administration, 2016)

Figure 11.7. Select Fossil Fuel Infrastructure Assets in Puerto Rico



SOURCE: Publicly available data from DHS HIFLD Open and Open Street Map (OSM). OSM gas station dataset includes only about half of the gas stations in Puerto Rico.

History and structure

The structure and governance of the fuel subsector in Puerto Rico includes both (a) stakeholders involved in a mix of fuel types used to produce electric power, and (b) the regulatory structure that oversees the safety, storage, and importation/transportation of various fuels (see Overview section). Because Puerto Rico imports most of its fuel sources (U.S. Energy Information Administration, 2018a), the regulatory environment for importation is determined by whether these fuel sources come from CONUS or international suppliers.

Unlike the electricity subsector, the fuel subsector has no publicly-owned utility or related independent regulatory commission to provide oversight. Instead, many government authorities, both in Puerto Rico and CONUS, have jurisdiction over various components of the fuel subsector. When considering the fuels and related infrastructure such as pipelines, key U.S. governing agencies with oversight for the fuel sector in Puerto Rico include the U.S. Department of Energy, the Pipeline and Hazardous Materials Safety Administration, and USACE.

Puerto Rico also imports goods, including fuel resources, from non-U.S. ports. The Federal Energy Regulatory Commission (FERC) has jurisdiction over LNG imports. For domestic distribution, the Puerto Rico Public Services Commission governs the retail sales of LNG for home use.

Other agencies have specialized jurisdiction over activities relating to the fuel subsector. For example, USEPA, Puerto Rico Department of Natural and Environmental Resources, U.S. Department of Transportation, and Puerto Rico Department of Transportation and Public Works oversee the safe handling, use, storage, and transmission of hazardous materials.

Pre-hurricane conditions

U.S.-derived fuel resources (those shipped from CONUS ports to ports in Puerto Rico) are subject to the Merchant Marine Act of 1920, otherwise known as the Jones Act. The Jones Act requires any transportation of goods from one U.S. port to another U.S. port to be ferried by a U.S.-flagged carrier (that is, a ship built, crewed, and owned by U.S. citizens). The Jones Act's rules generally apply unless specific waivers are granted by the executive branch. There may be higher costs for transportation from the CONUS to Puerto Rico (Frittelli, 2014). Whereas the Jones Act requirements can be and have been waived for the sake of hurricane recovery and rebuilding efforts, those waivers are often time limited. For Puerto Rico, the Trump administration issued a 10-day waiver from the Jones Act in September 2017 to facilitate emergency resupply efforts (Klein, 2017). The Jones Act's requirements do not appear to have contributed to the fuel distribution shortfalls after the hurricanes (described in the subsequent damage sections of this chapter).[174]

In general, aging and inadequately maintained fuel infrastructure assets left the system brittle and highly vulnerable to storm damage from the hurricanes ("Be PREPA-ed: The story of Puerto Rico's power grid is the story of Puerto Rico," 2017).

Hurricane damage

Key elements of the fuels subsector that sustained direct damage from the storms include the infrastructure required for fuel import from CONUS to Puerto Rico, fuel stockpiles, and distribution channels within Puerto Rico. In addition to these direct storm impacts, damage to other sectors, especially transportation and electricity, likely impacted the availability of fuel in the wake of the storm (U.S. Department of Energy and Office of Cybersecurity Energy Security and Emergency Response; U.S. Department of Energy, 2018a).

Damage to fuel import infrastructure

Descriptions of overall port damage are provided in the Transportation chapter of this report. The assessment of damage to the transportation sector (see HSOAC "Transportation" Sector Report, forthcoming) suggests that shipping terminals at the Port of San Juan suffered damage to buildings, fencing, fenders, and signage. The Port of Ponce sustained serious to critical structural damage, with the inspections also noting damage to liquid propane gas (LPG) pipelines. The ports of Fajardo, Pennuelas/Tallaboa, Guanica, and Yabucoa are all described as having sustained some damage, primarily due to wind, storm surge, and fallen trees. A damage assessments for the port of Guayanilla is not yet available as of the writing of this report.

In addition, according to the available information on the functionality of the privately operated Yabucoa terminal, which can store over 4 million barrels of crude and refined products,

[174] The Jones Act's effects on fuel supply to the island were invariant before, during, and after the hurricane. Thus, any changes to the fuel supply likely occurred due to a disruption along another part of the supply chain.

it had been supplying fuel from its storage tanks via truck since the week after Hurricane Maria but did not resume acceptance of incoming shipments until October 3, 2018 (Parraga, 2017b; Marex, 2017). According to a FEMA Fuel Crisis Action Plan from October 4, 2018, the terminal was operating in a degraded capacity because one of the terminal's industrial generators needed to be replaced (Federal Emergency Management Agency, 2018a).

Damage to fuel stockpiles

No damage to fuel stockpiles was identified. The only storage tank damage reported in available port assessments was to an asphalt storage container at Penuelas/Tallaboa (Gvelop, 2017,Transportation Damage Assessment Appendix).

Damage to distribution infrastructure

Without electricity and with many roads impassable to delivery trucks, fuel for cars and generators was quite scarce in the days immediately following the storm. On October 13, 2017, 238 of Puerto Rico's 1,110 retail gas stations (21 percent) were reported closed. It is not clear whether these stations were closed because of direct storm damage, lack of power, inaccessibility by road, economic factors, relocation of the owner, or some other reason.

While most fuel on Puerto Rico is transported by truck, some jet fuel is distributed via pipeline. The pipeline was not reported to have been directly damaged in the hurricanes but was temporarily removed from operation because of loss of electrical power.

Post-hurricane conditions

Emergency response

In early October 2017, additional shipments of diesel fuel and generators were delivered from CONUS to help restore power to critical facilities such as hospitals, airports, and ports. Fuel supply efforts were initially hampered by lack of power and damage to ports, debris, and damage to roadways.

Repairs and current conditions

Though the damage to the Puerto Rican fuel subsector was significant, it was not as long-lasting as the damage to the electricity subsector (U.S. Department of Energy, 2017). Notes in the DOE Daily Event Summaries for October 8, 2017 state that "Fuel supplies remain an area of focus across the region; however, the situation has stabilized" and that "Fuel stocks are adequate across the region; however, distribution remains a challenge" (U.S. Department of Energy and Office of Cybersecurity Energy Security and Emergency Response). By October 16, 2017, all ports that receive fuel petroleum deliveries in Puerto Rico and the U.S. Virgin Islands had been reopened, but with restrictions in place for some ports. The Governor's *Build Back Better* report notes a need for dredging at most of the major ports to address the continued restrictions on ship draft (Governor of Puerto Rico, 2017a).

By March 21, 2018, the assessment stated that fuel stocks were adequate, but that DOE continued to monitor the situation with the assistance of the Energy Information Administration (EIA) (U.S. Department of Energy, 2018a). Additionally, 140 of the island's 1,110 retail gas stations, or 13 percent, remained closed (U.S. Department of Energy, 2018a). The supply of tanker trucks delivering petroleum stored at the Yabucoa facility had resumed by September 28 (Parraga, 2017a), and a pipeline that delivers some jet fuel was restored to commercial power on December 27, 2017 (U.S. Department of Energy, 2018a).

Remaining needs and recovery priorities

The energy sector is a critical lifeline infrastructure. Most of the immediate emergency response needs (e.g., restore fuel supply, provide electricity to more than 95 percent of customers) have been met. Thus, this section summarizes both remaining needs for post-disaster response in the short term and needs for long-term resilience.

Short term

In the next one to 12 months, Puerto Rico's energy sector has a number of short-term priorities.

- *Electricity service for the approximately five percent of Puerto Rican customers who are still without power*. This is an immediate, high-priority need.
- *New inventory of energy assets to understand what types of energy assets exist, and where they are currently located so that emergency responders can enact repairs*. As Puerto Rico begins to enter the next hurricane season, existing vulnerabilities will continue.
- *Stockpiles of sufficient repair material and numbers of trained personnel or contractors authorized to conduct work in potentially unsafe conditions*. If materials are stockpiled at the same level as before the storm, all else being equal, stockpiled repair material will be insufficient if a Category 4 or 5 Hurricane makes landfall. It will also be important to ensure that sufficient numbers of trained personnel or contractors are authorized to conduct work in unsafe conditions.

Longer term

Building back to pre-storm conditions is not enough. The system needs to be "built back better." To build a resilient system, past issues of fiscal insolvency and technical deficiencies need to be identified and addressed using analyses that consider and balance governance, techno-economic, and financing evaluation criteria. Long-term resilience includes a need for an affordable, reliable supply of energy and a secure fuel supply. Meeting these needs will require addressing a number of challenges over the next one to 12 years.

- *Enhanced future response capacity, including improved communications within the utility, to customers (e.g., systems operation and billing), and among Commonwealth and federal agencies*. Reports suggest poor communications within the utility (e.g., SCADA) and to customers (e.g., systems operation and billing), a concern that may need to be

highlighted for future resilience. News reports suggested that, during response efforts, federal fuel demand crowded out demand from the Commonwealth and local stakeholders.

- *Sustainable funding for energy systems, ensuring sufficient funds for restoration and repair as well as future operations and maintenance*. Prior to the hurricanes, PREPA was already $9 billion in debt, and the Governor's Build Back Better Plan estimates that it will cost $17 billion to rebuild the grid. PREPA was collecting revenues from only 35 to 40 percent of customers more than four months after the hurricane, yielding insufficient funds for restoration and repair. The total amount of funding needed and sources from which this funding can be obtained are also highly uncertain. Thus, it is important to understand the range of likely scenarios and sources.
- *A clear, unified vision and improved management of the Energy sector*. This requirement includes both the need to understand which entity or entities are in charge and how codes and standards will evolve and be enforced. An overarching need in this area is to clarify the political landscape among PREPA, PREC, FOMB, and other stakeholders. Uncertainty in this sector will affect the viability of future response, recovery, and resilience efforts.

12. Water

Overview

This section documents the damage experienced by Puerto Rico's water sector in the wake of Hurricanes Irma and Maria, and needs to address long-standing management and infrastructure challenges within the water sector. For purposes of this assessment, we define the water sector broadly to include drinking water and wastewater systems and services; flood control and stormwater mitigation infrastructure and systems; and watershed management. The sections in chapter are organized around two subsectors: (a) Drinking water and wastewater and (b) Stormwater, flood mitigation, and integrated water management. Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Water" Sector Report.

The damage inflicted on Puerto Rico's water and wastewater systems has been one of the more highly publicized consequences of Hurricane Maria, especially owing to the critical functions that water and wastewater services play in maintaining public health, enabling commerce and economic activity, and conserving natural ecosystems and wildlife. Hence, recovery of water and wastewater systems is critical to broader recovery efforts across multiple sectors. In addition, the water sector encompasses other systems, such as stormwater and flood control infrastructure, that provide critical services. These, too, were damaged or disrupted by Hurricane Maria. Enhancing the resilience of Puerto Rico's water sector, however, necessitates repairing damage in a manner that acknowledges and addresses the legacy of system depreciation, underinvestment, lack of maintenance, and incomplete monitoring. Despite these challenges, the recovery process creates opportunities for renewing infrastructure and improving operations, finance, and asset management—all of which would place the sector on a more sustainable pathway.

A range of local and federal agencies have jurisdiction over different components of Puerto Rico's water resources (Table 12.1). Puerto Rico Aqueduct and Sewer Authority (or PRASA) is the principle principal public institution for development, operations, and management of Puerto Rico's water and wastewater systems and services. PRASA is regulated under the auspices of the Puerto Rico Public Service Commission (PRPSC). Given the interdependences between electricity and water, Puerto Rico Electric Power Authority (PREPA) also has an important role in ensuring the reliability of water infrastructure and services. The Department of Natural and Environmental Resources (DRNA) has responsibilities for environmental protection and natural resources management as well as the design, construction, and maintenance of flood-control works. Water research and professional development in Puerto Rico are led by the Puerto Rico Water Resources and Environmental Research Institute (PRWRERI) at the

University of Puerto Rico at Mayaguez, one of 54 water research centers established by an Act of Congress in 1964.

On the federal side, the EPA has regulatory oversight of drinking water, wastewater treatment, and discharges of pollutants into waterways. The EPA is currently working in Puerto Rico to support response and recovery efforts. Currently, USACE is supporting response and recovery of water resources infrastructure, particularly with respect to repowering pumping and wastewater treatment facilities. In addition, the U.S. Geologic Survey (USGS) collects water resources information in Puerto Rico, including at a number of surface, groundwater, and rainfall monitoring stations. The U.S. Department of Agriculture (USDA) supports drought monitoring and management efforts as well as water conservation programs to enhance the resilience of agricultural systems. The National Oceanic and Atmospheric Administration (NOAA) supports meteorological and climatological services, including weather forecasting and monitoring of oceanic and atmospheric conditions.

Table 12.1. Government Agencies in the Water Sector

Agency	Role
Puerto Rico Government	
Puerto Rico Aqueduct and Sewer Authority (PRASA)	Water and wastewater service, stormwater conveyance
Puerto Rico Public Service Commission (PRPSC)	Regulation of utilities and public services
Municipalities	Stormwater management, water and wastewater service
Department of Natural and Environmental Resources (DNER)	Watershed management and environmental protection, water storage
Puerto Rico Electric Power Authority (PREPA)	Irrigation conveyance systems, water storage (dams)
Puerto Rico Department of Health (DOH)	Drinking water monitoring
Puerto Rico Environmental Quality Board	Water and environmental quality
Puerto Rico Infrastructure Financing Authority	Financial oversight
Federal Government	
Environmental Protection Agency (EPA)	Water quality and stormwater management
U.S. Geological Survey (USGS)	Monitoring, modeling and scientific reporting
U.S. Department of Agriculture (USDA)	Rural assistance programs
U.S. Army Corps of Engineers (USACE)	Flood control
National Oceanic and Atmospheric Administration (NOAA)	Weather, climate analysis and reporting
Center for Disease Control (CDC)	Human health
Federal Emergency Management Agency (FEMA)	Disaster response

A number of other stakeholders also have interests in the health and functioning of the water sector. Manufacturing and industrial enterprises in Puerto Rico depend on the reliability of water

availability and quality. Medical and health services, such as hospitals, have similar sensitivities. The agricultural sector's distribution systems are often interlinked with residential water delivery. Satisfying the needs of those key consumers is important in enabling economic activity to recover. Recovery planning should include any short-term remedial water treatment needed due to impacts on Puerto Rico's water systems, and opportunities for improving water quality and reliability over the long term. A range of advocacy groups – environmental, consumer, or social justice – in both Puerto Rico and the United States likely have relevant knowledge and expertise and ideas for recovery. For example, the Natural Resources Defense Council has been a key advocate for water quality improvements in Puerto Rico.

Data sources and methods

Data sources

Our analysis has relied on available damage assessments provided by PRASA, FEMA, USDA, and EPA as well as Puerto Rico Government requests for federal assistance for disaster recovery. Arcadis was retained by subcontract to collect and survey damage to Puerto Rico's stormwater systems. Qualitative and quantitative information was obtained following interviews with agency staff and receipt of data transmitted directly to HSOAC researchers by the agencies. Table 12.2 summarizes the key datasets presented and analyzed in this section.

Table 12.2. Summary of Key Damage Assessment Data Sources

Dataset	Source	Date of Last Update	Evaluation Notes
Damage Inventory	PRASA, CSA Group, Arcadis	5/18/18	Inventory of 5,091 PRASA assets and surveyed damage
Operational Status	PRASA	2/28/18	Treatment plant and pumping station operating status and energy source (generator or grid)
Damage Assessments	PRASA, Arcadis	October/November 2017	Assessments and cost estimates of 159 PRASA facilities
Solar Assessments	FEMA	September 2017	Non-PRASA systems high-level damage, energy status
Damage Assessments	EPA, RCAP	2/22/18	Prioritized list of 27 non-PRASA drinking water systems, little damage data reported
Stormwater System Damage Assessments	Arcadis	5/14/18	Survey of damage and related costs to stormwater systems in 51 municipalities
Quantifying Sewage Contamination into the	NOAA	5/10/18	First order estimation of per month volumetric

Dataset	Source	Date of Last Update	Evaluation Notes
Environment			wastewater discharges into surface and coastal receiving waters
Surface Water Quality	USGS	Continuous monitoring	Continuous monitoring of surface water quality pre- and post-Maria in 2 streams and 1 coastal lagoon
Surface Water Stage	USGS	Continuous monitoring	Stream gauge measurements of surface water height before, during, and after Hurricanes Irma and Maria

Methods

The initial damage assessment process involved outreach to FEMA, other federal agencies, Puerto Rico government agencies, and non-governmental stakeholders to build understanding of the institutional arrangements and responsibilities for recovery and to survey potential sources of information on damage to the sector and its systems. Once data sources were identified, the HSOAC research team attempted to gain access, either directly from the source, such as PRASA or the EPA, or working through FEMA's Water Sector Chief and Deputy Chief. In addition, the HSOAC team identified data resources that are likely to become available in the future and characterized knowledge regarding damage that could be addressed through more-intensive data collection efforts, including the use of subcontractors.

Arcadis was contracted by HSOAC to conduct stormwater damage assessments. To perform these assessments, Arcadis gathered available mapping and system data, performed field interviews with 51 municipalities representing more than 70 percent of island municipalities, identified areas impacted by the hurricanes, and identified ownership of impacted stormwater assets. After collecting these data, Arcadis analyzed the information to develop an order-of-magnitude cost estimate of the damage per system based on two major categories: individual points of damage (collapsed pipe, damaged bridge culvert, landslide, etc.) and estimated area of damage (acres flooded, stormwater system area impacted, etc.) with average costs estimated on a per-item or per-acre basis. Most municipalities had no detailed cost estimates for damage, although actual cost estimates from municipalities were used when available. Source cost data included FEMA Cost Code Listing (2010), Arcadis Cost Guide (2014), Arcadis PRASA Hurricane Maria Recovery Efforts (2017) and detailed cost estimates or bid tabs from individual municipality stormwater system projects.

In addition to visiting municipalities, Arcadis met with the Department of Transportation and Public Works (DTOP) and Department of Natural and Environmental Resources (DNER) to discuss known damage to stormwater infrastructure managed by the departments. DNER provided the geographic coordinates of 14 pump stations that DNER owns or maintains. DNER did not provide additional information on damage to the pump stations as a result of Hurricane

Maria. Fourteen of the pumps are managed through the Division of Regional Operations, and two pumps are located at dams managed by the Division of Water and Minerals Management. DTOP described known areas of flooding following Hurricane Maria and approximate flood elevations, identifying a total area of approximately 19,800 acres. Damage and costs to DTOP and DNER systems are not included in this report, as data were not available.

The summary of damage provided in this document was derived from the data sources listed above (Table 12.2). With regard to PRASA facilities, separate Arcadis assessments carried out under contract to PRASA provided facility information, an itemized list of surveyed damage (with pictures), and an itemized list of costs corresponding to these damage. These assessments have been collated into a single spreadsheet for data analysis. Identified damage have been extrapolated to other facilities that lack assessments to generate estimated damage across Puerto Rico, either by PRASA or through this analysis. To ensure data consistency, the results from the Arcadis assessments of PRASA's facilities have also been cross-referenced against other inventories of damaged assets provided by PRASA and /FEMA. The damage inventory compiled by the CSA Group as of March 28, 2018 offers another set of information on damage to 5,091 PRASA facilities. While this inventory provides descriptions of damage for a significant fraction of those facilities, only a minority include detailed information on the value of those damage in dollars.

With regard to non-PRASA facilities, damage assessments were not standardized and rarely provided cost estimates. In this case, data analysis focused primarily on consolidating several different damage/status surveys into a single consistent assessment of each system. These surveys included details such as whether the site was still without power as of the most recent update, whether it had received a generator, whether it might be suitable for solar power, and what damage had occurred, although not all of this information was available for each of the non-PRASA sites. As such, the results presented in this report for non-PRASA facilities are largely qualitative since comprehensive quantitative damage data are unavailable.

Data gaps, assumptions, and uncertainties

Apropos to damage sustained by PRASA facilities, assessments for all damaged sites have been completed but require further detail and assessment before precise cost estimates can be obtained. In addition, PRASA's water mains and distribution and conveyance systems were not included in any damage assessments or inventories to date. These represent a large proportion of assets that could have been damaged in Hurricanes Irma and Maria.

Similarly, more-detailed and standardized damage assessments will be required to fully estimate damage and recovery costs for non-PRASA facilities damaged by the hurricanes. In addition, if renewable power generation for these more-rural facilities is the most viable option moving forward, more-complete assessments of solar power site compatibility will be needed.

A large proportion of dams, levees, and stormwater systems have been assessed by USACE, but those under the ownership of municipalities lack comprehensive assessments. The EPA is

working with Municipal Separate Storm Sewer System (MS4)-permitted municipalities to perform initial assessments and centralize information on the impacts of Hurricanes Irma and Maria for stormwater systems.

Until a more complete set of damage assessments is obtained, any total cost estimates made in this report will require extrapolation from existing data. For example, available estimated damage for a given water facility type, e.g., a wastewater treatment plan, will be applied to the same type of facilities that lack assessments. To the extent possible, available estimates in a given region will be applied in an attempt to account for spatial variation. This approach is intended to provide an initial, rough order-of-magnitude estimate of the total damage to Puerto Rico's water infrastructure. Uncertainties in this estimate will decrease as more damage assessment data are collected and acquired. Currently, quantitative damage estimates are limited to PRASA facilities derived from the estimated costs provided by PRASA.

Drinking water and wastewater

Background

History and structure

Formal water resources management in Puerto Rico dates to at least the early 20th century, when the demand for electricity to pump water for irrigation led to the development of various public and private hydroelectric power initiatives. Between 1913 and 1914, the demand for power triggered the construction of Puerto Rico's first dams: Carite Lake, Lago Guayabal, and Patillas Dam (Enciclopedia de Puerto Rico, 2017). Formed in 1926, Puerto Rico's first water management agency, the Water Uses Agency, oversaw the construction of additional hydroelectric facilities and the acquisition of various private electricity companies. In 1935, federal funding under New Deal legislation enabled further construction of hydropower capacity and additional consolidation of private electricity generators under public ownership. In 1941, Act 83 was passed, establishing the Puerto Rico Water Resources Authority (PRWRA) and creating a financing vehicle for bond issuance to raise capital for subsequent expansion of Puerto Rico's electricity network (Funding Universe, undated). Recognizing the need to create a similar financing vehicle to facilitate the development of Puerto Rico's drinking water and wastewater infrastructure, Puerto Rico passed Act No. 40 - Puerto Rico Aqueduct and Sewer Authority Act ("40-1945 Puerto Rico Aqueduct and Sewer Authority Act,") in 1945, authorizing the establishment of PRASA. Over time, electricity generation in Puerto Rico became increasingly dominated by petroleum-burning turbines. By the 1970s, only two percent of electricity was produced from hydropower, and PRWRA was renamed the Puerto Rico Electric Power Authority (PREPA) (Funding Universe, undated).

Since PRASA's creation, the population of Puerto Rico has nearly doubled, from approximately 2.2 million residents in 1950 to a peak of 3.8 million in 2004. This has

necessitated the expansion of water and wastewater systems to accommodate not only the rising population, but also the increase in commercial and industrial users. Today, PRASA continues to be the primary supplier of drinking water and wastewater services in Puerto Rico, serving 96 percent and 59 percent of the population, respectively (Puerto Rico Aqueduct and Sewer Authority (PRASA), 2018).

Meanwhile, as a U.S. territory, Puerto Rico was subject to the expansion of environmental regulations during the 1970s, such as the Clean Water Act, which placed additional requirements on PRASA to manage the discharge of pollutants into receiving waters, and the Safe Drinking Water Act, which led to EPA's issuance of many recommended maximum concentration levels for drinking water contaminants. Compliance with such regulations necessitated additional investments in infrastructure, some of which was provided by the federal government, and operations and the need to adopt a watershed and conjunctive management approach that integrates surface and groundwater systems.

Table 12.3 below details the operations and services provided by Puerto Rico's water sector under non-emergency conditions. These functions are consistent with those associated with U.S. states, territories, and municipalities, because Puerto Rico is a U.S. territory subject to federal regulations. The key distinctions, however, are (a) the manner in which Puerto Rico's water sector is governed and financed, and (b) the performance of the sector's various systems with respect to meeting the needs of Puerto Rico's people and industries while complying with regulatory standards (see *Pre-hurricane conditions* below).

Table 12.3. Overview of Subsector Operations

Sub-sector	Operations
Drinking Water	Infrastructure asset management Water treatment and monitoring Adherence to drinking water regulatory standards Water supply, reservoir. and demand management Utility workforce and business management Energy supply management
Wastewater	Infrastructure maintenance and asset management Wastewater treatment and monitoring Adherence to surface water regulatory standards Utility workforce and business management Energy supply management

Source: HSOAC summary

One of the primary objectives of these functions is the effective allocation of Puerto Rico's drinking water to end users in the domestic, industrial, agricultural, and energy sectors. Based on data from 2010, the largest non-consumptive use of water is for the energy sector, specifically hydropower. Domestic use comprises the next largest sector. PRASA provides drinking water to the large majority of Puerto Rico residents, but non-PRASA drinking water suppliers service approximately 76,000 residents (three percent of the pre-storm population) in over 200 small

communities. An even smaller number of largely domestic users supply their own water through private wells or springs. These localities represent a stakeholder population that is small, hard-to-reach, and difficult to regulate. In comparison, a relatively small fraction of water use has been associated with irrigation for agriculture (U.S. Geological Survey, 2014).

Puerto Rico's water sector also manages wastewater from domestic and industrial uses. According to the EPA's Integrated Compliance Information System, approximately 1,726 facilities are permitted under the National Pollutant Discharge Elimination System (NPDES) under the Clean Water Act to discharge wastewater and effluent to Commonwealth waterways (U.S. Environmental Protection Agency, 2017). This includes, among others, PRASA and non-PRASA wastewater treatment plants, resorts, infrastructure development projects, medical facilities, beverage companies, and landfills.

Key assets

PRASA's system is composed of raw water supply and intake facilities, water treatment plants, and distribution infrastructure (pipes and pumps). Assets and operations are divided into five management regions: Metro (including San Juan), North, South, East, and West. Each region is further divided into operational zones, and, at a lower level, potable water service areas, which are each served by a single water treatment plant (U.S. Department of Homeland Security Infrastructure Protection, 2018). PRASA maintains approximately 700,000 wastewater connections and over 1.1 million drinking water connections. To distribute drinking water, PRASA owns and operates 116 water treatment plants (WTPs) located across five service regions – East, West, North, South and Metro. Together, these WTPs produce 508 million gallons per day (MGD) of drinking water. PRASA also owns and operates 51 wastewater treatment plants (WWTPs), at a total treatment capacity of 210 million gallons of sewage daily. Of PRASA's 51 WWTPs, six treat wastewater using primary treatment standards, 33 use secondary treatment, and 12 use tertiary treatment. The four largest WWTPs by discharge – Ponce, Carolina, Bayamón and Puerto Nuevo – belong to the six facilities using only primary treatment (Autoridad de Acueductos y Alcantarillados, 2015). PRASA operates eight dams and 20 minor reservoirs for water storage, which are owned and managed jointly among PRASA, PREPA, the Puerto Rico Department of Agriculture, and DNER. PRASA also controls more than 4,000 ancillary assets. Its entire system is comprised of over 20,000 miles of pipeline.

The total number of water and wastewater systems operated by municipalities or other entities, often termed "non-PRASA" systems, is unknown. Estimates generally report 240 non-PRASA community drinking water systems, but experts indicate that the actual number may range somewhere between 250 and 500 community systems (Ramierz toro and Minnigh, 2017). In addition, 57 non-community systems provide drinking water to hospitals, schools, industrial facilities, and private companies. Forty-one percent of Puerto Rico's population is not serviced by PRASA's wastewater systems. Of this 41 percent, the majority utilize septic tanks for wastewater discharge. A small proportion of this 41 percent are connected to WWTPs that are

operated by municipalities or independent community organizations. The HSOAC team could not determine the exact number of assets and facilities.

Pre-hurricane conditions

There were a number of infrastructure needs and regulatory constraints that pre-dated the 2017 hurricane season. Puerto Rico's drinking water and wastewater systems have a history of violations of EPA Safe Drinking Water Act (SDWA) and Clean Water Act (CWA) water quality standards. In 2015, 99.5 percent of individuals in Puerto Rico received water from community drinking water systems that violated the SDWA (Natural Resources Defense Council, 2017). The PRASA system has been operating under consent decrees that mandate improvements in infrastructure and operations for drinking water and wastewater conveyance and treatment. Mandatory compliance to address consent decrees, administrative orders, or agreements constitute a large percentage of planned financial spending, maintenance and capital improvements. Nearly 30 percent of PRASA's 2016-2020 Capital Improvement Plan is dedicated to mandatory compliance measures (Puerto Rico Aqueduct and Sewer Authority (PRASA), 2018).

High leakage rates (50 to 55 percent) in PRASA's drinking water distribution systems have contributed to a significant volume of non-revenue water that is further heightened by poor metering and illegal connections (Puerto Rico Aqueduct and Sewer Authority (PRASA), 2018). Malfunctioning meters and incomplete metering have also complicated revenue collection, system situational awareness, and operations. Meanwhile, water supply scarcity concerns due to drought conditions also pre-exists the impacts of Hurricane Maria, particularly on the southern part of Puerto Rico. Water scarcity concerns have also been influenced by the lack of supply diversification, and the variability in reservoir ownership.

In its day-to-day operations, PRASA has faced challenges that hinder its ability to provide cost-effective, continuous, and safe drinking water and wastewater services. Among these, financial sustainability remains a significant concern. PRASA's credit rating, as of July 2, 2015, was CCC- with a negative outlook, according to Standard & Poor's, and CC with a negative watch, according to Fitch (Puerto Rico Aqueduct and Sewer Authority (PRASA), 2018). As of June 30, 2017, the total outstanding debt was just over $5 billion; $321 million in debt service was paid during 2017 (Federal Emergency Management Agency, 2012).

In terms of other funding sources, Puerto Rico operates two state revolving fund programs administered by USEPA: the Clean Water State Revolving Fund (CWSRF) and the Drinking Water State Revolving Fund (DWSRF). Revolving funds function like environmental infrastructure banks providing low-interest loans to eligible recipients for water and wastewater infrastructure projects. In 1991, EPA and PR EQB entered into an operating agreement for implementing and managing the CWSRF. In May 1998, EPA entered into a similar agreement with PR DOH for the DWSRF.

USEPA's Office of Inspector General reported on April 26, 2017 that over $774 million of state revolving funds are at risk due to the ongoing financial crisis in Puerto Rico ($194.5 million is not available because the PR Government Development Bank does not have the assets or cash to honor the balance. Approximately $580 million in repayments owed by the largest loan recipient – PRASA – are at risk of nonpayment for at least two to three years, maybe longer). Further, following the 2016 passage of PROMESA, PRASA, municipalities, and other public water agencies are subject to financial oversight by the FOMB. A specific process for critical infrastructure projects – the Critical Projects Process – was also established to identify and expedite approvals, when appropriate, for selected infrastructure investments (PROMESA). The 2018 New Fiscal Plan for Puerto Rico specifically calls out the need to upgrade policies for public private partnerships in the water sector, and repair and modernize water infrastructure and emergency response capabilities (Government of Puerto Rico, 2018b).

Non-PRASA drinking water systems have faced several unique challenges. Treatment, distribution and revenue collection for non-PRASA systems have been performed by the communities themselves. Because community members are not typically certified operators or utility managers, financial sustainability, technical capacity, and regulatory compliance remain challenges. These systems have typically been located in rural areas and rely on both surface water and groundwater for their water supply. As a result of these dynamics, non-PRASA systems have historically failed to comply with drinking water quality standards for total coliform, turbidity, and SDWA monitoring and reporting requirements. However, according to interviews with stakeholders, non-PRASA water systems have received less attention from federal regulators than PRASA systems, and federal interventions and financing have prioritized the need to address CWA violations (such as discharge of untreated sewage into surface water systems) over securing drinking water quality.

Further, due to their often-unofficial legal status as a drinking water utility, many non-PRASA drinking water systems are ineligible for federal grants and loans. Many small systems do not have meters, and, consequently, charge a flat monthly service rate. Various sources have reported rates ranging from $3 to $20 per month, and it has been reported that some systems do not charge any fee, leaving inadequate resources for compliance, repairs, or maintenance.

Prior to the hurricanes, on-site domestic wastewater systems served 41 percent of Puerto Rico's population, typically through septic tanks, which in many cases were improperly maintained, unsealed, and often discharged raw sewage directly into coastal, surface, and groundwater bodies. These tanks are regulated by the EQB under the Regulation for the Control of Underground Storage Tanks, but many communities have not had the financial or operational capacity to comply with such regulations (Puerto Rico Environmental Quality Board, 2014).

Hurricane damage

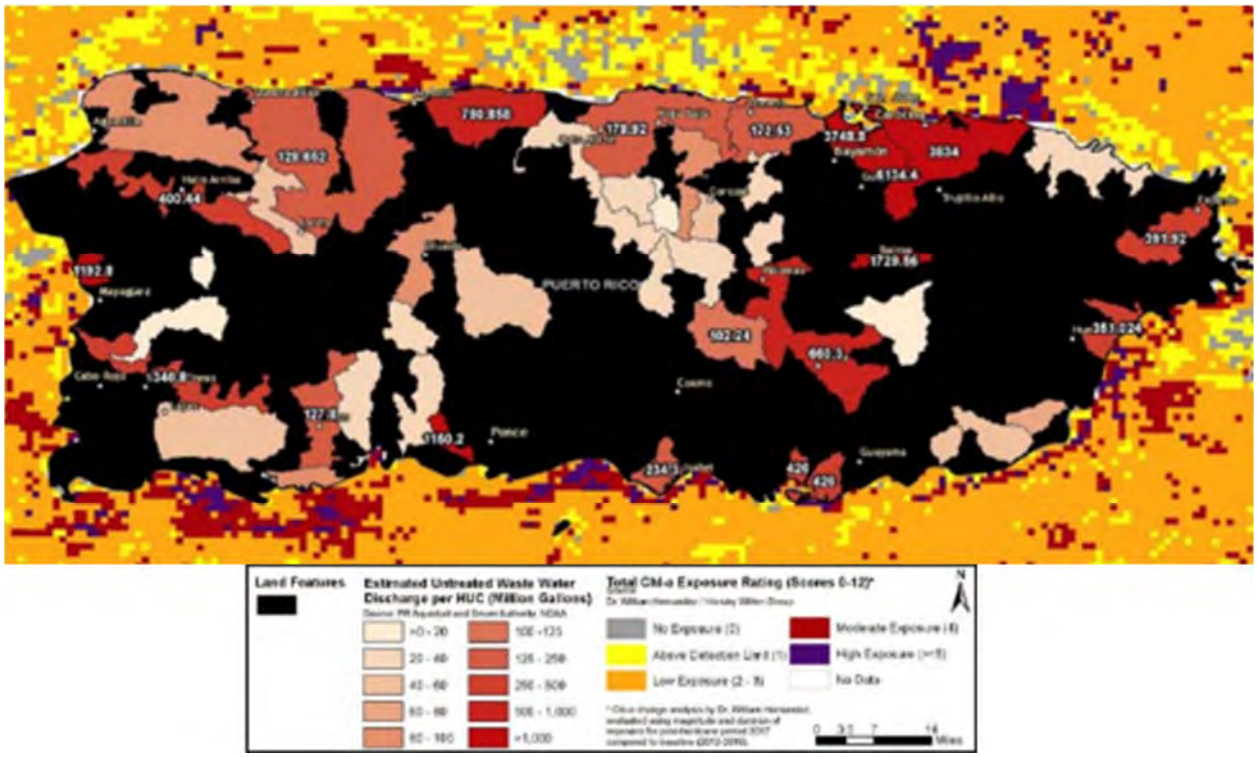
The large majority of available damage information has summarized impacts to the PRASA water and wastewater systems. Although several months have passed since Hurricane Maria

made landfall, PRASA's water and wastewater systems are still operating below full capacity. Most of the persistent issues PRASA faces are due to uncertain and limited energy supply and water supply, as well as water access limitations and operational challenges. In non-PRASA and non-regulated drinking water and private and on-site domestic wastewater systems, the lack of comprehensive damage assessments makes quantitative estimates and generalizations on the status of these systems difficult. It is likely that they also face similar, and possibly more severe, challenges as those faced by the PRASA systems.

In the days immediately following Hurricanes Irma and Maria, PRASA faced significant challenges in providing and restoring water and wastewater services. Directly following the hurricanes, around October 3, 2017, almost all PRASA clients faced several severe problems that limited access to drinking water. For example, of the system's 51 wastewater treatment plants, 22 were non-operational and three facilities were fully inundated. In addition, 222 of PRASA's 714 sanitary pumping stations were out of service, and those that were functional were operating on alternative power sources. Significant damage to trunk sewers, which are the primary conveyors of wastewater to sewage treatment plants, caused major sewage overflows, particularly at points of intersection with surface water. Immediately after Hurricane Maria, 40 of PRASA's 114 drinking water plants were out of service due to damage, debris, or inundation surrounding water intakes; 800 drinking water pumping stations lacked power and were out of service (U.S. Environmental Protection Agency, 2018b).

Further, many of Puerto Rico's wastewater treatment plants experienced overflow events, dumping raw sewage into watersheds (Figure 12.1). Thirty of PRASA's 85 sanitary sewer pumping stations also overflowed directly into waterways or land surfaces. From a NOAA analysis, over 13.7 billion gallons of untreated wastewater were estimated to have discharged into the San Juan metropolitan area, including into nearby Lake Carraizo, due to energy failures at PRASA's WWTPs and wastewater pumping stations, and an estimated 780 to 1,193 million gallons of untreated wastewater were discharged near Manatí, Mayaguez and Ponce (National Oceanic and Atmospheric Administration, 2018b). Estimates of wastewater discharges are aggregate and do not specify the location or extent of water quality impacts.

Figure 12.1. Cumulative sewage discharge by watershed (millions of gallons)



Source: NOAA, 2018.

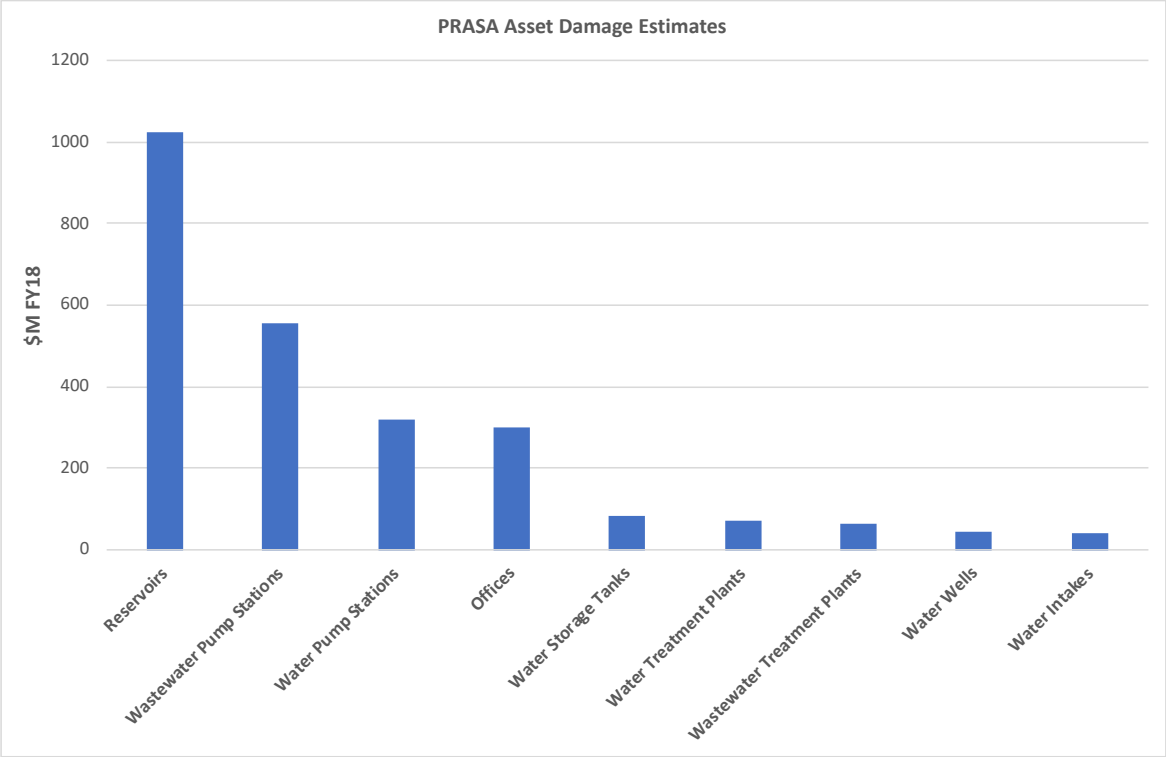
To comply with FEMA disaster assistance requirements, PRASA was also obligated to produce a damage inventory that catalogues damage for its assets. This inventory has been updated over time as assessments have been completed, with PRASA contracting much of the assessment work to CSA Group and Arcadis. As of May 18, 2018, that inventory contained 5,091 PRASA assets plus an overall assessment of damage to pipes, all of which had some form of qualitative damage description. These 5,091 assets included 1,900 water storage tanks, 1,311 water pump stations, 991 wastewater pump stations, 416 water wells, 191 water intakes, 116 water treatment plants, 87 offices, 51 wastewater treatment plants, 19 water mains, and 9 reservoirs. In addition, the inventory included information about the location of assets and causes of damage. It also included cost estimates, either direct or projected, of Category A, D, E, and F damage for all assets. It should be noted that, as of March 28, 2018, a proportion of the damage assessments and cost estimates carried out by Arcadis were for PRASA insurance claim purposes and do not constitute a Public Assistance-eligible damage assessment or cost estimate.

Based on a review of the qualitative damage descriptions, damage to electrical equipment, fencing, and building structures was common, as was mechanical damage at pump stations and offices; damage at storage tanks, intakes, and treatment plants to telemetry equipment; damage to signs at wells; damage to water treatment equipment and flocculators at treatment plants

experienced damage to; and erosion damage to pipes and reservoirs. Causes of damage at each site were not provided but were listed as wind, rain, flood, and debris across all assets.

Previous cost estimates generated on March 28, 2018 by PRASA based on extrapolations from CSA Group and Arcadis damage assessments totaled $1.14 billion[175] across the aforementioned asset types. The May 18, 2018 updated PRASA damage inventory costs total $18.96 billion and are broken down in Figure 12.2. Note, Figure 12.2 does not include damage to pipes, which total $16.45 billion, making up 86.8 percent of total estimated damage to PRASA assets. The previous estimate also did not include damage estimates to reservoirs, which total approximately $1.03 billion dollars in the updated inventory. The remaining $1.48 billion across remaining assets still exceeds the previous damage estimate by approximately 23 percent. Figure 12.2 also does not include water mains, as only $142,500 in damage was estimated and is a small amount of damage relative to other asset types.

Figure 12.2. Estimated Category A, D, E, and F damage costs for PRASA Assets



SOURCE: PRASA, dated: 5/18/2018.

The figures below show the spatial distribution of asset types inventoried (Figure 12.3), information on facilities reporting damage specific to generators (Figure 12.4), and cost estimates for damage by facility (Figure 12.5). The spatial distribution of assets in the inventory,

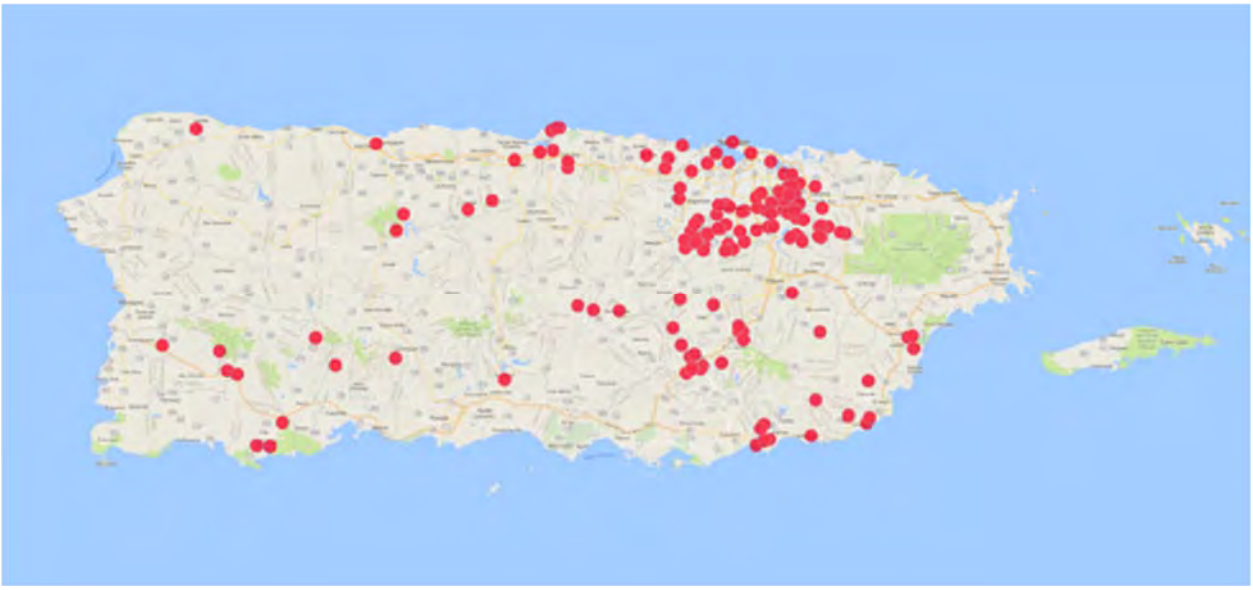
[175] Note that this estimate was for Category A, B, and F damages whereas the May 18, 2018, updated inventory estimates damages for Category A, D, E, and F damages.

shown in all three figures, demonstrates that damage to PRASA assets was experienced throughout the Commonwealth. However, the more costly damage tended to be clustered in the East, particularly around metropolitan San Juan, due to the region's higher concentration of population and greater number of drinking water and wastewater assets.

Figure 12.3. Select Assets Included in PRASA Damage Inventory

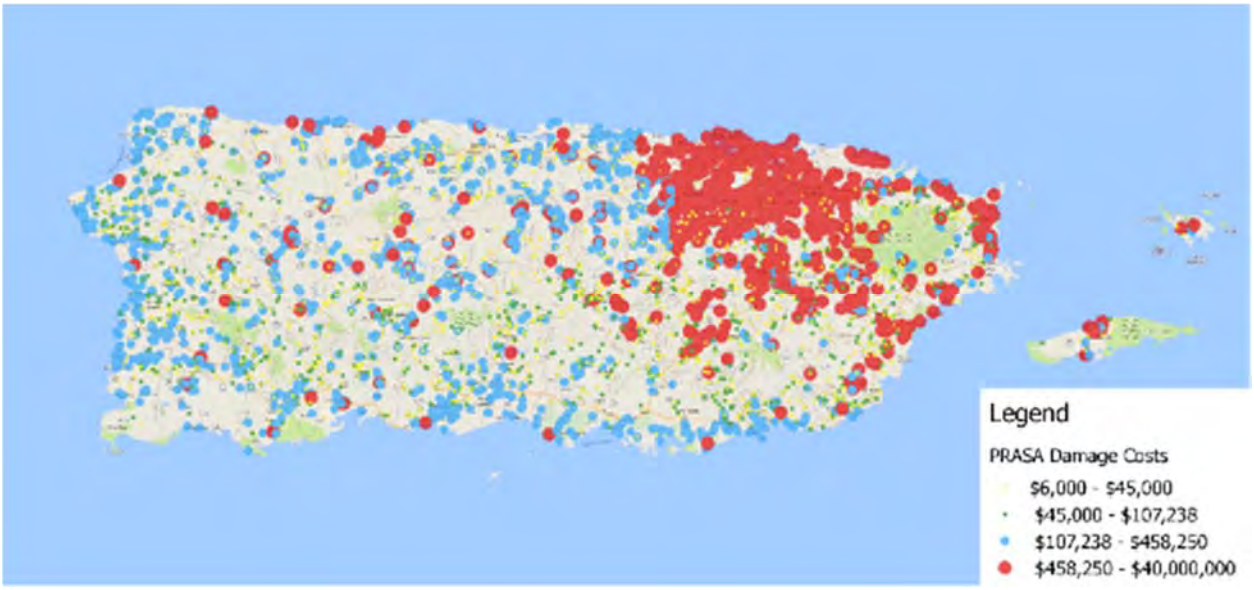
Notes: Solid circles represent the approximate location of PRASA assets, including water and wastewater treatment plants and pumping stations. SOURCE: PRASA's Damage Inventory, dated: 5/18/2018.

Figure 12.4. Known PRASA Assets Reporting Generator-Related Damage



Notes: Solid circles represent the approximate location of PRASA facilities that reported some form of damage to on - site electricity generators, including either superficial damage to generator buildings and/or direct damage to the generator itself. Source: PRASA's Damage Inventory, dated: 3/28/2018.

Figure 12.5 Cost Estimates for Damaged Assets included in the PRASA Damage Inventory



Notes: Solid circles represent the approximate location of PRASA assets. Size and color of the circles represent different levels of projected damage associated with each asset (see legend). For many assets, damage estimates are approximations based on extrapolation from assets for which information exists. SOURCE: PRASA's Damage Inventory, dated: 5/18/2018.

The primary impact of the storms on non-PRASA drinking water facilities, however, appears to be the loss of grid power, which rendered many of the community well and surface pumps inoperable.[176] In the majority of cases, generators have been provided or are currently being sought (by the EPA, FEMA, or Water Mission) to power these pumps. In some cases, generators have been collectively purchased by the community.[177] Many communities have reverted to the use of *manantiales*, small springs that either discharge from groundwater or from nearby surface water, which are unregulated and untreated.

The second primary impact of the storms appears to be their effect on water quality. As mentioned above, in addition to energy losses and use of manantiales, damage to chlorination systems was commonly reported. However, not all non-PRASA sources where contaminated water has been observed had disinfection capability prior to Hurricanes Irma and Maria. One community was reported to have fecal coliform in its water, suggesting serious health concerns. It is unclear, however, whether these water sources were contaminated prior to the storms. Pre-

[176] Unfortunately, the number of non-PRASA facilities that lost power immediately after Maria is currently unavailable, but the data imply that most, if not all, sites did lose power.

[177] Required generators at this scale are typically on the order of 20 kW, with one community spending approximately $18,000 on a single unit.

storm evaluations indicated that 24 percent of non-PRASA facilities did not treat drinking water, and 45 percent did not conduct monthly water quality testing. (Martinez, 2016). In total, 68 sites reported potential water quality issues, stemming either from damage to existing chlorination systems or a lack of disinfection capability.

Assessments were performed by EPA, Water Mission, USACE and Rural Community Assistance Partnership at 240 of approximately 244 known non-PRASA drinking water sites, focusing primarily on well and surface water sources that served approximately 90,000 people. Unfortunately, these surveys typically do not specify the damage that resulted from the hurricanes but focus instead on the operational status of the facilities, with damage discussed when relevant. A review of these status assessments indicates that damage to water distribution piping and storage tanks were reported at 60 and 65 sites, respectively, with some of these damage reportedly caused by landslides. Clogged piping/intakes and site inaccessibility due to debris were also reported. There were also some instances of damage reported to chlorination systems, pumps, and local infrastructure (e.g., roads that prevented access to water systems). In addition, damaged generators were also reported, although it was unclear whether those generators had been operating prior to the hurricanes. There have been no comprehensive damage assessments of non-PRASA wastewater systems following Hurricanes Irma and Maria. As such, septic and community wastewater systems are not described in this section.

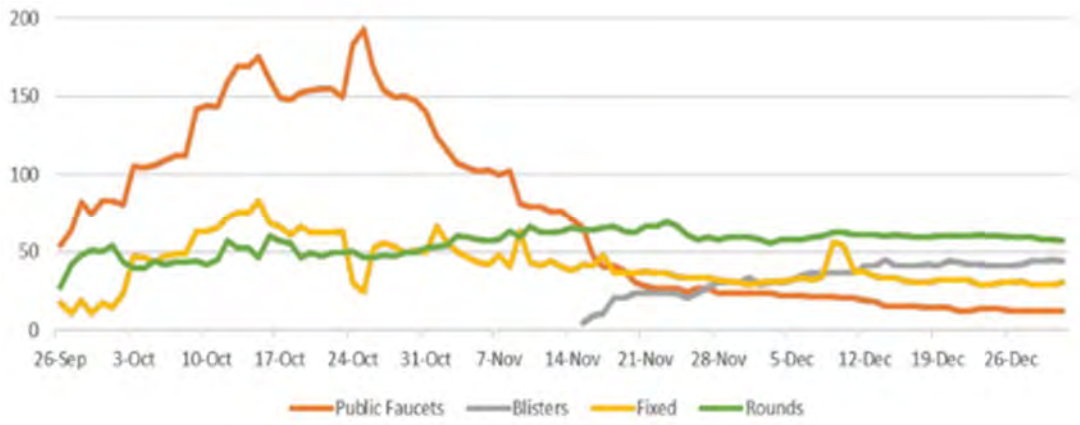
The loss of power did not cause all of the non-PRASA community water supply to become compromised as 60 wells were reported to be gravity-fed. In one case, a community had been relying on PRASA for its water but reverted to its gravity-fed well once power was lost. Some of these communities, however, still suffered damage to their water distribution systems.

Post-hurricane conditions

Emergency response

The majority of emergency response operations have focused on bottled water provision and the establishment of "oases," which refers to centralized water distribution locations serving at various times over 500,000 PRASA and non-PRASA clients (see Figure 12.6).

Figure 12.6. Emergency Drinking Water Distribution by PRASA, as of 1/28/2018



Source:. The vertical axis represents the number of units of each emergency drinking water source type provided (e.g., 40 blisters[178]).

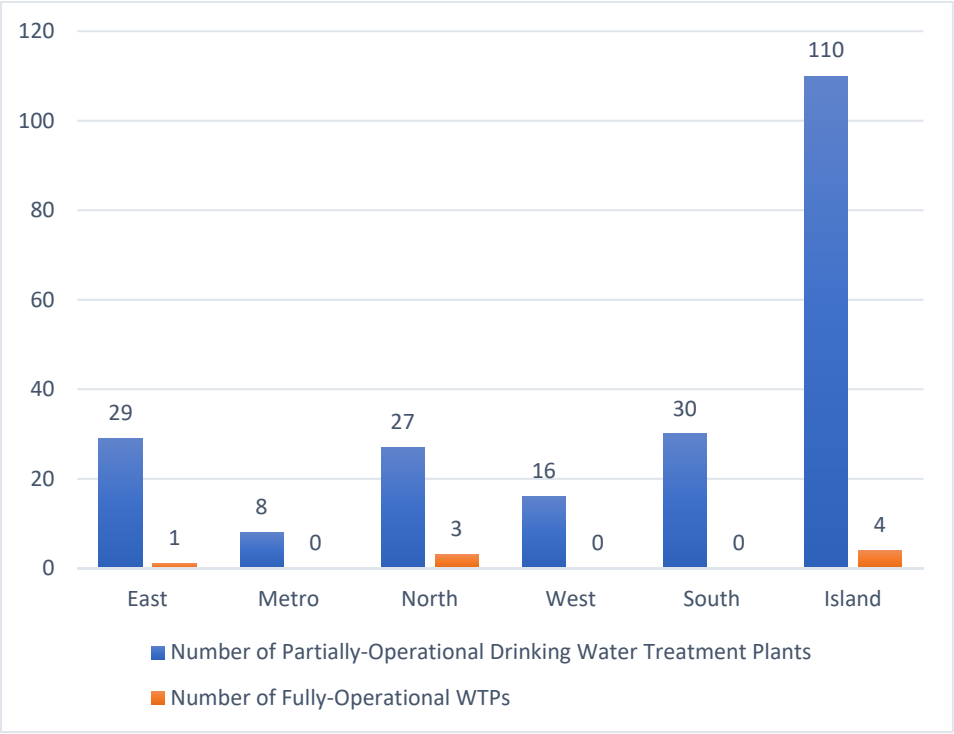
Other critical emergency response capabilities required to return WTPs, WWTPs, and pumping stations to operational conditions included emergency generator distribution, installation, and fuel provision. FEMA, PRASA and PREMA have been involved in these response activities.

Repairs and current conditions

Figure 12.7 and Figure 12.8 illustrate the number of fully-operational water and wastewater treatment plans in each of PRASA's principal service regions. As of February 28, 2018, all water and wastewater treatment plants in each of PRASA's principal service regions were operational, but 88 percent of water treatment plants and 98 percent of wastewater treatment plants are operating below their full operational capacity (U.S. Environmental Protection Agency, 2018b).

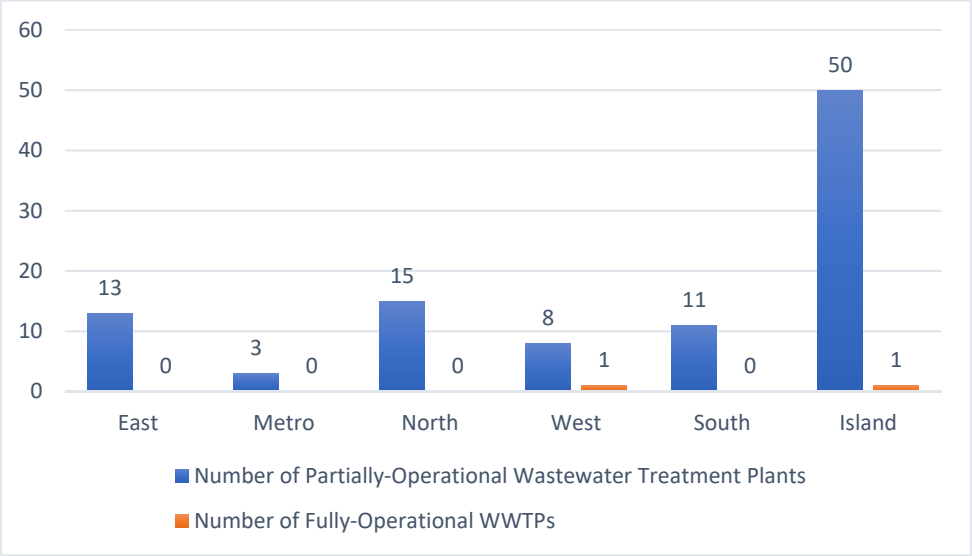
[178]As identified in the PRASA Fiscal Plan, blisters refer to a method for the distribution of emergency drinking water.

Figure 12.7. Operational Status – PRASA Drinking Water Treatment Plants, as of Feb. 28, 2018



Source: (U.S. Environmental Protection Agency, 2018b).

Figure 12.8. Operational Status – PRASA Wastewater Treatment Plants, as of Feb. 28, 2018

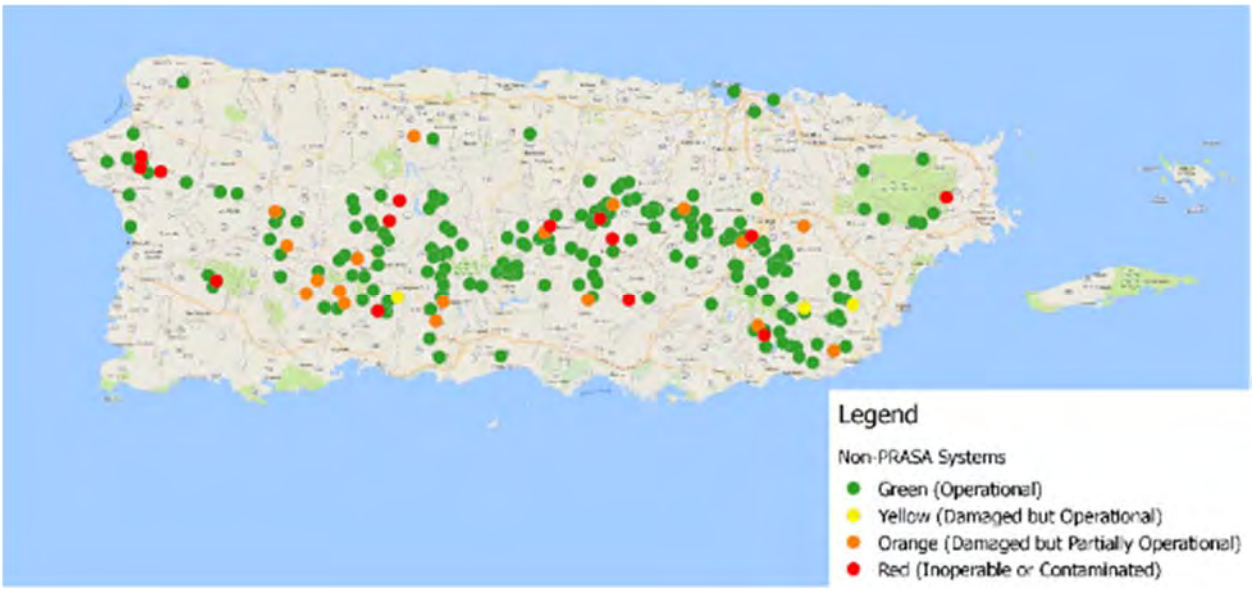


Source: (U.S. Environmental Protection Agency, 2018b).

The EPA performed assessments of non-PRASA drinking water systems in the months following Hurricane Maria, classifying the operational status of 236 out of the 244 non-PRASA

systems using a four-color system. "Green" typically referred to systems that were fully operational, even if using a temporary generator, and capable of providing a reliable source of water. Some of these sites, however, still lacked disinfection capability. "Yellow" typically referred to systems that were damaged and in need of repairs but were still functioning. "Orange" typically referred to systems that required major repairs but were still able to provide some water to its population. Finally, "red" typically referred to systems that were not able to dependably provide water, had no power, and/or had no generator. Of the 236 rated sites, 203 were "green," three were "yellow," 16 were "orange," and 14 were "red," with all surveys having been conducted in October and November 2017 (Figure 12.9). The status of those facilities may have changed between then and the writing of this report. In a more recent assessment performed on February 21, 2018, 10 non-PRASA facilities were classified as a priority for the commonwealth and eight were classified as an EPA priority, with these facilities typically still without power and serving 200 or more people. The majority of EPA priority systems were also commonwealth priority systems. It is unclear how these priorities were determined.

Figure 12.9. Post-Hurricane Maria Status of Non-PRASA Drinking Water Systems



Notes: Solid circles represent the approximate location and status of Non-PRASA drinking water systems as assessed between 10/10/2017 and 11/13/2017. The colors were adopted by the EPA to represent the operational status of each system, with green indicating the facility was in working order at the time of the assessment and red indicating the system was either not operational or not in compliance due to contamination. Yellow indicates systems that are damaged and still in need of repairs but still functioning. Orange indicates systems in need of major repairs but still partially operational. Source: Data provided by EPA, Water Mission, USACE and Rural Community Assistance Partnership, 2018.

EPA has been working with non-governmental organizations (including Water Mission, Samaritan's Purse, Project Hope, and RCAP Solutions) to assist communities that rely on drinking water sources from non-PRASA systems. Actions taken include repairing damaged

systems, providing generators, and in some cases, equipping systems to operate on solar power. To date, solar-powered water pumping systems have been installed to restore drinking water provision in 46 non-PRASA communities (EPA Press Office, 2017; Water Mission, 2018).

Over the several months following the hurricane and to the time of this writing, PRASA has worked to restore water and sewer services in an environment that they describe as including a multitude of challenges. Water supply sources have been limited due to reservoir levels, water supply interruptions, and blocked or collapsed water intakes. Uncertainty around electrification resulted from a lack of fuel for emergency generating units, shortages and theft of generators, and damaged electrical components in both generators and solar/voltaic energy systems. Sewage overflows from wastewater treatment plants have been compounded by collapsed trunk sewers and damaged sewer lines. Operational capacity was constrained due to severe damage to operational facilities and office buildings, vehicle and communication line damage, and blocked access to assets. The demand for damage assessment and repair efforts, not only for the water sector but across Puerto Rico, significantly strained the Commonwealth's human capital. The limited availability of workers, including qualified engineers and technicians, created an additional barrier to restoring water and wastewater services.[179]

Despite these barriers, a number of characteristics of Puerto Rico's water sector help to facilitate recovery planning and implementation. As described earlier, the history of water resource management in Puerto Rico dates back almost a century, resulting in a concentration of technical expertise in water resources management in utilities like PRASA and many other organizations that can provide technical support,—ranging from the University of Puerto Rico, to other federal agencies, to private consultants and contractors. Furthermore, because the bulk of the Commonwealth's need for drinking water is provided by one utility, much of Puerto Rico's post-hurricane drinking water recovery needs may be addressed by focusing on that one organization.

Stormwater, flood mitigation, and integrated water management

Background

History and structure

Water management in Puerto Rico extends beyond simply drinking water and wastewater to include flood control, stormwater management and integrated water management more broadly (Table 12.4). The majority of stormwater systems in Puerto Rico have typically been managed by municipalities – all 79 municipalities have some form of storm sewer system. Another 17 non-municipal stormwater systems were permitted under the EPA's MS4. These systems were managed by governmental entities, including the University of Puerto Rico, DNER, DTOP, Fort

[179] Comments made in a meeting with PRASA

Buchanan, Veteran's Hospital and the Local Redevelopment Authority for Roosevelt Roads (U.S. Environmental Protection Agency, 2018a). The management, operation, and maintenance of dams and levee systems across Puerto Rico are delegated among PRASA, PREPA, municipalities, and DNER, with a minor share of responsibility residing with other Commonwealth and U.S. federal agencies.

Historically, prevention of river flooding through levee construction was considered the responsibility of the Department of Transportation and Public Works (DTOP), which often worked with the USACE on levee design and construction. Responsibility for flood control planning and maintenance of USACE levee systems was transferred to the DNER in 1972 due to the need for more comprehensive watershed management to achieve flood control objectives. DNER develops water plans and works with other Commonwealth agencies, such as the EQB, to ensure both environmental protection and maintenance of surface water quality standards. Since watershed management is often a local municipality issue, stormwater management functions are typically the responsibility of municipalities, which apply for permits administered by the EPA to discharge stormwater effluent to waterways. However, in some urban areas, PRASA also has responsibility for stormwater management efforts and maintains the Puerto Nuevo combined sewer system that conveys both wastewater and stormwater (U.S. Environmental Protection Agency, undated).

Table 12.4. Overview of Subsector Operations

Sub-sector	Operations
Stormwater	Infrastructure maintenance and asset management MS4 permit and water quality management
Flood Control	Infrastructure maintenance and asset management Natural infrastructure management Urban flood management
Integrated Water Management	Multi-governance and interagency cooperation Conjunctive management of surface and groundwater systems Land use management Erosion and debris control Reservoir management Environmental management

Source: HSOAC Summary

Key assets

The stormwater, flood mitigation, and water management systems of Puerto Rico are comprised of storage, distribution, filtration, pumping, and treatment, and protection of physical and natural infrastructure assets. Critical physical infrastructure includes storage and distribution networks, as well as dams, and levees.

Stormwater infrastructure systems are highly decentralized in Puerto Rico, so it is difficult to determine an exact number of infrastructure assets. Within the municipality of San Juan, for example, at least three different public agencies own separate portions of the stormwater system:

DNER, the Department of Transportation, and the Department of Public Works. According to the EPA, Puerto Rico has 85 separate permitted municipal storm sewer systems (MS4) as of this writing.

The USACE National Levee Database currently has 14 levees registered, spanning a total of 32 miles. All were inspected in 2015 prior to Hurricanes Irma and Maria. However, at that time, only one of the 14 was evaluated to be in an acceptable condition (U.S. Army Corps of Engineers). USACE-built levees are currently managed by DNER. In addition, based on the *Build Back Better* report's initial assessments of water sector needs in the wake of Hurricanes Irma and Maria, Puerto Rico has at least an additional 13 levee systems, likely managed by municipalities (Governor of Puerto Rico, 2017a).

The National Inventory of Dams identifies a total of 38 dams in Puerto Rico, which vary in terms of their year of construction, design, and height. All of these dams are rated as having a high damage potential in the event of failure and all have emergency action plans (U.S. Army Corps of Engineers). Puerto Rico's dams are owned and operated by both public and private agencies, although most (24) are owned by public utilities (PRASA or PREPA).

Puerto Rico has 224 rivers and 553 streams, many of which drain into the 54 dominant river systems that discharge to the ocean. Hydrologically, Puerto Rico is divided into 134 watersheds bounded in many cases by one or more of the three mountain ranges that run from east to west: Cordillera Central, Sierra de Cayey and Sierra de Luquillo ("Plan y Reglamento del Area de Planificacion Especial del Carso (PRAPEC)," 2013).

Pre-hurricane conditions

Prior to the hurricanes, most municipalities managed stormwater via their emergency management, transportation, or planning departments, but many municipalities lack dedicated staff. A legacy of insufficient maintenance and oversight among most municipal and non-municipal systems in addition to outdated or insufficient cleaning equipment led to clogging and blockages. Outdated, incomplete, or non-digital stormwater maps and unknown or illegal wastewater connections complicated system operations and degraded the quality of receiving waters. The prevalence of undersized systems also contributed to regular urban nuisance flooding. While some municipalities have funded capacity improvements or cleaning and maintenance from their general fund, insufficient funding for stormwater management often further compounded efforts to mitigate urban flooding. The EPA's Puerto Rico office manages and grants Municipal Separate Storm Sewer (MS4) permits for small and large systems. Compliance with these standards remains a challenge across the island.[180]

As noted earlier, even prior to the storms, multiple levee systems existed around Puerto Rico, and those systems varied in age, level of maintenance, and capacity to mitigate significant flood

[180] Personal communications with the Environmental Protection Agency.

risk. As of 2010, several levees in Puerto Rico were out of compliance with USACE design standards and were thus judged to be ineffective in providing mitigation against a one percent annual probability flood event.[181]

Because many of the Commonwealth's reservoirs were designed for hydropower generation, operational rules have followed guidelines and practices for optimal hydropower generation. The majority of these reservoirs, however, have also served flood control or water supply purposes. In newer reservoirs designed for flood control, like the Portugues Dam in Ponce, operational rules were designed specifically to mitigate flooding. Due to high rates of sedimentation, regular dredging has been carried out to maintain channel navigability, preserve dam storage capacity, and retain the design life and purpose of dams and levees.

Watershed and groundwater management and affiliated activities, such as land use planning, erosion and sediment plans, and climate planning, have mostly fallen under the responsibility of DNER. In recent years, budgetary constraints have led to operational limitations for DNER and restricted its capacity to enforce, manage and implement existing plans and land use policies.[182]

Hurricane damage

Arcadis U.S. (Arcadis) was contracted by HSOAC to conduct stormwater damage assessments from Hurricanes Irma and Maria in Puerto Rico and develop an order-of-magnitude cost estimate of the damage per system based on two major categories: individual points of damage (collapsed pipe, damaged bridge culvert, landslide, etc.) and estimated area of damage (acres flooded, stormwater system area impacted, etc.). Using cost data sourced from FEMA Cost Code Listing (2010), Arcadis Cost Guide (2014), Arcadis PRASA Hurricane Maria Recovery Efforts (2017) and detailed cost estimates or bid tabs from individual municipality stormwater system projects, post-Maria construction costs were found to be up to five times more expensive than the pre-Maria costs. All unit costs for infrastructure repairs from 2017 or earlier had an additional cost increase factor added to account for this change when converted to 2018 dollars.

Table 12.5 and Figure 12.10 consolidate the results of the stormwater system assessment and provide a summary of system damage costs, which amount to more than $215 million or an average of approximately $5,300 per damaged acre. Table 12.5 presents total land slide and pipes collapse incidents, total area flooding in acres, and estimated costs by region of the main island of Puerto Rico. Figure 12.10 displays Commonwealth-wide damage graphically for each municipality.

In general, the Arcadis assessments found that in many of the municipalities interviewed, lack of data, monitoring, and maintenance have contributed to regular urban flooding and a slow

[181] In total, USACE surveyed 25 unique levee systems (19 groups), reporting damage to five of them. Of these 25, 12 of the systems were found to be consistent with the national levee inventory.

[182] Information gathered in USACE, EPA, Solutions Team meetings

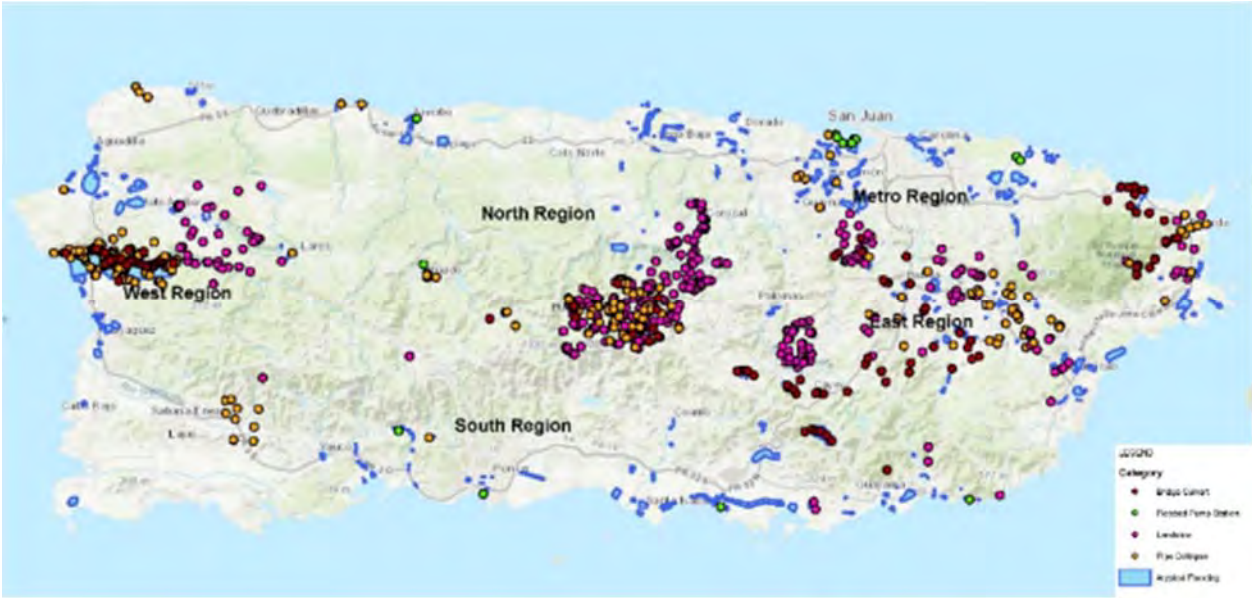
recovery and clean-up of stormwater systems after Hurricane's Irma and Maria. Some municipalities, such as Arecibo, do have digital records and have already hired contractors to perform post-hurricane cleaning to remove debris and blockages. The majority of municipalities, however, still lack comprehensive assessments of damage and the conditions of their systems. Municipalities also reported that system capacity is often undersized for the quantity and frequency of rainfall events, and, when combined with damage and debris, will likely continue to underperform in heavy precipitation event.

Table 12.5. Summary of Stormwater System Damage Assessments by Region

Region	Pump Stations Damaged	Total Pipe Collapse Incidents	Total Area Impacted by Atypical Flooding (acres)**	Estimated Stormwater System Damage Cost
West	0	202	13,900	$67,054,000
North	2	15	3,938	$37,901,800
East	0	56	5,979	$39,732,200
Metro*	11	9	6,094	$36,610,300
South	4	78	6,830	$34,545,700
Total	**17**	**360**	**36,741**	**$215,844,000**

NOTES:
* San Juan has not provided damage information to date.
** Total area impacted by flooding only collected for 51 of Puerto Rico's municipalities.
Source: (Arcadis, 2018)

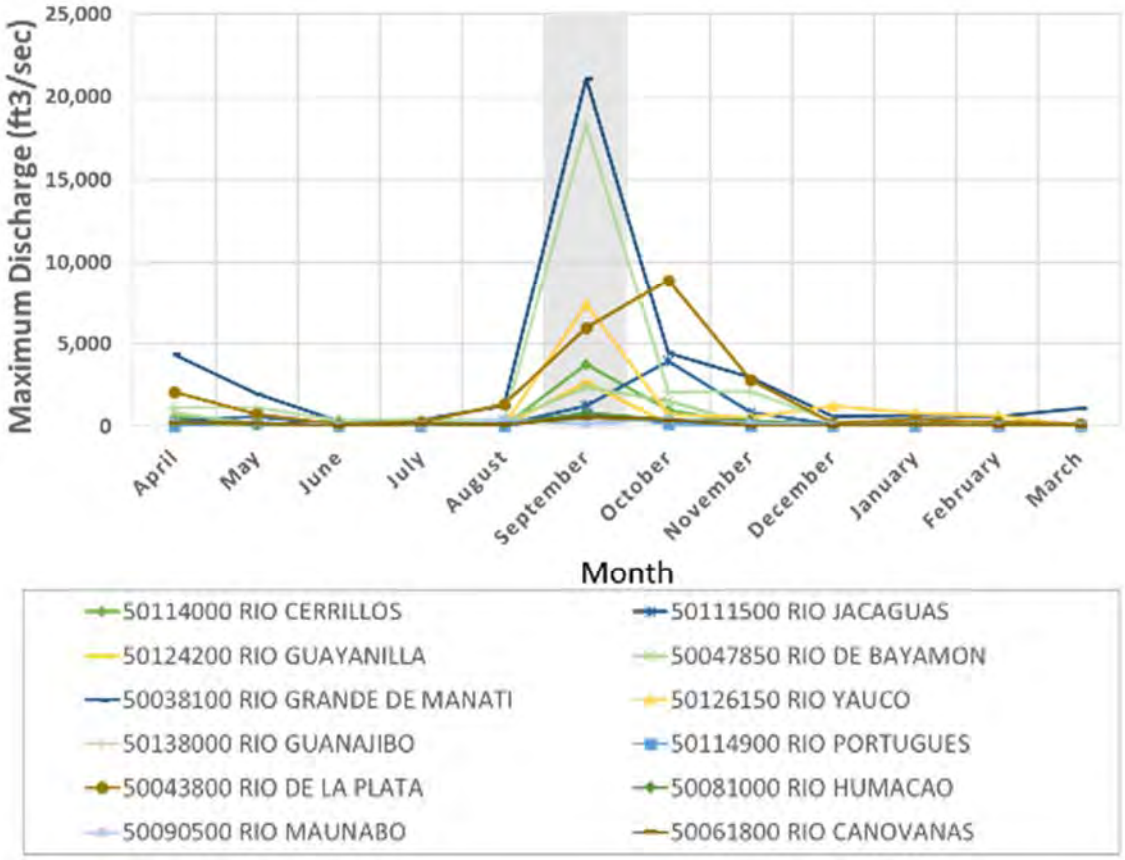
Figure 12.10. Map of Island-wide Stormwater System Damage from Hurricane Maria



Source: (Arcadis, 2018).

Stream gauge data from Puerto Rico indicate that discharge rates for some streams were several-fold higher than observations in prior or subsequent months (Figure 12.11). These data reflect the risk not only for floods, but also for significant erosion and scouring of waterways, which contributed, in some cases, to damage to Puerto Rico's flood control infrastructure (see Natural Resources chapter of this report).

Figure 12.11. Monthly maximum stream discharge information for selected USGS gauge stations



Notes: Curves represent the monthly maximum observed discharge for 12 U.S. Geologic Survey stream gages around Puerto Rico from April 2017 through March 2018. Data reveal the anomalously high discharge values observed for some streams in September associated with Hurricanes Irma and Maria. Source: (U.S. Geological Survey, 2018).

With regard to the levee systems, the *Build Back Better* report stated that, in total, 13 levee systems were damaged by the storms and were in need of repair to restore full integrity. The report also requested $100M in the coming years for these repairs and associated compliance. Surveys conducted by USACE in early October,[183] however, reported damage to only five levee systems: the Rio Matilde, Rio Anton Ruiz, Rio Grande de Arecibo, Rio Grande de Manati, and Bucana East Waterway. Of these five, the Rio Grande de Arecibo and Rio Grande de Manati levee systems were classified as severely damaged. The former sustained damage to its western levee, including its culvert outlet that was dislodged from its supports. The latter suffered damage to the embankment of its eastern levee from high-velocity flows while its western levee was affected by a landslide. The other three levee systems were classified as more moderately

[183] In total, USACE surveyed 25 unique levee systems, reporting damage to five of them. Of these 25, 12 of the systems were found to be consistent with the national levee inventory (U.S. Army Corps of Engineers, undated-b; U.S. Army Corps of Engineers, 2017).

damaged primarily due to embankment erosion from flooding and debris buildup. The Rio Anton Ruiz system also experienced damage to its culverts due to increased water salinity. Some of the systems that were classified as having no damage (e.g., no embankment erosion or culvert dislodgement) in some cases still experienced debris buildup.

USACE also conducted surveys of 18 dams[184] at the end of September and beginning of October 2017,[185] with only one, the Guajataca, assessed as having safety issues of concern. The remaining 17 dams[186] were found to have "no immediate… safety issues" though, with 11 reporting issues/damage from erosion to abutments, discharge channels, etc., six reporting facility access issues due to debris, three reporting instrumentation (e.g., gage) issues, and one, the Dos Bocas, reporting damage to all three of its hydroelectric turbines due to landslides, with one damaged beyond immediate repair. USACE also observed that several of these dams also had minor damage to spillways, although these were not classified as safety issues. In addition, only the assessment of the Toa Vaca Dam found reservoir water-level control issues. Finally, while Guayabal Dam was classified as having no safety issues, a survey of the dam determined that additional erosion from future storms could create a safety concerns if current erosion to its embankments are not addressed.

The most significant damage was seen at the Guajataca Dam, which, until recently, posed a major safety concern to the Puerto Rican population downstream. During Maria, Guajataca's reservoir surged, ultimately overwhelming and cracking the emergency spillways and compromising its flood control. In addition, erosion was observed in the channel downstream of the spillway and a downstream bridge was also destroyed. Also, riprap that had armored the downstream spillway channel was destroyed, allowing a head cut to form and further compromising channel integrity. A surface tension crack of approximately 30-foot length was observed in the channel. The USACE advised the dam owner to reduce the reservoir levels to mitigate the channel head cutting, given the associated safety risk if the cut were to move up to the dam. The USACE survey also found that the dam's 56-inch water supply and 96-inch river outlet pipes had been damaged, with the water supply pipe operating at only 10 percent volume.

HSOAC was unable to identify a comprehensive assessment of watershed issues in Puerto Rico following Hurricanes Irma and Maria. As described above, many of Puerto Rico's wastewater treatment plants are experiencing overflow events, dumping raw sewage into watersheds. Thirty of PRASA's 85 sanitary sewer pumping stations are overflowing directly into waterways or land surfaces. Anecdotal reports indicate that debris blockages in and around urban watersheds have caused flooding, ponding, and damage to water intakes. Debris is likely a

[184] Personal communication ESF-2 and other FEMA officials March 2, 2018.

[185] These 18 dams are consistent with those listed in the national inventory, which reports a total of 38 dams in Puerto Rico. Assessments for the remaining 20 dams have not yet been obtained

[186] These 17 dams are the Caonillas, Carite, Cerrillos, Cidra, Upper and Lower Comerio, Dos Bocas, Garzas, Guajataca, Guayabal, La Plata, Las Curias, Loiza, Lucchetti, Mutrillas, Patillas, Portugues, and Toa Vaca.

concern in the upper reaches of rivers and streams, as is erosion and sedimentation of waterways and reservoirs. The timing, extent, and magnitude of desilting and sediment removal in reservoirs, such as in the damaged Guajataca Dam in Northwest Puerto Rico, are operational questions currently facing disaster response teams. An analysis of the Dos Bocas Watershed, the main source of water for the San Juan area, following Hurricanes Irma and Maria, found that 30,091,078 cubic yards of sediment was released from 12,597 landslides across the watershed. (U.S. Department of Agriculture, 2018).

Post-hurricane conditions

Emergency response

Following Maria, residents downstream from the Guajataca Dam were at risk of flooding due to dam failure, placing 70,000 people in immediate danger. USACE noted the severity of the damage to the Guajataca Dam, stating on September 28, 2017 that the spillway was in a progressive failure mode and that complete failure could lead to loss of downstream life. Dam failure would have also compromised the water supply to nearly 350,000 Puerto Ricans (Kahn, 2017). Residents were advised to evacuate at the end of September, although few ultimately sought emergency shelter.

Repairs and current conditions

PRASA has applied for and received FEMA Public Assistance reimbursements for debris removal and emergency generators (including fuel, operations, and maintenance for emergency purposes). Since October, dam integrity has somewhat stabilized and as of January 18, 2018, the second phase of repairs was underway to provide temporary fixes to the spillways using low density concrete. Work will continue for the next two years to continue to repair and improve the spillways. Total estimated cost made by the Governor's report to reconstruct the spillways and modernize the dam design is $200M. In addition, pumps have been installed to maintain the reservoir's supply of water while recovery efforts are ongoing.[187]

Remaining needs and recovery priorities

Given the damage sustained by Puerto Rico's water sector from Hurricanes Irma and Maria, and the repairs that have been completed to date, a number of critical needs and challenges will need to be addressed in the recovery process.

[187] Personal communication with PRASA.

Short term

Short-term challenges are those associated with immediate safety and health concerns and the reliable restoration of drinking water and wastewater services (if not individual infrastructure assets themselves) within the next one to 12 months.

- *Repairs to Guajataca Dam, especially the water supply conduit and spillway, to address immediate safety concerns.* Although multiple dams in Puerto Rico experienced some degree of damage, Guajataca dam is the only one that has been evaluated to pose immediate safety concerns. In particular, the replacement of the water supply conduit and the stabilization and restoration of the spillway are priorities and efforts are underway to address both of these needs by PREPA, PRASA, and USACE.
- *Reliable electricity supply to reduce water safety risks at drinking water and wastewater facilities*– As of March 2017, a significant number of drinking water and wastewater facilities in Puerto Rico are still operating on temporary generators. The burden of providing fuel and security for generators reduces the reliability of drinking water and wastewater services, which poses potential risks to water safety (see below). In the post-response period, provision of adequate and reliable electricity to drinking water and wastewater facilities, including treatment plants and pumping stations, requires either reconnecting facilities to a functioning electricity grid or installing renewable generation to independently power facilities. In addition, based on the damage sustained by the water sector during Hurricane Maria, installing more-robust back-up power for water facilities to enhance redundancy is an important action to increase the sector's resilience.
- *Repairs to water treatment facilities to restore the confidence that Puerto Rico residents and industries have in the safety of water systems.* Repairs to water treatment facilities, pumping stations, and wells are needed to increase the reliability of drinking water supply. The legacy of water quality violations, combined with the reduced reliability of drinking water services due to the disruption of water services and infrastructure by Hurricanes Maria and Irma, have reduced the confidence that Puerto Rico residents and industries have in the safety of water systems. In addition, Puerto Rico does not routinely test non-PRASA systems, collect data on water-related disease outbreaks or notify the public when violations have occurred. Restoring confidence is a fundamental need for the sector and the broader recovery of the Commonwealth.
- *Repairs to wastewater pumping stations and treatment plants to avoid discharge of untreated effluent to Puerto Rico's waterways.* Due to high rates of contamination from wastewater, stormwater, and industrial sites, Puerto Rico's surface water systems are highly degraded. PRASA's largest four WWTPs discharge primary treated wastewater directly into coastal and estuarine waters. Over 27,000 sanitary overflows occur each year from wastewater systems alone, and many septic tanks are improperly maintained, or unsealed and often discharge raw sewage directly into coastal, surface, and groundwater bodies. der Undermaintained and undersized stormwater systems contribute to overflow events and, in combined systems in San Juan, combined sewer overflows further compromise the health of surface and groundwater bodies. Repairing wastewater pumping stations and wastewater treatment plants to avoid the discharge of untreated effluent to Puerto Rico's waterways is a priority. Improved water source protection will safeguard water supply, human health, and ecosystem services.

Longer term

Over the next one to ten years, looking beyond immediate needs toward the development of a water sector that is modern, robust, efficient, and equitable will require prolonged investment in infrastructure and the reform of management practices and operations. Recovery actions funded by FEMA and other federal agents can establish a foundation for future development of the sector.

- *Enhanced fiscal sustainability of the water sector addressing PRASA's ongoing challenges with servicing federal and private debt, fees evasion, declining population, and lack of access to capital markets.* PRASA projects a decrease in operating revenue in the upcoming five-year period due to declines in population and consumption, deficient service and increases in uncollectible accounts. During this same five-year period, expenses are expected to decrease following projected decreases in energy costs and labor costs, but the rate of decrease is likely less than that of revenue, potentially leading to an imbalance (Puerto Rico Aqueduct and Sewer Authority (PRASA), 2018). PRASA's ongoing challenges with servicing federal and private debt, fees evasion, declining population, and lack of access to capital markets are critical issues for both the near-term recovery of the water sector and the ability to build and sustain resilience over the long-term. The financial health of non-PRASA and stormwater systems also could compromise their ability to provide safe and reliable water services.
- *New investment addressing infrastructure degradation across drinking water, wastewater, and dams and levee systems to reduce water quality violations and improve regulatory compliance*. The high rate of non-revenue drinking water in the PRASA drinking water distribution system is indicative of long-term deferred maintenance and infrastructure degradation and sub-optimal metering. Such degradation is also evident in the wastewater system, particularly in areas where population has been in decline and pipe corrosion associated with hydrogen sulfide has undermined the structural integrity of the system. Building back Puerto Rico's water systems in the face of a legacy of water quality violations in both PRASA and non-PRASA systems will require enhanced capacity building and technical assistance, monitoring programs and education and outreach to community members. With regard to Puerto Rico's dams and levee systems, while assessments by the USACE indicate that there are not any immediate threats, a range of issues need to be addressed. This includes ensuring regular maintenance of dams and levees to maintain armoring and vegetation clearance. There are also opportunities to improve situational awareness at dams through upgrades to instrumentation. Given that many dams and levees were constructed decades ago, ongoing monitoring of structural integrity is necessary. Such monitoring and inspections for both dams and levees are routinely conducted by the USACE. However, identified deficiencies may not necessitate immediate interventions, depending on the nature of the deficiency and the potential for health and safety concerns. Addressing such degradation is a critical element to building the water sector back to a more resilient state.
- *Strategies to address long-term sedimentation issues exacerbated by Hurricane Maria in order to enhance capacity, operations, and water quality in Puerto Rico's reservoirs* – Enhancing the capacity and operations of Puerto Rico's reservoirs is critical for conveying greater drought resilience to the Commonwealth's drinking water supply and

for enabling greater flexibility in flood mitigation. Most dams are operated for either water supply or based on outdated hydropower generation rules, not to optimally balance flood control and water supply. Improving reservoir operations and reversing the sedimentation that has occurred over multiple decades and which was exacerbated by Hurricane Maria is a key element for the long-term sustainability of Puerto Rico's water sector.

- *Improved capacity to manage drought risk for Puerto Rico's water systems.* While much attention is currently focused on the damage experienced by the water sector from Hurricane Maria – specifically those brought on by high winds, flooding, and failures in other critical infrastructure systems – a resilient water sector must be prepared to manage other threats as well. As a case-in-point, the 2015 Caribbean drought exposed approximately 20 percent of Puerto Rico to "moderate" to "extreme" drought (NOAA's National Centers for Environmental Information, undated).[188] As a result, water rationing was implemented in order to manage demand. Therefore, as recovery efforts proceed, consideration should be given to how to improve the capacity of Puerto Rico's water systems to manage drought risk. Efforts to address challenges with water that leaks from the distribution system before reaching users are one key mechanism to improve water security. In addition, enhancing flexibility in drinking water supply sources such that resources can be more readily transferred among service zones during times of drought would provide greater resilience over the long term.

[188] Areas in "moderate" drought are areas where damage to crops and pastures can be expected and where fire risk is high, while stream, reservoir, or well levels are low. Those in "severe" drought are areas where crop or pasture losses are likely, fire risk is very high, water shortages are common, and water restrictions are typically voluntary or mandated.

13. Telecommunications/Information Technology

Overview

This chapter documents the damage and needs assessment conducted for Telecommunications/Information Technology (IT) in support of the 180-day Plan development. The assessment addresses the telecommunications infrastructure required to provide both continuity of government functions after a disaster and adequate public safety services to the residents of Puerto Rico. This sector also includes commercial telecommunications, such as telephone and internet services for businesses and residents of the island. As such, this chapter is divided into two subsections: (1) commercial services and (2) public safety communications. Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Telecommunications/IT" Sector Report.

Modern governance of telecommunications in Puerto Rico dates to the mid-1990s. The Puerto Rico Telecommunications Act of 1996 introduced competition in the telecommunications market and established the Puerto Rico Telecommunications Regulatory Board (PRTRB) (Public Law 104-104, Puerto Rico Telecommunications Act of 1996, Statute 56). PRTRB regulates the telecommunications industry and has overseen the build out of infrastructure for mobile telephony in Puerto Rico. The board has also been active in Connect Puerto Rico and other broadband initiatives to increase the widespread deployment of broadband internet in Puerto Rico.

The Puerto Rico Emergency Management Agency (PREMA) is the Puerto Rico government agency that oversees all emergency activities, and uses its radio network to communicate between its headquarters and 12 regional offices (Public Law 104-104, Puerto Rico Telecommunications Act of 1996, Statute 56). It also manages the Interoperability Radio Network (Public Law 104-104, Puerto Rico Telecommunications Act of 1996, Statute 56). Table 13.1 provides an overview of the regulatory, governance, and public safety and commercial communications entities in Puerto Rico.

Table 13.1. Commonwealth Agencies Responsible for Governance of Telecom/IT in Puerto Rico

Agency	Responsibilities	Authorities
Puerto Rico Telecommunications Regulatory Board (Junta Reglamentadora de Telecomunicaciones de Puerto Rico)	Regulates telecommunications services in Puerto Rico Ensures compliance with the Puerto Rico Telecommunications Act of 1996 (the Act) to include imposing reasonable administrative fines for violations of the Act and ordering the ceasing of activities in violation of any provision Conducts inspections, investigations, and audits, if necessary, to attain the purposes of the Act Has primary jurisdiction over all telecommunications services and	Established by the Puerto Rico Telecommunications Act of 1996 (this statute has been amended 21 times between 1999 and 2017)

Agency	Responsibilities	Authorities
	persons who render these services in Puerto Rico Performs Emergency Support Function #2 responsibilities[189] Board's President and four members are appointed by the Governor with advice and consent by the Senate	
Department of Public Safety	Includes the following organizations: Puerto Rico Police Department (Policía de Puerto Rico), Puerto Rico Fire Department (Cuerpo de Bomberos), Emergency Medical Services (Cuerpo de Emergencias Médicas), PREMA (Agencia Estatal Para el Manejo de Emergencias y Administración de Desastres), 911 System (Sistema de Emergencia 911), Forensic Sciences Institute (Instituto de Ciencias Forenses), and Office of Special Investigations (Negociado de Investigaciones Especiales (NIE) Oversees and has direct authority over all the organizations listed above Led by the Secretary of Public Safety who reports to the Governor	Law of the Department of Public Safety of Puerto Rico (law number 20 dated Apr. 10, 2017 and amended by law number 78 dated Feb. 4, 2018)
Office of the Chief Information Officer of Puerto Rico (Principal Ejecutivo de Informacion de Puerto Rico)	Advises the governor on the creating and implementating public policy about the use of information and telecommunication technologies (technologias de informacion y comunicacion or TIC) Advises the governor on the strategic management and best use of TIC for the government Responsible for an inventory of TIC of the government of Puerto Rico Establishes and implements strategic plans, policies, standards, and integrated architecture of the TIC of the government of Puerto Rico Establishes and implements policies and security measures of the government for the use of the internet and of the interagency network Led by the Chief Information Officer who reports to the Governor	Reestablished by Governor's Executive Order, dated Jan. 24, 2017 (published in Bulletin OE-2017-014); First established in 2009 under Executive Order (published in Bulletin OE-2009-09) but eliminated in 2015 by Executive Order (published in Bulletin OE-2015-19)

Note: In addition to the agencies in Table 13.1, in June 2017, the Governor appointed a Chief Innovation Officer. According to the Governor's announcement, the Chief Innovation Officer is responsible for leading innovation processes in the Government of Puerto Rico to make the processes more agile and facilitate the accessibility of government services to citizens.

Data sources and methods

Overview

This report relies on two sources of data: (1) secondary sources which could be publicly available records, reports, and communication plans, and (2) interviews with lead officials involved with the hurricane response efforts. The sections below elaborate the approach and include a description of specific data sources referenced, as well as the methods used.

[189] Executive Order OE-2001-26. "Order Ejecutiva de la Gobernadora del Estado Libre Asociado de Puerto Rico para establecer la coordinacion de funciones ejecutivas en manejo de emergencias o desastres y derogar los boletines administrativos OE-1993-23 y 4974-E. Dated June 25th 2001. According to FEMA, Emergency Support Function #2 (ESF-2) is responsible for supporting the restoration and recovery of communications and coordination of related response activities. ESF-2 coordinates federal actions to assist industry in restoring public safety communications systems and infrastructure and first responder networks.

Data sources

Table 13.2 provides a summary of the key data sources used for this assessment. As of this report writing, this list does not include sensitive information, such as FOUO or proprietary information from commercial carriers.

Table 13.2. Summary of Key Telecommunications/IT Data Sources

Dataset	Source	Date	Evaluation Notes
Puerto Rico Public Safety Communications Summary and Recommendations Report	FEMA	Feb. 2018	Good descriptive detail on public safety telecommunications systems
DR-4339-PR Consolidated Communications Restoration Plan	FEMA	Oct. 2017	Good descriptive detail on public safety telecommunications systems
Letter from the Puerto Rico Telecommunications Regulatory Board to the Chairman of the Federal Communications Commission	PRTRB	Jan. 2018	Good descriptive detail on telecommunications
CTIA comments on 2017 hurricane season	FCC publicly available	Jan. 2018	Commercial perspective with some aggregate data
AT&T comments on 2017 hurricane season	FCC publicly available	Feb. 2018	Commercial perspective with some aggregate data
T-Mobile comments on 2017 hurricane season	FCC publicly available	Jan. 2018	Commercial perspective with some aggregate data
Verizon comments on 2017 hurricane season	FCC publicly available	Jan. 2018	Commercial perspective with some aggregate data
Puerto Rico Police Department Damage Report	Puerto Rico PD	Sept. 2017	Photographic evidence of damage
Communication Status Reports	FCC publicly available	Sept. 2017 and Mar. 2018	Data on cellular site service outages
Puerto Rico Emergency Medical Services (EMS) Inspection Report for Communication Sites	Government of Puerto Rico	Sept. 2017	Photographic evidence of damage
PREMA Inspection Report for Communication Sites	Government of Puerto Rico	Sept. 2017	Photographic evidence of damage

Methods

To report on pre-storm conditions and challenges, damage caused by Hurricanes Irma and Maria, and post-hurricane response, this assessment relies on documentation and testimonial evidence. Two primary sources of information were provided by FEMA officials—an October 2017 report completed by Emergency Support Function (ESF) 2 and a February 2018 report completed by DHS Office of Emergency Communications Interoperable Communications Technical Assistance Program (DR-4339-PR Consolidated Communications Restoration Plan and Puerto

Rico Public Safety Communications Summary and Recommendations Report). This chapter includes information from the FCC and other publicly available sources including comments from various commercial carriers in response to a notice for public comment regarding the 2017 hurricane response. It also leverages information provided by the Puerto Rico police department and PRTRB. The report also includes information received through discussions with various officials involved with the hurricane response efforts.

Related to the two DHS reports cited above, the HSOAC project team interviewed the lead official responsible for overseeing these reports. However, data directly from commercial carriers were not obtained due to its proprietary nature.[190]

This assessment mitigates this information gap by utilizing publicly available information from commercial carriers and the FCC. Such information provides an aggregate overview (rather than a detailed view) of Puerto Rico's Telecom/IT, which can be used to assess damage and needs. Additionally, to protect critical infrastructure information, this discussion does not include specific information on public safety telecommunication sites, such as their location, names, ownership, or specific damage status.

Data gaps, assumptions, and uncertainties

As noted above, FOUO and proprietary information was not included in this assessment. As a result, information in this assessment is largely presented at an aggregate level. The lack of a more granular view may miss opportunities to describe the impact of the damage on specific municipalities. Further, although additional quantitative data on key metrics, such as the percentage and number of central offices of the incumbent local exchange carrier that are operational at a certain point in time, might be helpful in assessing damage, these data are considered company-proprietary information.

Cellular site outage data reported by the FCC provides an example of how aggregate data might not be representative of certain municipalities. Because, months after the hurricanes, certain municipalities continued to experience higher percentage of cellular site outages than the average across Puerto Rico, analysis based on aggregated data may miss opportunities to describe the impact of the damage to specific municipalities and status of response activities.

[190] HSOAC could have obtained such data by signing Non-Disclosure Agreements (NDAs) with each of the private companies. However, NDA-protected information is generally not releasable in a wide dissemination report such as this one because it is defined as competitively sensitive information.

Commercial services

Background

History and structure

In 1897, the Sociedad Anonima de Telefono offered public telephone service for the first time in San Juan, Ponce, and Mayaguez (National Telecommunications and Information Administration). In 1914, Ricotelco was founded by Sosthenes and Herman Behn in San Juan (Harvard Business School). In 1920, Sosthenes Behn founded International Telephone & Telegraph (ITT) (Harvard Business School). ITT served as a holding company for Ricotelco and several other Caribbean telephone companies (Harvard Business School). In 1974, Puerto Rico acquired Ricotelco from ITT for $200 million and created the Puerto Rico Telephone Company (PRTC) (Harvard Business School). In 1980, PRTC began deploying fiber-optic capability, and completed its fiber-optic network in 1994 (Parra Blessing, 2005). In 1994, PRTC introduced cellular services in Puerto Rico, and, in 1996, began providing internet services (Parra Blessing, 2005). At this point, PRTC was the government-owned and government-run monopoly provider of telecommunications services in Puerto Rico.

The U.S. Congress enacted the Telecommunications Act of 1996 (the 1996 Act), which required incumbent local exchange carriers (ILECs) like PRTC to interconnect with new rivals, Competitive Local Exchange Carriers (CLECs), at cost-based rates for unbundled network elements (Public Law 104-104, Puerto Rico Telecommunications Act of 1996, Statute 56). The Puerto Rico legislature enacted the Puerto Rico Telecommunications Act of 1996 (Public Law 104-104, Puerto Rico Telecommunications Act of 1996, Statute 56) and created the Puerto Rico Telecommunications Regulatory Board as the regulator for the telecommunications industry in Puerto Rico (Public Law 104-104, Puerto Rico Telecommunications Act of 1996, Statute 56).

In 1997, the Puerto Rico legislature enacted a law to allow the sale of PRTC. In 1998, GTE purchased PRTC from Puerto Rico for $2.25 billion (Harvard Business School). In 2000, Bell Atlantic (now Verizon Communications) purchased GTE. In 2001, PRTC launched Verizon Wireless and introduced digital subscriber line (DSL) service (Parra Blessing, 2005). PRTC was a subsidiary of Verizon Communications until it was fully acquired by America Movil in 2007 (Parra Blessing, 2005). In 2011 and 2013, America Movil rebranded many of PRTC's services to the name "Claro." Currently, Claro provides residential wireline, wireless, broadband DSL, television, dial-up, and internet protocol television (IPTV) services, as well as services to business, government and enterprises in Puerto Rico (Bloomberg, 2018a).

Key assets

Prior to Hurricane Maria, telecommunications in Puerto Rico were primarily achieved wirelessly; over 80 percent of Puerto Rico customers exclusively used cellular phone or other wireless connections (Hurricane Maria Communications Task Force, 2017). The FCC's 2018

Broadband Progress report shows that currently approximately 99% of Puerto Ricans have access to cellular service (Federal Communications Commission, 2018b, Appendix E). Broadband internet use in Puerto Rico was much less common than in the continental United States, and broadband service is not available throughout the Commonwealth. Rural areas in the central and western parts of the main island particularly lack connection (Connect Puerto Rico, 2014), such that in 2016, 62 percent of all Puerto Ricans and 98 percent of residents in rural areas lacked broadband access (Federal Communications Commission, 2016,Appendix D). Since 2010, there have been government-sponsored efforts through Connect Puerto Rico and the Broadband Initiative to increase broadband deployment and penetration in Puerto Rico. The National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce has awarded over $41 million in broadband-related federal grants to Puerto Rico (National Telecommunications and Information Administration, undated).

Prior to the 2017 hurricanes, the commercial telecommunications network of Puerto Rico was made up of different technologies that interconnect to provide voice and data communications. All of these technologies require continuous and sufficient power to function, either via the electrical grid or generator. A single generator can be used to power one telecommunications site for short durations as backup power but is not intended to serve as a primary electric power source. The different network architectures supporting commercial services in Puerto Rico include:

- wireline service provided by Claro (the Public Switched Telephone Network or PSTN)
- cellular service provided by AT&T, T-Mobile, Claro, and PRWireless
- broadband internet service provided by Liberty Cable
- microwave point-to-point communications used for backhaul[191] to the public switched telephone network by the cellular carriers
- satellite communications used for voice and data connections in an emergency.

The providers of wireless infrastructure (cell towers) such as Crown Castle, American Tower, SBA, and Innovattel provide the infrastructure needed to mount radios and antennas. In addition, AT&T and other mobile telephone providers lease space on poles owned by PREPA or Claro, the incumbent local exchange carrier (ILEC), to deploy their aerial fiber network. Aerial fiber optic cable, which is typically used for outside installation of telecommunications lines strung on poles above ground, has been used for a very significant amount of backhaul, which is the portion of the network which provides links between the core network and other subnetworks between cell sites and the telecommunications network (Bloomberg, 2018a). Puerto Rico has little copper utility line infrastructure or fiber buried underground (Bloomberg, 2018a).

Key infrastructure also includes the six submarine cable and cable landing stations that connect calls from Puerto Rico to destinations outside of Puerto Rico. Submarine cable-related

[191] The backhaul portion of a network comprises the intermediate links between the core network and smaller subnetworks at the "edge" of the entire hierarchical network.

infrastructure has constituted the primary high-capacity telecommunications links from Puerto Rico to the outside world. Puerto Rican landing stations have been concentrated on the northern side of Puerto Rico, centered on San Juan. These cables have provided connectivity to points throughout the Caribbean, South America, and North America.[192] Both submarine cabling and related terrestrial infrastructure are vulnerable to storm damage (Madory, 2017).

In addition to the residential and business wireline, wireless, broadband DSL, dial-up services, and internet protocol television (IPTV) provided by Claro (the former government-owned monopoly provider of telecommunications services), new entrants have also begun providing wireless and internet services in Puerto Rico. Until very recently, there were five providers of mobile telephone service in Puerto Rico: AT&T, T-Mobile, Claro, Sprint, and Open Mobile. In mid-November 2017, Sprint and Open Mobile formed a joint venture, PRWireless, LLC, which has been approved by the FCC and the PRTRB (Kantrow, 2017).

Internet services is provided using technologies such as cable (Liberty), DSL (e.g., Claro, WorldNet), fiber (e.g., Optico Fiber), and fixed wireless (e.g., IP Solutions, Caribe.net, Inteco, Neptuno Networks) (BroadBandNow, 2018a; BroadBandNow, 2018b). Liberty Cablevision of Puerto Rico is the only cable provider on the Island. According to its website, "Liberty provides video, broadband Internet, and fixed-line telephony services to residential and/or business customers in Puerto Rico" (Bloomberg, 2018b).

Figure 13.1 below provides an aggregate view of all the telecommunication sites in Puerto Rico prior to the 2017 hurricanes. The map reveals that:

- The telecommunications infrastructure density is greater (more sites per unit area) within and around the metropolitan San Juan area (northern region).
- The next-densest level of telecommunications infrastructure is near the coasts, where terrain is flat (note that topography is not depicted in the map).
- The fiber-optic backhaul (not shown) tends to follow the road that roughly parallels the coast.
- Certain population centers (e.g., Mayaguez) and others also near the coast have higher density of telecommunication sites, possibly due to the higher concentration of industry.
- The mountainous center of Puerto Rico has the lowest density of telecommunication sites.
- Areas that lack access to the internet or that have insufficient wireless coverage tend to lie within the areas of low telecommunication site density in this map.

[192] Technical details on the submarine cable infrastructure, including the landing stations, are considered sensitive information.

Figure 13.1. Aggregated View of Private and Public Telecommunications Sites in Puerto Rico

Source: Puerto Rico Telecommunications Regulatory Board.

Pre-hurricane conditions

Puerto Rico faced some pre-storm challenges that made communications networks vulnerable in the event of a natural disaster. As Table 13.3 illustrates, these conditions have had a severe impact on commercial communication services.

Table 13.3. Summary of Key Commercial Communications Pre-storm Conditions and Challenges

Condition	Challenge
Lack of buried fiber	Aerial fiber was exposed to the elements, which resulted in a greater loss of communications networks than if buried fiber had been utilized.
Improper maintenance	Lack of proper maintenance to utility poles that carried aerial fiber including, for example, excess weight of attachments increased susceptibility to damage/destruction.
Aging power grid	Communications, including wireless, wireline, and cable, depended on an aged electrical grid.
Concentration of submarine landing stations	Locating the submarine landing stations in one area increased the risk of losing communications to and from the island if a major disaster occurs.

According to expert interviews, Puerto Rico's telecommunications infrastructure was in a fragile state prior to the storms.[193] Telecommunication towers were overloaded with equipment, making them less stable and more prone to hurricane damage, and many telecommunication sites were

[193] Personal communication, ESF-2 and other FEMA officials, March 2, 2018

not properly maintained.[194] The remote mountainous locations of some key sites made them difficult to access for regular maintenance or vegetation clearing, in turn making them more susceptible to the damage inflicted by wind and hurricane debris. Additionally, according to one wireless carrier, since all of Puerto Rico was predicted to be in Maria's path, response equipment could not be prepositioned before the storm due to the risk that it would be lost, damaged, or destroyed (Federal Communications Commission, 2017).[195]

As a further complication, many telecommunication sites in Puerto Rico have multiple owners and multiple users. This means that buildings housing the electronic equipment and the land on which these buildings stand may belong to different owners.[196] Numerous users, including different public safety agencies (police, emergency medical service [EMS], PREMA) and private carriers, may lease both space in the tower to install their antennas and part of a building to house their electronic equipment. As a result, for many sites it has often been difficult to determine which owner is responsible for any maintenance or repairs.[197]

Information on the pre-storm funding environment had not been obtained as of the drafting of this assessment. However, one wireless carrier noted that the power grid was ill-prepared to sustain a major hurricane.[198] Lack of resources could be a cause for insufficient preparation. However, the PRTB did *not* cite lack of resources as a "major cause" of telecommunications outages due to the hurricanes. According to the PRTRB, commercial carriers will need to make significant investments in their wireline and wireless infrastructure.

Hurricane damage

Commercial telecommunications networks in Puerto Rico were significantly impacted by Hurricanes Irma and Maria. FEMA officials could not differentiate damage caused by Irma and Maria due to the close proximity of the storms and scope of the damage sustained, but suggest that the impact of Hurricane Maria was likely far worse on telecommunications systems (Hurricane Maria Communications Task Force, 2017).

The impact of the destruction caused by Hurricane Maria to Puerto Rico's telecommunications networks was unprecedented, widespread, and devastating. The lack of commercial telecommunications had a profound impact on daily life for the citizens of Puerto Rico. Even as commercial telecommunications were restored, progress was likely slow for many of Puerto Rico's citizens. For example, in some cases, voice and text messaging services were

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[194] Interview with ESF-2 and other FEMA officials, March 2, 2018

[195] Personal communication, AT&T response to FCC press release.

[196] According to telecommunication experts interviewed, this situation is not uncommon in the U.S. mainland.

[197] Personal communication, ESF-2 and other FEMA officials, March 2, 2018

[198] Comments of T-Mobile USA, INC., In the Matter of Response Efforts Undertaken During 2017 Hurricane Season, Jan. 22, 2018.

restored before data services. FEMA officials noted that these limitations, including lack of access to the internet, limited citizens' ability to apply for important relief through FEMA.[199] Since the telecommunications system depends on electrical power, individuals without power could not fully benefit from restored telecommunications networks if their mobile devices were not charged. Further, the government of Puerto Rico had limited means by which to communicate essential information to its citizens.

Commercial telecommunications were almost nonexistent in Puerto Rico immediately following Hurricane Maria. Due to the ubiquity of mobile technology and its dependence on the electrical system infrastructure, most residents lacked the ability to communicate until repairs were made and the electricity grid restored. Additionally, according to comments from private sector officials, lack of telecommunications and internet connectivity impeded businesses' abilities to contact employees, fulfill orders, and run web-based enterprise software.[200]

According to the PRTRB, as of September 24, 2017, Hurricane Maria resulted in 91 percent damage to the private telecommunications infrastructure—primarily antennas and fiber—which affected the government, retail, banks, pharmaceutical, developers, food, transportation, and other businesses (Torres Lopez, 2018). Ninety-five percent of cellular sites were out of service, and 75 percent of cell sites throughout all municipalities were out of service. Forty-eight out of 78 municipalities lost 100 percent of their cell sites (Federal Communications Commission, 2018a).

Additionally, ESF-2 reported that 80 percent of the approximately 350 linear miles of core above ground fiber were destroyed, and 85 to 90 percent of the approximately 1,500 linear miles of "last mile" fiber were destroyed (Hurricane Maria Communications Task Force, 2017). According to a Puerto Rico homeland security official, it was reported that 48,000 utility poles had been damaged by the storm.[201]

As indicated previously in this report, all the cable landing stations in Puerto Rico were located on the northern coast in the San Juan metropolitan area. According to news reports (Becker, 2017), the primary submarine cable landing stations for many of the major U.S. telecommunication carriers were damaged during Hurricane Maria, leaving only one of six landing stations to support off-island telecommunications (Becker, 2017).

Separate from the restoration of public safety communications systems, in January 2018, the PRTRB estimated that the private telecommunications damage totaled more than $1.5 billion, not including the restoration of public safety communications systems (described below) (Torres Lopez, 2018). This estimate is consistent with the $1.5 billion estimate to reconstruct the fiber network and replace damaged cell sites, as described in *Build Back Better Puerto Rico* (Governor of Puerto Rico, 2017a). Additionally, in March 2018, the FCC Chairman announced a plan to

[199] Email from FEMA Economic Sector Task Force, May 12, 2018.

[200] Email from FEMA Economic Sector Task Force, May 12, 2018.

[201] Interview with Mr. Felix Garcia, March 1, 2018.

invest $750 million in Puerto Rico through the creation of the *Bringing Puerto Rico Together Fund*. The funding would address short-term restoration of service and long-term improvement and expansion of broadband (Federal Communications Commission, 2018c). While the announced investment does not represent direct estimates related to the costs of the damage, it provides some corroboration of the scale of the investment needed for communications to be restored and to recover from Hurricane Maria.

Post-hurricane conditions

After the 2017 hurricanes, commercial carriers reported taking a number of steps to restore wireless service to customers, such as using cells on light trucks, cells on wheels, and portable generators. In addition to leveraging this equipment, four wireless carriers opened up roaming to ensure service to the maximum population with the coverage available.[202] Carriers also used non-traditional means to restore service. For example, AT&T used "flying cell on wings" or a drone cell site to temporarily provide data, voice, and text messaging services over a 40-mile radius. In another example, AT&T and T-Mobile partnered with Alphabet's Project Loon to provide LTE-based services to tens of thousands of citizens through the use of network balloons. Such efforts helped restore wireless service despite catastrophic infrastructure damage and sustained electrical outages. According to a lead FEMA official, a lack of coordination between PREPA and commercial carriers resulted in some restoration setbacks. For example, PREPA would cut lines or remove fiber from poles that had already been restored by commercial carriers in order to restore electricity. Such activities were stopped and coordination improved as restoration activities progressed.[203]

According to comments provided to the FCC, CTIA noted that, as of early November, 74 percent of Puerto Ricans had wireless coverage, despite the fact that less than 43 percent had access to commercial power at that time.[204] This progress was made in large part due to the use of generator power.

In addition, given the high use of mobile phones and damage to the infrastructure, most people (91%) were unable to communicate.[205] Figure 13.2 reflects the fact that 95 percent of cellular sites were out of service as of September 21, 2017. All municipalities saw more than 75

[202] Comments of CTIA, In the Matter of Response Efforts Undertaken During 2017 Hurricane Season, January 22, 2018.

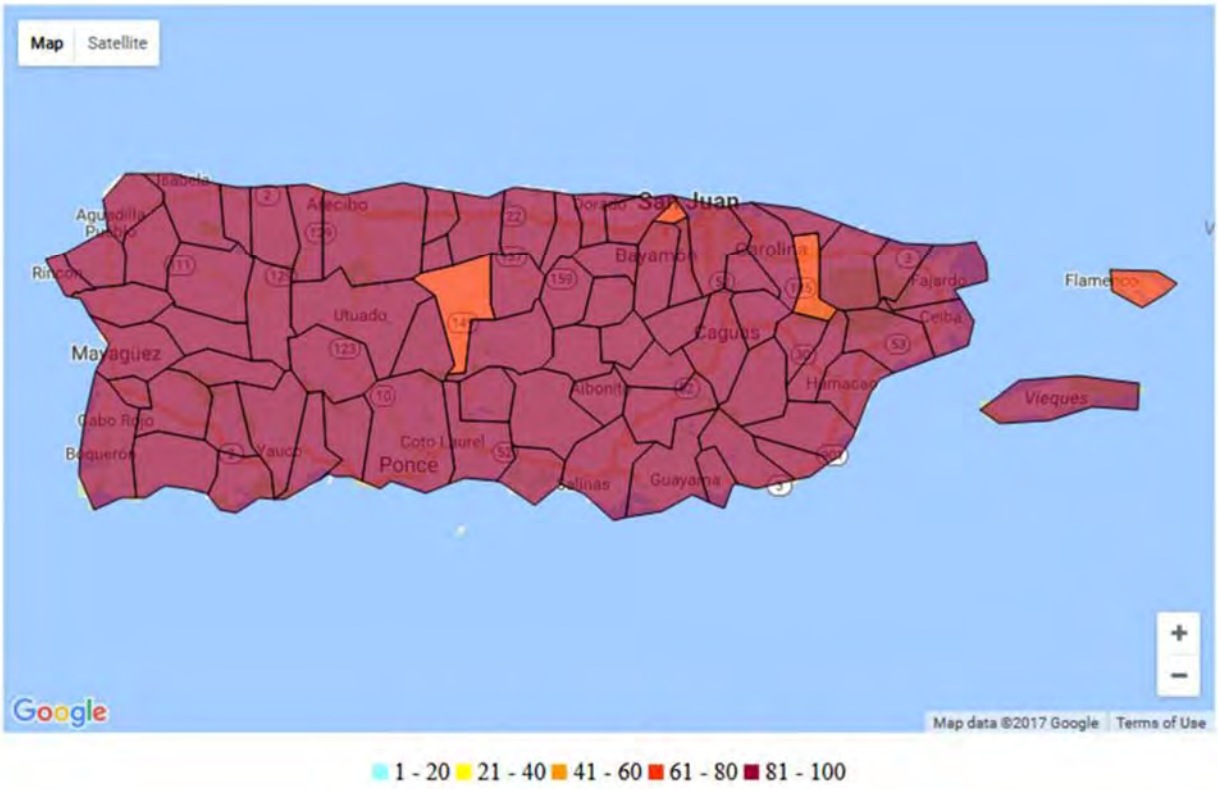
[203] Interview with Mr. Chris Tuttle and other FEMA officials, Mar. 2, 2018.

[204] Comments of CTIA, In the Matter of Response Efforts Undertaken During 2017 Hurricane Season, January 22, 2018.

[205] Sandra E. Torres Lopez, Letter from the Puerto Rico Telecommunications Regulatory Board to the Honorable Ajit Pai, the Chairman of the Federal Communications Commission. Jan. 22, 2018.

percent of their cell sites go dark, and 48 of the 78 municipalities lost 100 percent of their cell sites.[206]

Figure 13.2. FCC Data on Cellular Site Outages as of September 21, 2017



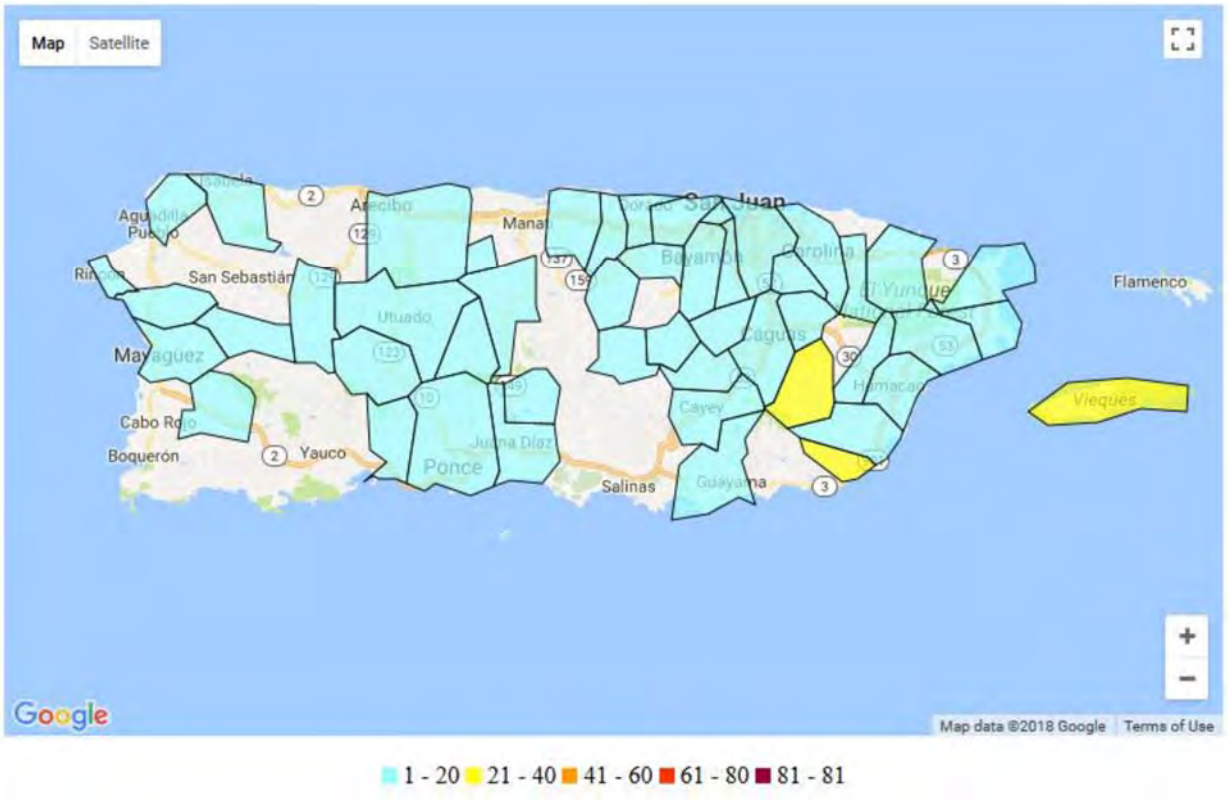
Repairs and current conditions

Specific information on repairs conducted to date remains limited as of the writing of this report since FEMA is working to approve funding for various projects. Figure 13.3 below illustrates the progress made to date in restoring cell sites to operation. According to the FCC communications status report from March 21, 2018, only 4.3 percent of cell sites in Puerto Rico were out of service as of that date. However, variability exists by municipality; for example, Maunabo had three out of 12 cell sites out, or 25 percent, according to the FCC's report (Federal Communications Commission, 2018a). In addition, FCC's reports do not provide additional detail, such as whether these sites have been fully restored to pre-storm status or whether they continue to use fuel-based generators for power.

[206] Federal Communications Commission, Communications Status Report for Areas Impacted by Hurricane Maria, Sept. 21, 2017.

According to a January 22, 2018 PRTRB filing to the FCC, over 115 days after the hurricane, 60 percent of communications infrastructure in Puerto Rico still relied on generator power.[207] Generators are stored at cell sites for intermittent back-up in case of an emergency; they are not designed to run continuously for weeks to months. Generators require diesel or gasoline fuel, and supplying fuel to cell site generators has been both logistically challenging and expensive.[208]

Figure 13.3. FCC Data on Cellular Site Outages as of March 21, 2018



Note: The numbers and associated color represent percentage ranges for cell sites out of service. Grey areas indicate either an absence of data or lack of cell sites out of service. FCC does not clarify in its reports. Source: Federal Communications Commission daily report for March 21, 2018.

Additionally, all submarine cable landing stations on the main island, used by many of the major U.S. telecommunication carriers, have been repaired to allow communication with CONUS and other places in the world.[209] The status of cable infrastructure located on Vieques

[207] Comments submitted by the Puerto Rico Telecommunications Regulatory Board to the FCC on January 22, 2018, regarding the Public Safety and Homeland Security Bureau questions in the proceeding under PS Docket No. 17-344.

[208] See, e.g., Comments of Verizon in PS Docket No. 17-344, filed January 22, 2018, at p.18.

[209] Personal communication with PREPA Networks on June 12, 2018.

and Culebra, which allow for communication outside of Puerto Rico and also intra-island communication within Puerto Rico, is unknown at the time of writing.[210]

Infrastructure, geographic, bureaucratic, and other barriers have increased the complexity of the response environment in Puerto Rico. One wireless carrier cited three main causes of communications outage due to the hurricanes: loss of commercial power, loss of backhaul transport communications, and total tower loss.[211] Communications interdependence on electrical power remains a barrier and possible facilitator to the response. Private ownership of towers also adds complexity to the response efforts, since each tower owner must coordinate repairs and reconnection to electrical grid. As discussed previously, Puerto Rico's geography creates a challenging environment in which to gain physical access to some remote sites for response activities. According to PRTRB, lack of electricity, lack of physical access to sites, multiple incidents of copper theft, fiber optic cuts, and theft of generators and fuel delayed recovery efforts and increased costs (Torres Lopez, 2018).

Public safety telecommunications

Background

History and structure

The Puerto Rico Department of Public Safety has oversight authority regarding organizations with responsibility for public safety telecommunications. These include the Puerto Rico Police Department (Policía de Puerto Rico), Puerto Rico Fire Department (Cuerpo de Bomberos), Emergency Medical Services (Cuerpo de Emergencias Médicas), PREMA (Agencia Estatal Para el Manejo de Emergencias y Administración de Desastres), 911 System (Sistema de Emergencia 911), Forensic Sciences Institute (Instituto de Ciencias Forenses), and Office of Special Investigations (Negociado de Investigaciones Especiales (NIE).

Key assets

Prior to Hurricane Maria, Puerto Rico's main public safety telecommunications assets consisted of a series of Island-level radio systems, including the Puerto Rico Police Department P25 Trunk System, Puerto Rico Police Department SmartZone (San Juan metropolitan area only), EMS system ultra-high frequency (UHF) medical channels, PREMA system very high frequency (VHF) channels, and an interoperability system intended to provide statewide telecommunications in emergency or urgent situations, and during non-emergency operations. To support these systems, Puerto Rico used two primary microwave networks as backbone (Puerto

[210] Personal communication with PREPA Networks on June 12, 2018.

[211] Comments of AT&T, Public Safety and Homeland Security Bureau Seeks Comment on Response Efforts Undertaken During 2017 Hurricane Season, February 21, 2018.

Rico Police Department and EMS networks, respectively) (DHS Office of Emergency Communications and Interoperable Communications Technical Assistance Program, 2018a). These systems and networks were critical for the proper operation of 9-1-1 emergency response.

Pre-hurricane conditions

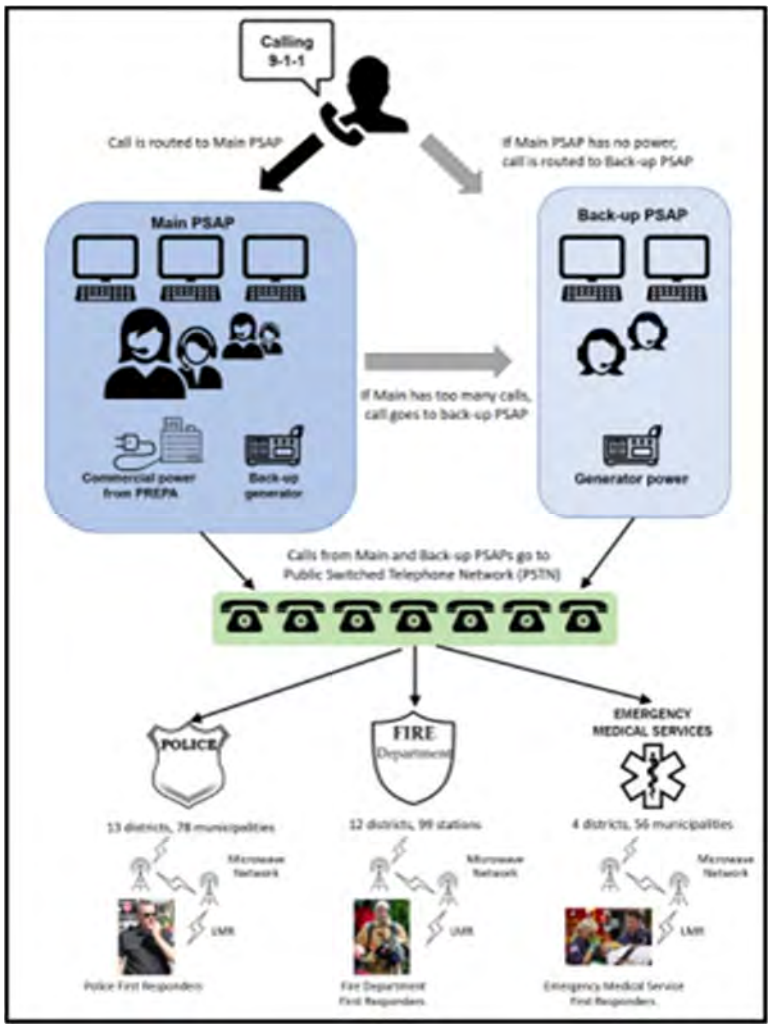
Prior to the 2017 hurricanes, public safety telecommunications in Puerto Rico involved a diverse collection of telecommunications resources. 9-1-1 calls would typically be directed to a primary Public Safety Answering Point (PSAP) or a back-up PSAP. However, these PSAPs did not have a dispatch capability. Instead, they used the Public Switched Telephone Network (PSTN) to relay emergency information to police, fire, and emergency medical services in each of Puerto Rico's 78 municipalities. Emergency services were then dispatched by the appropriate municipal organization (Hurricane Maria Communications Task Force, 2017). This structure presented a challenge since, without a functioning PSTN, emergency calls could not be properly relayed. In 2015, Puerto Rico reported receiving 2.5 million 9-1-1 calls (DHS Office of Emergency Communications and Interoperable Communications Technical Assistance Program, 2018a).

Figure 13.4 depicts the emergency response process as used prior to the hurricanes. The 9-1-1 caller would make a phone call to the main PSAP (shown by the arrow at top left). The main PSAP required either commercial power or a backup generator. If neither was available or if the main PSAP was overwhelmed with calls, the 9-1-1 call would be routed to an operator in a backup PSAP (shown by the arrow at top right).

The PSAP operator would then call the district or municipal office in charge of the appropriate first responders (shown by the arrows in the center of Figure 13.4. Puerto Rico's Process for Responding to 9-1-1 Emergency Calls

). That office then would dispatch a police patrol, ambulance, or fire truck via land mobile radio (LMR) or one of the microwave networks if the first responders were not reachable by LMR (represented by the icons above the photos at the bottom of Figure 13.4).

Figure 13.4. Puerto Rico's Process for Responding to 9-1-1 Emergency Calls



Source: HSOAC analysis of DHS Office of Emergency Communications documentation.

Governance challenges for emergency telecommunications were identified as critical pre-storm issues to be addressed. Specifically, while the Governor created a Puerto Rico Interoperability Committee for Emergency Communications in 2011 through executive order, the committee was ineffective and rarely met (DHS Office of Emergency Communications and Interoperable Communications Technical Assistance Program, 2018b). Given the complexities of Puerto Rico's telecommunications systems, coordination across government is important to planning for and implementing an effective emergency telecommunications system.

Prior to Hurricane Maria, the government of Puerto Rico also reached Memoranda of Understanding (MOUs) with the main telecommunication carriers on the island so that in case of emergency each carrier could provide a certain number of cellular phones for emergency use by the government and the municipalities. Each agency of the Puerto Rico government has an emergency plan that explains the procedures to follow and lists the phone numbers of officials

and personnel to be contacted in case of an emergency. There is also a master plan. Of course, emergency phone numbers are not useful when 95 percent of the telecommunications infrastructure is not operating. PRTRB provided a certain number of satellite phones to the Governor and other heads of agencies. After the disaster, FEMA brought additional satellite phones to the island for use by the Puerto Rico government.

Hurricane damage

Public safety telecommunications networks in Puerto Rico were significantly impacted by Hurricanes Irma and Maria, leaving citizens unable to access critical emergency services (Governor of Puerto Rico, 2017a). Moreover, citizens fortunate enough to have their emergency calls received by 9-1-1 dispatchers may not have received a response from emergency services due to the lack of emergency telecommunications linkages across municipalities and agencies.

Although some elements of the public safety telecommunications network were minimally impacted and operational after the 2017 hurricanes, other elements sustained major damage and crippled the ability of Puerto Rico to access public safety services. PSAP sites were operational once fuel-based generators were utilized, and the PR Emergency Management Agency radio network was also only minimally impacted. However, most agency stations across municipalities were unable to relay information. The following information summarizes the number of stations able to directly relay call information as of October 30, 2017 (Hurricane Maria Communications Task Force, 2017):

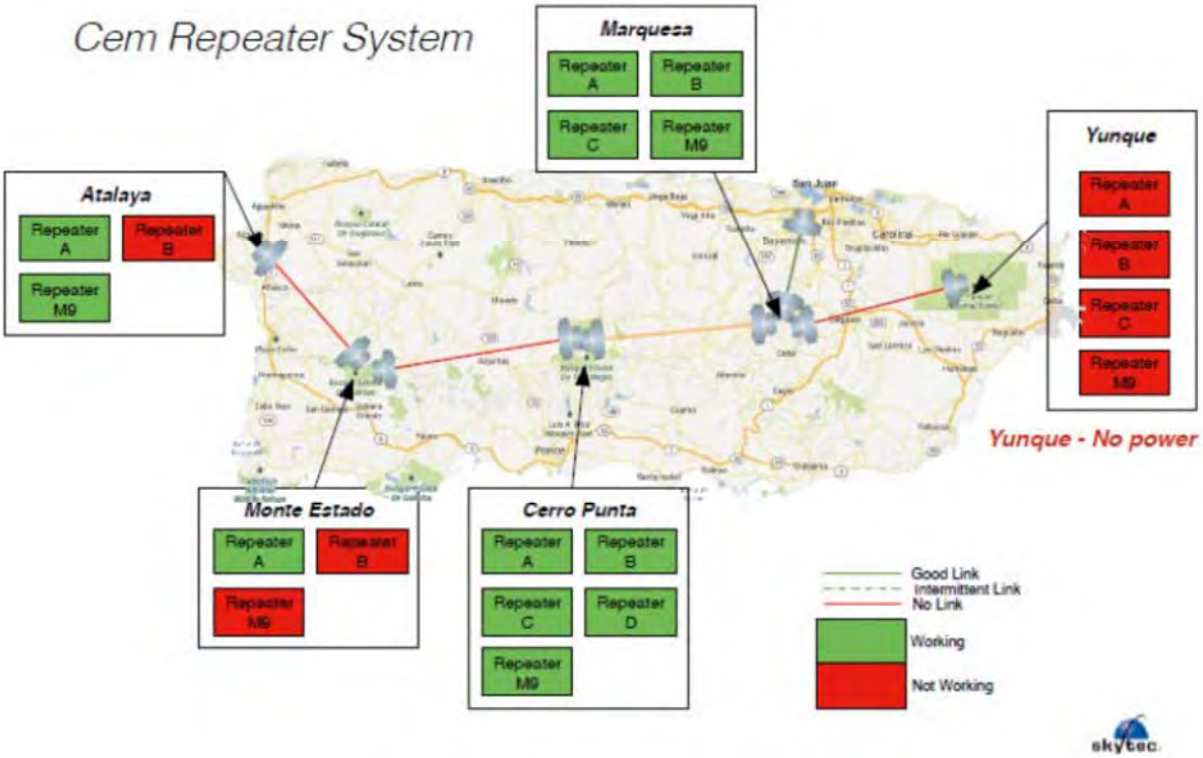
- Police: 12 of 78 stations
- Fire: 0 of 99 stations
- EMS: 14 of 56 stations

Public Safety LMR systems were severely impacted due to their dependence on infrastructure that had been destroyed by Hurricane Maria. The primary Puerto Rico police department radio system provided limited voice communications to fewer than half of fire stations (40 out of 99 stations). According to the Puerto Rico Police Department, 50 percent of the Police Department's primary network sites—the P25 radio system—were damaged, meaning they were either out of service and equipment and/or towers were damaged (Puerto Rico Police Department, 2017).

The EMS radio network (referred to in Figure 13.5 below as "CEM") also sustained critical damage. As the graphic shows, after Hurricane Maria, several elements of the system were not operational and numerous links were either intermittent or not functional. Regions where repeater systems or linkages were not working would have been unable to effectively communicate medical emergencies. As a result, EMS communications were partitioned and areas without operational systems were forced to use other means of communication, such as satellite phones. The boxes in this figure depicted in green indicate that the equipment was

operating after the hurricane and in red if the equipment was not. The red lines represent microwave links that were not functioning.

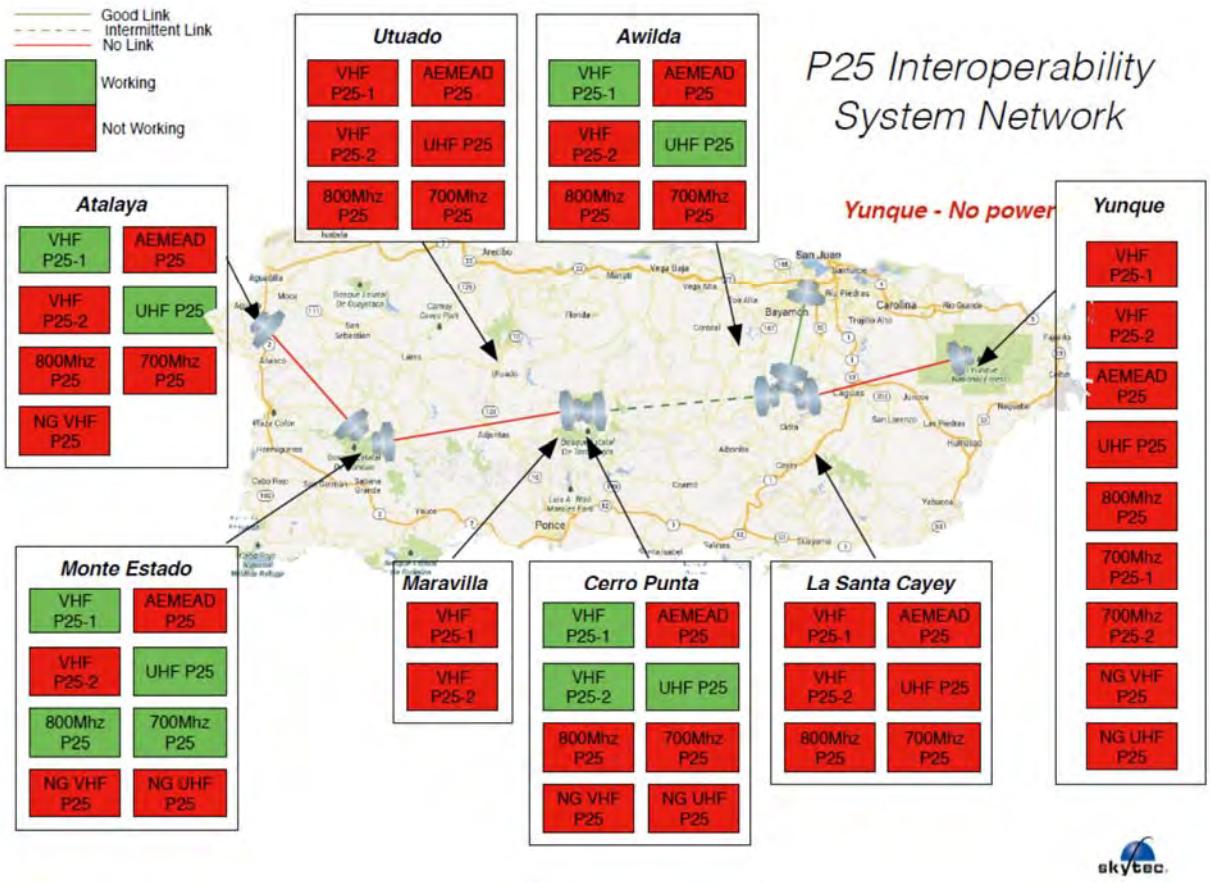
Figure 13.5. EMS Radio Network Status Post-Hurricane Maria



Source: October 2017 Hurricane Maria Communications Task Force report.

Additionally, much of Puerto Rico lost the use of the State Interoperability System (Figure 13.6). The boxes in this figure depict whether the equipment was operational after the hurricane (shown in green) or not operational (shown in red). As the figure shows, most equipment was damaged, demonstrating the significant impact of Hurricane Maria on Puerto Rico's public safety telecommunications, which resulted in a partitioned network.

Figure 13.6. Puerto Rico State Interoperability System Status Post Hurricane Maria



Source: October 2017 Hurricane Maria Communications Task Force Report.

Other important issues severely affecting public safety telecommunications included the substantial loss of electricity, microwave network connections, physical access to roads, landing stations, and backhaul infrastructure. To further illustrate the damage caused by Hurricane Maria, the Government of Puerto Rico conducted site visits to locations across the Island (see example in Figure 13.7below; as of September 20, 2017). On a broader scale, the Government of Puerto Rico had limited means by which to communicate essential information to its citizens (Hurricane Maria Communications Task Force, 2017).

Figure 13.7. Examples of Damage from Hurricane Maria to Public Telecommunication Sites

Source: Government of Puerto Rico, 20 September 2017.

Data on total costs associated with the damage to public safety telecommunications systems were not available at the time of writing this report, in large part because preliminary estimates were low and did not include rebuilding the numerous towers used for public safety, since these towers are privately owned (Hurricane Maria Communications Task Force, 2017).

Post-hurricane conditions

Emergency response

According to ESF-2's October 2017 report, immediate steps were taken to restore public safety telecommunications. Due to a generator failure at the primary PSAP, USACE provided a generator to the primary PSAP location as well as weekly fueling immediately after the storm. As a result, the primary PSAP was fully operational. Use of the generator continued during intermittent power outages.

ESF-2 also deployed tactical telecommunications equipment to 13 police district headquarters, 12 fire district offices, and 4 EMS offices. The purpose of this effort was to restore basic voice communications to facilitate transmission of 9-1-1 calls to municipalities. PREMA requested that EMS stations have internet connectivity, which required offices to relocate where ESF-2 solutions were already deployed. To restore LMR communication systems, ESF-2 used additional communications systems such as VSATs, radios, satellite phones, and MSATs. Civil Authority Information Support units from the Department of Defense were assigned to provide alert and warning capabilities as part of restoring the emergency alert system (Hurricane Maria Communications Task Force, 2017). According to a lead FEMA official, ESF-2 utilized a significant amount of equipment from mainland United States. As of this writing, this equipment largely remains deployed in the event of challenges during the upcoming hurricane season.[212]

Repairs and current conditions

Specific information on repairs conducted to date remains limited as of the writing of this report since FEMA is working to approve funding for various projects. FEMA has approved funding for the restoration of the Puerto Rico Police Department LMR and microwave networks. Restoration is planned to begin soon. According to FEMA, emergency communications equipment including MSAT terminals and Hughes VSATs were deployed in May 2018. FEMA officials plan to deploy additional equipment in June and have identified appropriate sites, are installing and testing equipment and training personnel as of May 22, 2018.

Remaining needs and recovery priorities

According to the *Build Back Better* report, communications network failures were one of the most consequential impacts of Hurricanes Irma and Maria to Puerto Rico (Governor of Puerto

[212] Interview with Mr. Chris Tuttle and other FEMA officials, Mar. 2, 2018.

Rico, 2017a). Repair and restoration in these areas will take a sustained and significant investment of resources. This will require proper planning, design, and engineering to create and maintain resilient emergency communications. However, these challenges also present opportunities to reimagine Puerto Rico's telecommunications networks and implement a more resilient system that leverages cutting-edge technology to better serve Puerto Rico's citizens. The needs can be broken out into shorter and longer-term investments:

Short term

Short-term challenges are those associated with immediate repairs to restore critical communication networks within the next one to 12 months.

- *Repairs to damaged infrastructure to support the telecommunications network, such as electricity, aerial fiber, and cell tower sites.* Significant work remains to support the telecommunications network, such as electricity, aerial fiber, and cell tower sites.
- *Backup power or other options to reduce dependence on electrical grid during emergencies.* Telecommunications interdependence on electrical power remains a barrier to the response. Addressing this need moving forward is a critical step to prepare for future disasters.

Longer term

Over the next one to ten years, priorities include the development and deployment of a modern telecommunications network that is resilient to future disasters, as well as one that supports the current and future economic needs of Puerto Rico.

- *Improvement or replacements for vulnerable and outdated telecommunications infrastructure*. This is an essential step for continuity of critical government functions required to provide public safety to the residents of Puerto Rico and other critical government entities. Failures during Hurricane Maria underscore the importance of having survivable technologies that are redundant and resilient.
- *Effective governance that takes a unified approach to multiple emergency communications systems*. Telecommunications infrastructure in Puerto Rico involves a number of public and private stakeholders who also rely on local infrastructure and the power grid, and who also experienced pre-storm challenges with ownership and governance.
- *Access to broadband technology for residents of Puerto Rico.* Broadband technology is an area that has the potential to transform Puerto Rico's telecommunications and to spur economic growth.

14. Transportation

Overview

This section documents the damage experienced by Puerto Rico's transportation sector in the wake of Hurricanes Irma and Maria, and the needs within the transportation sector to address long-standing transportation network access, quality, and funding challenges. This sector covers all transportation modes available in Puerto Rico, including ground, water, and air. The chapter is divided into three subsections: (a) Surface, (b) Maritime, and (c) Airports. Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Transportation" Sector Report.

The transportation system dates to Spanish colonial times, when Puerto Rico was established as a port (Puerto Rico means "rich port," highlighting its value to Spain). The Spanish established two main ports by the early 19th century, in San Juan and Ponce (Dietz, 1986). As discussed earlier in this report, the Jones Act, passed in 1920, prohibits foreign-flag ships from carrying goods between two U.S. ports. The body that oversees most ports in Puerto Rico, the Puerto Rico Ports Authority, was formed in 1955.

After sugar cane became Puerto Rico's predominant crop, private rail lines were built beginning in the 1890s to move crops to processing centers. This resulted in an extensive rail system that moved both goods and passengers around the perimeter of the main island. Additionally, in the first half of the 1900s, San Juan had an extensive streetcar network, although service ended after World War II (Latimer Torez, 1997). Both goods and passenger inter-city rail transport ended in the 1950s, a period of major roadway expansion (Surillo Luna, 2017). However, the Tren Urbano, a heavy-rail commuter metro system serving the municipalities of Bayamón, Guaynabo and San Juan, opened in 2005. It is the only active rail system in Puerto Rico.

The interstate highway era began in the mid-twentieth century with the passage of the Federal-Aid Highway Act in 1956. The Puerto Rico Highway and Transportation Authority (PRHTA) was created in 1965 (Puerto Rico Department of Transportation and Public Works, 2013).

Puerto Rico's first airports were built in the 1920s and 1930s, and by the 1940s, more than 20 airlines were operating flights to Miami and New York (Rivera, 2018b). From the 1960s through the 1990s, a number of commuter airlines and smaller cargo airlines operated in Puerto Rico. Many of these are now defunct, having either gone out of business or been acquired by larger carriers.[213]

[213] Carriers listed without attribution at Wikipedia (2018)

Puerto Rico was an early adopter of public-private partnerships (P3s) to build and operate major transportation infrastructure. The Teodoro Moscoso Bridge in San Juan, completed in 1994, is considered the first P3 of the modern era (U.S. Department of Transportation, 2014). Other major P3s from the 2010s include state roads PR-22 and PR-5, as well as Luis Muñoz Marín International Airport in San Juan.

Multiple public agencies and private operators are involved in maintaining assets and supplying transportation services within, as well as to and from, Puerto Rico. Table 14.1 lists the agencies responsible for transportation subsectors in Puerto Rico. Other key stakeholders, including public and private organizations that rely on transportation infrastructure (e.g., airline carriers, maritime companies), are detailed in the Transportation Sector Report (forthcoming).

Table 14.1. Agencies and Operators Responsible for Transportation

Subsector	Agency/Operator	Role
Roads and bridges	Municipalities	Maintain local roads and bridges
	Department of Transportation and Public Works (DTOP)	Maintains federal-aid and non-federal-aid roads; designs, rehabilitates, and builds new roads
	Federal Highway Administration (FHWA)	Funds roads on the federal-aid highway system; designs and builds roads on federal lands
	Puerto Rico MPO	Develops long-range transportation plans
	Public-Private Partnership (P3) Authority	Issues RFPs and negotiates for P3 arrangements. Act No. 4, 1990, allowed PRHTA to enter concession agreements to build and operate roads
	Abertis (parent company of Metropistas and Autopistas)	Operates PR-22, PR-5, and Teodoro Moscoso Bridge
Public transportation - surface	DTOP	Commonwealth-level agency responsible for providing public transportation
	Integrated Transit Authority (ATI)	Agency within DTOP responsible for providing public transportation
	Metropolitan Bus Authority (AMA)	Agency within DTOP that provides bus service
	Puerto Rico Highway and Transportation Authority (PRHTA)	Agency within DTOP responsible for Tren Urbano
	Alternate Concepts, Inc. (ACI)	Private sector joint-venture partner that operates Tren Urbano
	Herzog Transit Services, Inc. (HTSI)	Private sector joint-venture partner that operates Tren Urbano
	First Transit	Private sector provider of express and regular bus service
	Municipalities	Provide local bus and demand-responsive service
Seaports	Puerto Rico Port Authority (PRPA)	The largest port authority; controls operations in the ports of San Juan, Fajardo, Culebra, Vieques, Ceiba, Yabucoa, Guayanilla,

Subsector	Agency/Operator	Role
		Guanica, and Arecibo
	Ponce Port Authority	Muncipal-level agency that controls operations at the port of Ponce
	Port of the Americas Authority	Administers the transition of the Port of Ponce to transshipment port; currently in the process of merging with the Ponce Port Authority
	Portek	Private firm with a three-year contract (2015-2018) to operate the Port of the Americas
	Mayaguez Port Commission	Oversees the Port of Mayaguez for the city of Mayaguez
	Maritime Transport Authority (MTA)	Agency within DTOP responsible for providing ferry service
	Municipalities	Those ports not listed above are generally controlled by the municipality
Airports	Puerto Rico Port Authority (PRPA)	Owns the airports listed in this report including: ABO, VQS, CPX, MAZ, SIG, X63, RVR, SJU, PSE, and BQN; responsible for operations at all of these airports except for SJU
	Aerostar Airport Holdings	Operates and manages Luis Muñoz Marín International Airport (SJU); public-private partnership with a 40-year lease that began in 2013

Long-range planning (up to a 30-year timeframe) for surface transportation is conducted by the Puerto Rico Metropolitan Planning Organization (MPO). Unlike MPOs in the continental U.S., the Puerto Rico MPO covers all of Puerto Rico (not individual metropolitan regions). The Commonwealth is divided into several regions: San Juan (which includes 38 municipalities), Aguadilla (11 municipalities), and five "non-metropolitan" transportation planning regions (TPRs) (North, Southwest, South, Southeast, and East) (Figure 14.1). However, the MPO produces four distinct long-range plans: one for San Juan, one for Aguadilla, one for the five combined TPRs, and one Commonwealth-wide plan. The MPO is staffed with employees of DTOP and PRHTA (Puerto Rico Department of Transportation and Public Works, 2013). The most recent Commonwealth-wide long-range transportation plan, with a forecast date of 2040, was released in 2013. MPO staff are currently working on the next plan, which will not be released until September 2018 (a draft was not available for review).[214]

[214] Personal communication, PRHTA staff.

Figure 14.1. Transportation Planning Regions in Puerto Rico

Source: Long-Range Transportation Plan, Figure 4.3.

Data sources and methods

Data sources

Data from a variety of government agencies were consulted for this assessment. These include Puerto Rico Department of Transportation and Public Works (DTOP) data on roads, condition and traffic volume data, and Puerto Rico Ports Authority (PRPA) data on passenger and cargo volumes at airports and seaports. The HSOAC Team also referenced information from the Puerto Rico 2040 Islandwide Long Range Transportation Plan on strategic highway network and transit service provision. Federal agencies provided data on roadways and transit ridership, Federal Highway Administration (FHWA) data and Federal Transit Administration (FTA), respectively. Table 14.2 summarizes these data sources as of May 30, 2018, and notes where data gaps are still present as of the writing of this report.

Table 14.2. Summary of Data Sources and Information Gaps for Transportation

Dataset	Source	Date Range	Pre-Storm	Post-Storm	Recovery	Data acquisition status	Evaluation Notes
Highway segment length, location, condition and information about traffic volumes	DTOP	2016	Y			Available	Useful for DTOP roads; does not cover all roads.
Cargo and passenger volumes by airport	PRPA	July 2013-Mar 2018 (monthly)	Y	Y		Available	Passenger, cargo, and flights for all airports except SJU (passenger only)
Cruise ship passengers, vessel calls, and cargo movement (tons and TEUs)	PRPA	July 2012-Mar 2018 (monthly)	Y	Y		Available	Port of San Juan only
Port cargo volumes and movements	U.S. Army Corps of Engineers	2000-2016	Y			Available	Short tons of cargo in- and outbound for six ports; cargo by type; basic origin/destination (U.S. mainland vs. international)
Roadway ownership (Highway Performance Monitoring System)	FHWA	2014	Y			Available	Centerline miles owned by DTOP and municipalities, divided by rural/urban
Roadway functional classification (HPMS)	FHWA as provided in LRTP	2012	Y			Available	Centerline miles by functional classification, divided by rural/urban
Transit ridership	FTA and LRTP	2000-2016	Y			Available	Number of weekday boarding by transit service
DTOP Status Dashboard	DTOP	Current as of March 9		Y	Y	Available	Concise one-page summary of operational status for roads, bridges, and San Juan public transportation systems
Executive Summary	DTOP	Current as of January 18		Y	Y	Available	More details on operational status for roads, bridges, and San Juan public transportation systems; has not been updated since January 18

Dataset	Source	Date Range	Pre-Storm	Post-Storm	Recovery	Data acquisition status	Evaluation Notes
Tracking Table	FHWA	Current as of March 20		Y	Y	Available	Describes Detailed Damage Inspection Reports on roads and bridges, the majority of which have been "signed" by FHWA engineers. Includes cost estimates for individual reports and some summary statistics. Costs are broken down into emergency and permanent repairs.
Infrastructure Restoration and Assessments Workbook	FTA	Current as of December 15th 2017		Y	Y	Available	Gives information on the damage done to public transportation services around the island as well as smaller regional services. Includes repair cost estimates.
Consultant damage assessment reports on three small ports	Gvelop	Current as of November 2017		Y		Available	Covers three ports; good narrative summary of above-ground damage (underwater assessment not conducted)
Consultant damage assessment report on Port of San Juan	Iglesias-Vasquez and Associates	Current as of November 2017	Y	Y	Y	Available	Covers multiple piers at Port of San Juan; good narrative summary of above-ground damage (underwater assessment not conducted)
Port/pier structural assessments	Matrix New World Engineering, Land Surveying and Landscape Architecture, PC; DCM Architecture and Engineering	Current as of May 2018		Y	Y	Available	Two MARAD contractors conducted 23 assessments, which include underwater assessments and estimates to both repair and make more resilient various port assets
Consultant damage assessment reports on PRPA-operated airports	Gvelop	Current as of Sept./Oct. 2017		Y		Available	Good narrative summary of damage

Dataset	Source	Date Range	Pre-Storm	Post-Storm	Recovery	Data acquisition status	Evaluation Notes
Report on damage at Luis Marin Munoz Airport	Interlink-Hunt LLC	Unknown		Y		Unknown	PRPA referenced a report on damage to this airport, but we have not yet obtained this report
Report on damage to PR-22, PR-5, and Teodoro Moscoso Bridge	Not available	Unknown		Y		Unknown	While we assume that Metropistas and Autopistas have undertaken an assessment of the damage suffered by Hurricane Maria, they have not provided it to FEMA
Air Traffic Activity Data System (ATADS)	FAA	1989 – preceding month (updated regularly)	Y	Y		Available	Daily counts of arrivals and departures at SJU, BQN airports (only) broken down by type of traffic (military, cargo, etc.). No data for the period during and immediately after hurricane landfall.

NOTE: Blank cells indicate that data are not available for these time periods.

Methods

Since extensive damage assessments had been conducted by FEMA and other agencies in the transportation sector, HSOAC did not conduct any independent damage assessments. The discussion below synthesizes the various assessments that we have been provided through FEMA, FHWA, DTOP, and PRPA. The HSOAC Team also examined hurricane impacts by studying data from the PRPA on the utilization of different airport and port facilities. While HSOAC reviewed reports to develop a sense of their thoroughness, and cross-checked reports with each other for consistency, the team did not conduct separate site visits to verify any of this information.

Most of the analysis consisted of developing tables, maps, and other graphics to illustrate notable trends in the data or spatial patterns. The HSOAC Team also used monthly data on passenger and freight volumes at airports and seaports to develop a regression analysis of the impact of Hurricane Maria on passenger volumes.[215]

Data gaps, assumptions, and uncertainties

At the time of this writing, damage assessments were unavailable for the main airport, Luis Muñoz Marín, and two major highway segments that are privately operated. Given that the airport and these two road segments are privately operated, we have assumed that the companies would consider these proprietary and would not make them available (they have not been provided to FEMA). Road and bridge assessments continue to change as additional inspections are completed; for this report, we have used sources current as of March 19.

Also lacking were complete data on TEUs (20-ft. equivalent unit cargo containers) moved by port, which can give an indication of containerized shipping before the storm. While such a data series was available for the Port of San Juan through the Bureau of Transportation Statistics, similar information was not available for other ports. MARAD data on TEUs did not include Jones Act trade (trade with U.S. ports), which excludes a large portion of inbound and outbound shipments.

[215] It is important to note that some of the reductions in utilization observed could be due to storm damage reducing the supply of infrastructure (i.e. a damaged airport can't receive passengers), but some of that reduction could also be because of reduced demand (people not wanting to travel to Puerto Rico after a severe hurricane). Comparing findings from the HSOAC analysis with the damage assessments can help to uncover which explanation is driving outcomes.

Surface

Background

History and structure

Approximately two-thirds of Puerto Rico's road network is owned by the 78 municipalities. Municipalities are generally responsible for maintenance, but not for design and construction of new roads (or major repairs to existing roads). The Puerto Rico Department of Transportation and Public Works (commonly known by its Spanish acronym, DTOP) owns the remaining one-third of the network. DTOP also assists municipalities that require major rehabilitation and construction. Within DTOP, the agency responsible for road maintenance is the Puerto Rico Highway and Transportation Authority (PRHTA).

The U.S. Federal Highway Administration (FHWA) provides funding for major improvements on the approximately 3,500 miles of road that are considered part of the federal-aid network, which includes the National Highway System. FHWA's Office of Federal Lands Highway, Eastern Federal Lands Highway Division (EFL) is responsible for design and construction of roughly 30 miles of road in land owned by other federal agencies. These roads are in El Yunque, a forest owned by the National Forest Service, and in several wildlife refuges owned by the U.S. Fish and Wildlife Service.

Two toll roads (PR-22 and PR-5) and one bridge (Teodoro Moscoso) are privately operated, both by organizations (Metropistas and Autopistas, respectively) that are part of the Spanish firm Abertis. The toll roads are operated through a 50-year public-private partnership (P3) agreement signed in 2011 (U.S. Department of Transportation, Federal Highway Administration and Center for Innovative Finance Support), while the bridge is operated through a P3 agreement signed in 1991. Autopistas designed and built the bridge and currently has a concession agreement to collect tolls and maintain the bridge through 2044 (U.S. Department of Transportation, 2014). In both cases, the agreements were made between PRHTA and the private operator and negotiated with the assistance of Puerto Rico's P3 Authority.

Public transportation is fairly limited across Puerto Rico, with relatively little service provided outside the San Juan metropolitan area. All public transportation in San Juan is provided or overseen by Commonwealth-level agencies; there are no local transit operators or transit authorities. Within DTOP, the Integrated Transport Authority (known by its Spanish acronym, ATI) oversees bus service, while, within ATI, the Metropolitan Bus Authority (commonly known as AMA, its Spanish acronym) provides bus service. Private operator First Transit (headquartered in Cincinnati, Ohio) operates the three San Juan express bus lines and some of the regular bus service; the other lines are directly operated by AMA (Office of the Governor, 2015).

Two private contractors, Alternate Concepts, Inc. (ACI, headquartered in Boston) and Herzog Transit Services, Inc. (HTSI, headquartered in St. Joseph, Missouri) have a joint venture

to operate the commuter rail system in San Juan (Tren Urbano) (Alternate Concepts, 2018). ACI was part of the P3 team that designed and built the Tren Urbano, and has operated the system since it opened in 2005; the joint venture was established in 2016. The public partner was the PRHTA (Government of Puerto Rico, 2011).

More than two dozen municipalities operate some limited bus and demand-responsive services, according to FTA statistics. The long-range plan for the five TPRs refers to publicos,[216] which are regulated by the Public Service Commission. The long-range plan also mentions social service agencies providing some transportation services, but the team has been unable to determine the extent of their activities.

While freight rail and pipelines carry a substantial fraction of goods and fuels in the continental U.S., *all freight in Puerto Rico moves via truck*. Many of these movements take place either on the strategic highway network that circles the main island or in the San Juan metropolitan area. During a serious disruption, goods can be moved via alternate routes, but not alternate modes.

Key assets

Puerto Rico has more than 16,500 miles of roads,[217] giving it one of the densest roadway networks in the United States.[218] There are 2,222 bridges and two tunnels within Puerto Rico's road network (Puerto Rico Department of Transportation and Public Works, 2013) and approximately 1,100 gas stations.[219] The strategic highway network, defined in the long-range transportation plan as the "core roadway network linking all regions of the island" (Puerto Rico Department of Transportation and Public Works, 2013), is shown in Figure 14.2.

[216] Publicos are a jitney service—privately operated vehicles that generally serve standard routes, either within or between cities.

[217] These are centerline miles of road (that is, one mile of roadway is considered one centerline mile, regardless of the number of lanes).

[218] With 16,500 miles of road in an area of 5,300 square miles, the roadway network is of similar density to that of Rhode Island, Connecticut, and Massachusetts (based on data from the Highway Performance Monitoring System and the U.S. Census).

[219] Department of Energy daily summaries.

Figure 14.2. Strategic Highway Network in Puerto Rico

Source: Long-Range Transportation Plan, Figure 5.1. Note: Segments in black are completed; segments in red are slated for major rehabilitation or new alignments.

The Tren Urbano commuter train in the San Juan metropolitan area is the only rail system in Puerto Rico. The Tren Urbano consists of one line with 16 stations over an approximately ten-mile right-of-way. Ten stations are elevated, four are at-grade, and two are underground. Five have park-and-ride stations (Puerto Rico Department of Transportation and Public Works, 2013).

Two types of bus service operate in San Juan:

- fixed-route bus service along about two dozen fixed-route service routes in mixed right-of-way.[220] This service has a total fleet of 118 vehicles (Federal Transit Administration, 2017)
- express bus service "MetroBus" along three routes, one of which is a bus rapid transit line operating on a highway that connects to the Tern Urbano (Colucci Rios, 26-29 May 2015).

According to FTA statistics for 2016, there are 32 vehicles in maximum service for Tren Urbano and 26 for Metrobus, with a total (including spares) of 128 vehicles available (this total does not break out rail cars and buses into service vehicles and spares).

While there is a jitney network ("publicos") that serves both major cities and some inter-city trips, vehicles are privately owned and operated and do not operate on fixed schedules. According to the FTA's National Transit Database, there were 1,884 vehicles in service before Hurricanes Irma and Maria made landfall. In addition, 28 municipalities operated some type of bus service and demand responsive (paratransit) service, but these were generally at a small scale. The majority of these operators have had fewer than 10 vehicles in service. Taxis and one

[220] This website describes the 2015 re-organization of the bus network, and thus supersedes bus information in the 2013 long-range plan. This reorganization eliminated about a dozen routes (Office of the Governor, 2015).

ride-hailing service, Uber, operate in the largest cities, but information on the number of vehicles is not available. There are no inter-city scheduled buses.

Pre-hurricane conditions

Roads and bridges: structure and serviceability

This subsection focuses on the condition of the roads and bridges in Puerto Rico rather than on their use. Major roads in Puerto Rico were, overall, in fair condition before Hurricane Maria (on a scale of good/fair/poor). Data provided by DTOP (taken from the organization's Highway Performance Monitoring System (HPMS)[221] submittal to FHWA) describe the extent and severity of various distresses[222] on sections of roadway including:

- roughness as measured by the International Roughness Index (IRI)
- percentage and length of cracking
- depth of ruts in vehicle wheel paths
- faulting (defined as a difference in elevation between adjacent sections of road surface separated by a crack or joint).

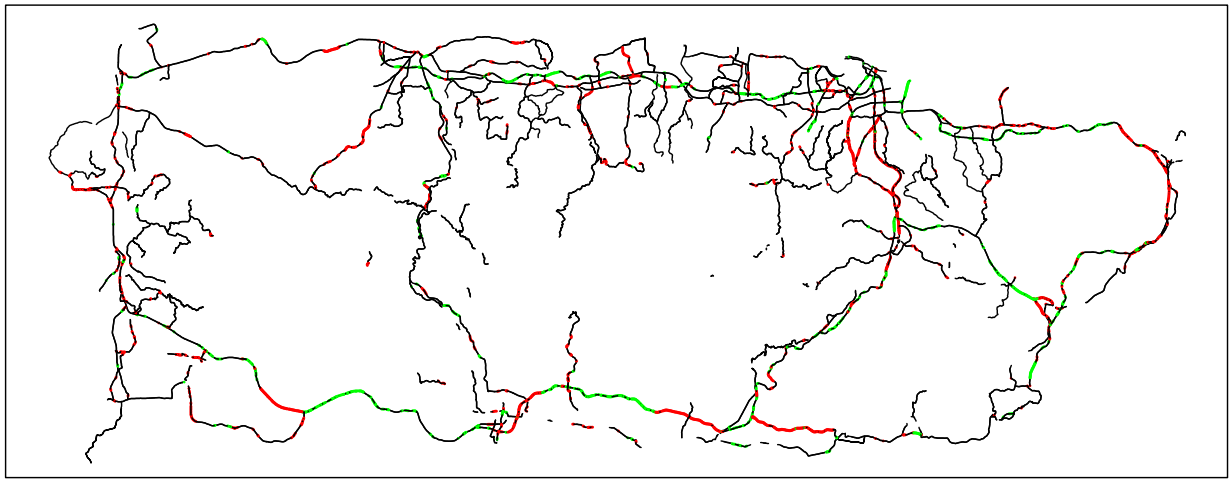
Before the storms, there were sections of roads in good, fair, and poor conditions in different areas of Puerto Rico. Figure 14.3 shows the geographic locations of the sections of road by condition. This map is based on the ratings that combine data on different distresses, which is why the vast majority of the road sections displayed are rated as fair (shown in black).

Looking at specific distresses, road roughness was a widespread challenge, even on roads considered to be in good condition otherwise. Rough roads led to relatively high user costs, including lower traffic speeds, higher accident risks, additional fuel use and pollutant emissions, and reduced ride quality. The rough condition of Puerto Rican roads indicates that, even before the storms, increased maintenance and repair activities were likely warranted.

[221] HPMS is a national system to which all states and Puerto Rico submit data. This dataset with information on road segment condition includes only data from the 4,357 kilometers of road in Puerto Rico eligible for federal aid.

[222] "Distress" is the umbrella term used by civil engineers for all types of road surface damage or degradation.

Figure 14.3. Map Showing Pavement Conditions on Federal-Aid Roads in Puerto Rico



SOURCE: GIS data provided by DTOP; map by authors.

NOTE: Green = good condition, black = fair condition and red = and poor condition

Puerto Rico's bridges were assessed by the FHWA in 2012. Of the 2,222 bridges under its jurisdiction, 50 percent (1,110) were classified as structurally deficient or functionally obsolete. The FHWA determined that about 11 percent of the 2,222 bridges were "structurally deficient," meaning they required structural repair or replacement, and an additional 39 percent were "functionally obsolete" (Puerto Rico Department of Transportation and Public Works, 2013, Table 5-3). The structurally deficient proportion is only slightly higher than the 9 percent of bridges identified as structurally deficient across the United States in 2016 (Kirk and Mallett, 2018). The functionally obsolete bridges needed improvements such as widening to be categorized by the FHWA as being in an "acceptable" state, but they were not considered a safety hazard. A significantly higher proportion of "locally owned" (as opposed to state-owned) bridges were deficient, which demonstrated a strong downward trend over time, with over 15 percent of bridges being structurally deficient in 2000 (Puerto Rico Department of Transportation and Public Works, 2013).

Roads and bridges: congestion and safety

The Texas Transportation Institute conducted its most recent analysis of traffic congestion in metropolitan areas in 2014. Its analysis found that San Juan's cost of congestion was about $1.6 billion, an increase from a cost of less than $1.5 billion in 2000 (Lomax, Schrank and Eisele, 2015). Across the island, roughly 60 percent of vehicle miles traveled (VMT) occurred in San Juan, with the southern part of the main island having the second-most VMT at 10 percent. The highway network experienced congestion in its urban areas due to daily commuter traffic. Road use relative to road capacity (level of service) was found to be "worst in the municipalities comprising the central core of the San Juan region," though there were additional issues with

some older, smaller roads in other cities (Puerto Rico Department of Transportation and Public Works, 2013). In addition to increasing travel times for road users, such congestion could affect emergency services or efforts to distribute relief supplies after a disaster.

Puerto Rico's traffic safety record has been mixed. On the positive side, fatalities have been declining: in 2016, the most recent year for which figures are available, there were 279 fatalities from vehicle crashes, a decrease from 310 in the previous year (most U.S. states experienced an increase in fatalities over this period). However, the number of people who died in car crashes in Puerto Rico per 100 million miles driven was 2.12, well above the U.S. average of 1.13 and higher than in any state (the next highest state is South Carolina, at 1.89 fatalities per 100 million miles driven) (National Highway Traffic Safety Administration and National Center for Statistics and Analysis, 2017). While this rate has declined over the past 15 years, it has remained higher than the rate in the continental U.S. throughout that period.[223] The low ratio of deaths per 100,000 population, by contrast, reflects the fact that Puerto Rico had the least miles traveled per capita—4,200 in 2014—in the United States (Federal Highway Administration Office of Highway Policy Information, 2018).

Public transportation

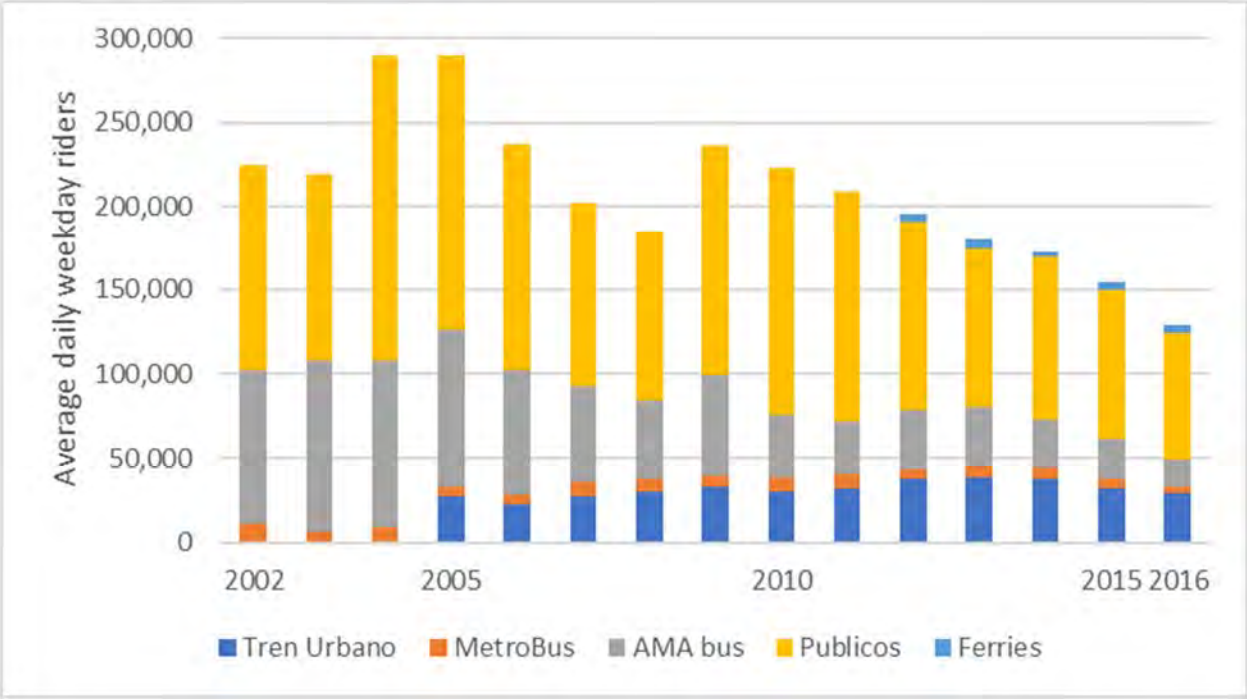
Prior to the hurricanes, public transportation was generally considered inadequate, and ridership of both fixed-route public transportation and publicos (jitneys) has been declining over the past decade, despite the lack of transportation options for many households in Puerto Rico without access to a car (Figure 14.4) (Puerto Rico Department of Transportation and Public Works, 2013).

Ridership on the Tren Urbano grew from about 26,000 daily boardings in 2005, the year it opened, to 32,000 in 2011 (Puerto Rico Department of Transportation and Public Works, 2013). This increase in ridership seemed to be linked to a fare reduction in 2010; fares returned to their previous level ($1.50 per ride, which remains the current fare) in 2014 (Puerto Rico Highway and Transportation Authority, 2017). FTA statistics for 2016 show daily boardings of 28,562, a drop from its peak of 37,706 in 2014 and far below the planning estimates of over 110,000 riders per day (Federal Transit Administration, 2008). This could have been due to the higher fare, population decline, unemployment, or other factors. Among the country's 15 heavy rail systems, Tren Urbano has the highest operating costs and costs per passenger, second lowest farebox recovery (proportion of operating costs paid directly by riders through fares), and second lowest ridership.

[223] Because the absolute number of crashes in the United States is not available (there is no national database of all vehicle crashes, only a sample that is too small to make comparisons between states), it is impossible to say whether this reflects a higher number of crashes per mile driven, whether the crashes that occur are more serious, or whether the difference is due to post-crash survival rates that may be lower if crash victims do not have rapid access to appropriate levels of trauma care. The rate may also be influenced by inaccurate data on total VMT, which would skew the results. DTOP staff told us that VMT data provided by FHWA may be incorrect, but even the most recent Strategic Highway Safety Plan Annual Report for Puerto Rico for 2016 puts the 2015 rate at 1.96.

Ridership on other transportation modes, including buses and publicos, has been declining gradually since 2009, most precipitously on AMA bus service, which fell from over 100,000 average weekday boardings in 2003 to 16,000 in 2016. Bus service was reorganized in 2015, with about a dozen routes eliminated; this may account for some of the decline (Office of the Governor, 2015). Overall transit ridership—including all modes—was lower in 2016 than when the Tren Urbano opened.

Figure 14.4. Transit Ridership in Puerto Rico, by Mode (2002–2016)



SOURCES:(Puerto Rico Department of Transportation and Public Works, 2013; Federal Transit Administration, 2017)

Funding challenges

Puerto Rico's fiscal crisis has led to insufficient funding for the public agencies responsible for surface transportation. According to the PRHTA Fiscal Plan for the period 2017-2026,

> PRHTA's current fiscal situation reflects a $4.49 billion financial gap for the next 10 year[s] mostly impacted by the clawback provision which redirects 73 percent, or about $4.57 billion, of its operating revenues to the Central Government. Bondholders of the PRHTA are expected to cease receiving money for debt repayment by July 2017, when the reserve funds that have been used until now run out (Puerto Rico Highway and Transportation Authority, 2017).

The agency has experienced operating losses each year since 2012. These problems have been ongoing; according to a 2010 study,

> the financial position of the PRHTA appears to be deteriorating further. Tax and fee income generated from its dedicated revenue sources have not kept pace with

> inflation due to inflation-based increases in costs and no commensurate increase in revenues. Moreover, there have been significant expenses linked to Tren Urbano, putting pressure on the PRHTA budget (Puerto Rico Public-Private Partnerships Authority, 2010).

The long-range transportation plan notes that fully half of revenues are pledged to debt repayment. Also, many conventional sources of revenue for transportation agencies have not been raised in decades. The 16-cent per gallon gas tax in Puerto Rico has not been raised since 1976, the $15 license fee has not been raised since it was introduced in 1982, and the $3/barrel petroleum tax has not been raised since 2005. "Toll leakage" (the underpayment of tolls) adds to the revenue shortage (Puerto Rico Department of Transportation and Public Works, 2013), and the gas tax is the lowest of any U.S. state except Alaska (American Petroleum Institute, 2018).

Functional and operational challenges

The Puerto Rico Highway Transit Authority faces a number of challenges with regard to its capacity and operations. A 2016 Memorandum of Understanding with the Federal Highway Administration requires PRHTA to revise its billing process to ensure prompt payment to contractors; validate its toll credit balance; engage a consultant to develop an organizational capacity development plan; and upgrade internal systems to expedite project delivery. According to the PRHTA Fiscal Plan, all four initiatives are underway (Puerto Rico Highway and Transportation Authority, 2017).

With regard to capacity, the PRHTA Fiscal Plan enumerates the following challenges:

- Over $400 million in available federal funding that has not been deployed due to delayed projects or payments to providers[224]
- outdated and non-standard documentation and requirements
- lack of communication and feedback integration between planning and construction departments
- increased project costs and overruns from original budgets
- misalignment of current capabilities with needed core competencies.

Hurricane damage

Transportation damage was extensive. With regard to surface transportation, the main immediate effect was debris blocking roads, but over 6,000 incidents were reported to DTOP, including landslides and collapsed or seriously weakened bridges.[225] Roadside signs were destroyed and many traffic signals were damaged physically or rendered nonoperational.

Table 14.3 summarizes the dollar values of damage to surface transportation, as obtained by the HSOAC team as of the writing of this report. We believe the estimates based on inspections

[224] Essentially this means that DTOP cannot spend all of the money it is eligible to receive from FHWA.

[225] Documentation obtained from DTOP, including a summary from their emergency Operations Center dated January 18, 2018, did not contain the appendices that should provide a more specific count of incidents by category. The HSOAC team requested these appendices, but did not receive them.

are largely complete and the best available, although we have not been able to verify them independently. These estimates are discussed further in the subsections below.

Table 14.3. Summary of Available Damage Estimates for Surface Transportation

Transportation Mode	Estimated Dollar Value	Source	Notes
Estimates Based on Inspections			
Roads and Bridges	$646.7 million	PRHTA New Fiscal Plan	Analysis by McKinsey for PRHTA New Fiscal Plan, April 20, 2018
	$14.5 million	Metropistas/Moody's	PR-22 and PR-5
Public Transportation	$256.6 million	FTA	Tren Urbano repair with mitigation costs
	$16.4 million	FTA	Metropolitan Bus Authority (AMA) repair with mitigation costs
	$37.5 million	FTA	Municipalities repair with mitigation costs
Estimates Based on Build Back Better request			
Roads and Bridges	$1.9 billion	Build Back Better	Bridge reconstruction and improvements (further details not provided)
	$1.6 billion	Build Back Batter	Included in "Roads and Bridges" but not specified
	$1 billion	Build Back Better	Extension of PR-22
Public Transportation	Not included		

Roads and bridges

As noted in the Build Back Better request, Maria generated over 6 million cubic yards of debris, and at the worst point, fewer than 400 miles of the 16,700 miles of roadways were passable. Most traffic signals were not operating after the storm, either due to physical destruction or the lack of power (Governor of Puerto Rico, 2017a). Gasoline was scarce in the weeks following the hurricane, leading to long lines and the closure of some gas stations (Levin, Newkirk and Ockerman, 2017).

Debris in roadways made the initial assessment of damage to other critical infrastructure difficult. In addition, the need to clear debris and repair roads to gain access to facilities slowed the rate at which response actions could be conducted. While such problems were observed throughout Puerto Rico, they were most acute in rural areas.

In terms of the dollar value of hurricane damage, two estimates are available. FHWA has referenced 1,179 Detailed Damage Inspection Reports (DDIRs) describing the conditions of different sections of roadway and bridges in Puerto Rico, as of March 20, 2018. Nine hundred and sixty-five of these reports were approved by an FHWA engineer. Many of the damage are

listed as being caused by "washout" or "landslide(s)." A smaller number of DDIRs (206) have been categorized as being "Not Eligible and Signed" by a FHWA engineer, and many of these are described as pertaining to pre-existing damage.

Updated DDIR figures were used to develop the estimate of road repairs needed for the most recent PRHTA Fiscal Plan. This source indicates that expected costs for emergency and permanent repairs to roads and bridges will total $646.7 million (Puerto Rico Highway and Transportation Authority, 2018).[226] While FEMA did not inspect PR-22 and PR-5, since they are privately operated, a Moody's investor report indicated that repairs to those roads were estimated at $14.5 million (Moody's, 2017). Note that the figures cited above do not include the cost of debris removal, which is a considerable cost.

The Build Back Better request, alternately, provided a figure of almost $4.5 billion needed for recovery efforts for roads and bridges. This included $1.9 billion for bridge reconstruction and improvements, and $1 billion to extend PR-22, a highway around the west coast that is called out in the long-range plan for either reconstruction or realignment. This estimate was much higher than the $370 million in confirmed repair costs provided by FHWA, which might be explained by several factors. First, the Build Back Better request was made in November 2017, when the full scope of the damage was not yet assessed. Such initial "ballpark" estimates might be later amended when more-detailed inspections have been conducted. Second, it included one major project, PR-22, with a cost of building a new road or substantially overhauling an existing one, which would be considered outside the scope of a DDIR. It is possible that other such improvement costs were included, along with assumptions that roads and bridges would be rebuilt to higher standards.

Public transportation

After the hurricanes, service on the Tren Urbano was suspended until December 19, 2017 largely due to the lack of power at key substations and the difficulty of running tests to evaluate operations (Hill International, 2018). Three stations suffered structural damage (Rolon Cintron, 2017). No bus service was provided immediately following the storm (Gray, 2017), but AMA service on 21 of 23 routes was restored by September 29 (Hill International, 2018).

Damage to the surface transit systems was reported in the *Puerto Rico Hurricane Maria Transit Infrastructure and Vehicle Damage Assessment Report* (Final Draft) (Hill International, 2018). The assessments offered three different estimates for repair costs, from least to most costly: repair to functionality, repair to code and standard, and repair with mitigation (with additional resiliency upgrades).

Total damage to the Tren Urbano system was estimated to cost $257 million. The operations and maintenance (O&M) facility and yard suffered some damage to components and roofing,

[226] This plan contains a figure of $653 million for storm damage, but subsequent personal communication with staff at the consulting firm McKinsey, which developed the cost estimates, provided the adjusted $646.7 million figure.

with some water and mold damage to interiors with damage totaling $7.5 million and an additional $3.5 million in recommended upgrades. Among the 16 stations, repairs to code and standard ranged from $3.3 million to $7 million. Most stations did not suffer any structural damage; however it was common for there to be component and cladding damage, along with water intrusion and mold. Rail cars sustained very little damage, and there was no structural damage to the guideway and track, but the report identified $6 million in repairs to upgrade the guideway and track to code. The power systems are the largest repair cost for the Tren Urbano, with an estimated systemwide repair cost of $11 million and $140 million for additional resilience.

The Metropolitan Bus Authority's (AMA) facilities were impacted to a much lesser degree than the Tren Urbano. The total repair costs were estimated at $16 million, $8 million of which is required to repair the AMA O&M facility. In addition to structural damage, water damage left electrical systems and interior items damaged or unusable. Damage to bus terminals was quite varied, with some terminals suffering no damage at all, while others like Carolina Bus Terminal and Iturregui Bus Terminal were in need of $2 million and $1.7 million in repairs, respectively.

Repair costs estimated for the municipalities' transit systems totaled $37.5 million. The bus terminals in Aguadilla, Arecibo, Cayey, and Loiza were among the most costly sites to repair, with each terminal's estimated repairs costing approximately $2.5 million (Hill International, 2018).

Structural, interior, and fencing damage, in addition to water intrusion, was common in these terminals. Damage to vehicles was generally much less costly than damage to structures.

Post-hurricane conditions

Emergency response operations

In the immediate aftermath of Hurricane Maria, removing debris from transportation networks was a critical issue. FHWA made available $40 million in "quick release" Emergency Relief funds to help restore essential services (Chirls, 2017). FTA made available $8.4 million (Chirls, 2017) to help restore public transit service immediately following the hurricane (funds that could be used for both surface and maritime transportation).

Repairs and operational restoration conducted to date

According to DTOP, as of January 18, 2018, there continued to be 15 bridges and 21 state roadway segments closed for safety reasons. By March 9 there were still nine bridges and 15 roadway segments closed, all on secondary or tertiary roads[227] and mostly in smaller towns or

[227] Secondary roads are considered collector roads and tertiary are the equivalent of local roads. Information about which roads remained closed is from the DTOP Emergency Operations Center, fact sheet dashboard dated March 9,

rural areas. Road damage were reported as kilometer posts, not segments, so the data do not show the length of segments affected.[228] Repairs on these and other roads have been ongoing (Department of Transportation and Public Works (DTOP) Emergency Operations Center, 2018).

By March, the Tren Urbano system was operating normally, with the exception of two stations that remained closed due to damage (trains pass through the stations but do not service those platforms). The last of the closed stations re-opened in late May ("The Domenech station of the Urban Train reopens," 2018). By March, San Juan bus services were operating at similar service levels as before the storm.

Barriers and facilitators to response

Across multiple subsectors, damage assessments are still ongoing. The lack of an existing asset management system meant that standardized information was not available on all transportation assets and created barriers to systematically assessing damage.

For all transportation modes, the pre-storm financial challenges have continued to make response difficult. Assets may have been past their useful life even before the storm, making it difficult to prioritize reconstruction activities when the needs are so widespread. In addition, supplies on the ground have been limited and must be brought in via ship, and many construction projects are competing for the same workers, materials, and equipment.

Because multiple public and private owners and operators govern the transit system (e.g., Tren Urbano is operated by a consortium of two private firms, and a third firm operates some bus service), it may be challenging to coordinate recovery planning.

Specific to Puerto Rico's road networks, difficult terrain (especially in the mountainous interior) makes it challenging to rebuild roads that are more resilient to landslides, as sleep slopes create the need for better road design. Additionally, many roads lack an alternative right-of-way (the land on which roads are built), meaning that many roads cannot be relocated to other areas where the terrain is less challenging.

Maritime

Background

History and structure

The port system is extremely important to Puerto Rico. The Port of San Juan, for instance, has been called the single most important piece of infrastructure in Puerto Rico, given the high

2018. Information on road type is from DTOP's Emergency Operations Center, Hurricane Maria 2017, Executive Summary, January 18, 2018.

[228] The DTOP summaries report damage at a specific kilometer post along a road segment (e.g., kilometer post 2.2 along roadway PR-109). Without information about the distance to the nearest alternative route, it is impossible to say how many miles of road are affected. Note also that DTOP's list does not include roads maintained by municipalities, about which no centralized information is available.

reliance on imports (for example, approximately 85 percent of food is imported, as is all liquid fuel). The Port of San Juan handles 79 percent of all shipments for Puerto Rico (USACE Navigation Data Center). Without a robust port system, economic activity would be severely hampered. Additionally, the Port of San Juan is a critical element of Puerto Rico's tourism infrastructure, as many tourists arrive in Puerto Rico by sea via cruise ships.

Ports are owned and operated by multiple entities. In the Port of San Juan, most of the port terminal property and docks are owned by the PRPA but are leased by privately owned entities that are responsible for the security, safety, and supporting infrastructure within their properties.

The Puerto Rico Maritime Transport Authority (ATM) oversees maritime transportation for passengers within Puerto Rico and the municipalities of Vieques and Culebra. The agency is part of DTOP.

Key assets

Puerto Rico relies on maritime shipping to maintain daily life, economic activity, government services, and disaster preparedness, response, and recovery. Puerto Rico's dependence on the maritime transportation system (MTS)[229] means that there is a high probability that the loss of a port, particularly the Port of San Juan, would have significant cascading impacts on its lifeline infrastructure, including fuel, food, and electric power. Consequently, such a loss would have an appreciable impact on Puerto Rico's economy and the health and safety of its population (Regional Resiliency Assessment Program, 2014).

Fifteen cities in Puerto Rico are supported by maritime trade or activities within seaports (Figure 14.5). Nine ports support the MTS. The three major ports are the Port of San Juan, owned by the PRPA; the Port of Ponce (Port of the Americas), owned by the Municipality of Ponce; and the Port of Mayaguez, owned by the Mayaguez Port Commission. The PRPA, a public corporation of the Commonwealth of Puerto Rico, also has authority over additional smaller ports, including Arecibo, Guanica, Guayanilla, Yabucoa, and Fajardo.

In addition, the PRPA owns the dock areas at the port of Ceiba, also known as Roosevelt Roads. Ceiba is a deepwater port that was previously used by the U.S. Navy and is currently being considered for use as ferry terminal, as well as the site of a potential redevelopment project (Local Redevelopment Authority, 2014). The PRPA also has jurisdiction over the ports serving the small islands of Culebra and Vieques, which are located 15 to 30 miles off the coast of Puerto Rico. The remainder of the ports supported by maritime trade generally have single-purpose terminals or are based around tourism and local fishing industries.

[229] MARAD defines the MTS as "waterways, ports, and inter-modal land-side connections that allow the various modes of transportation to move people and goods to, from, and on the water" Source: MARAD (undated)

Figure 14.5. Map of Seaports

Source: HSOAC Team.

There are several passenger and vehicle ferries that service the outlying islands of Puerto Rico, as well as the Virgin Islands. Ferry service was previously available from both San Juan and Mayaguez to the Dominican Republic, but this has been discontinued (Direct Ferries, undated).

Pre-hurricane conditions

San Juan is a major port, the thirteenth largest in the United States (Bureau of Transportation Statistics, 2017) and the eleventh largest in Latin America and the Caribbean in 2015 in terms of container throughput. San Juan trades with both the continental U.S. and foreign countries; in 2016, as measured in short tons, approximately 58 percent of imports into San Juan were from foreign ports and 36 percent of exports were destined for foreign locations (USACE Navigation Data Center). San Juan is the dominant shipping hub for Puerto Rico. The share of imports entering Puerto Rico via San Juan has risen steadily for the past 15 years, from 74 percent in 2000 to 88 percent in 2016. In 2016, it saw 1,501 vessel calls, including 254 container ships, 27

dry bulk vessels, 455 dry bulk barges, 711 other freight vessels, and 55 other freight barges (Bureau of Transportation Statistics, 2017). The share of exports has been much more variable over this same period of time, with San Juan's share even dropping below 50 percent in one year. However, in 2016, 83 percent of exports were shipped from San Juan.

The Government of Puerto Rico has attempted to create a major transshipment hub, called the Port of the Americas, at the Port of Ponce. According to press reports, between $250 and $300 million was invested in the port over the past decade (Pipoli, 2015; "Can Portek revive Ponce's hub ambitions? ," 2017). However, both the quantity and share of imports and exports declined over time. Similarly, the Port of Fajardo had a sizable share of exports in the early 2000s, up to 36 percent in 2004 (950,000 short tons), but this declined to less than 10 percent in recent years (about 150,000 short tons). The Port of Fajardo's share of total imports to Puerto Rico has been less than one percent in recent years.

For the period 2000 to 2016, petroleum products (by weight) were the largest commodity shipped into Puerto Rico (46 percent) followed by food products (15 percent) and unclassified manufactured products (14 percent). These proportions have remained relatively constant over this period. Shipping routes and costs between the United States, Puerto Rico, and surrounding Caribbean destinations are largely influenced by the Jones Act, discussed in the Economy chapter of this report.

In addition to container shipping, passenger cruises also frequent the ports of Puerto Rico. In 2016 there were 24.2 million cruise passengers globally, a four percent increase over 2015, with about 1.4 million people visiting Puerto Rico on cruise ships in 2016 (ranked seventh in the Caribbean). The number of passengers visiting San Juan has increased since its low point in 2012, but has remained relatively flat since 2000 against a backdrop of global cruise ship passenger growth.

Maritime public transportation is provided by ferries, with average ridership between 3,000 and 5,700 boardings on weekdays (Puerto Rico Department of Transportation and Public Works, 2013).

The HSOAC team identified a series of challenges in the maritime sector evident prior to the 2017 hurricane season. These included the following:

- *Puerto Rico's dependence on the maritime transportation system (MTS).* There is a high probability that that the loss of a port, particularly the Port of San Juan, would have significant cascading impacts on its lifeline infrastructure, including fuel, food, and electric power.
- *High cost of investments to make ports usable for new purposes.* For example, MARAD estimates that the cost to repair piers and bulkheads at Roosevelt Roads to facilitate usage as a cargo seaport (operating at bare minimum capacity) at $86 million. Upgrading cargo

operations so that it could support disaster response would cost $93.7 million, while the cheapest of three options to provide ferry service would be $55 million.[230]

- *Coordination and collaboration among multiple jurisdictions and diverse owners and operators.* As noted in one document, "There are no known capital improvement plans for maritime transport by the Puerto Rico Ports Authority as the ports have many different tenants and operations requirements and capital improvement plans would be determined by the individual companies" (Puerto Rico Climate Change Council (PRCCC), 2013).
- *Competition from other Caribbean transshipment ports with similar facilities but lower costs.* Puerto Rico has had a long-standing goal to develop a transshipment port, but faces competition with other areas that do not have limitations imposed by the Jones Act (Kulisch, 2014).

There is evidence that agencies operating in this sector aim to address facility improvements, capacity expansion, and access improvements at principal seaports (Puerto Rico Department of Transportation and Public Works, 2013). However, the Statewide Transportation Improvement Program for fiscal years 2014-2017 contains relatively few projects targeting the MTS. Projects include maintenance of existing equipment and systems for dry-docking vessels, security systems, ship-lift, ferry operation and maintenance, and dredging projects to maintain port depths that do little to expand overall port capacity or capability (Commonwealth of Puerto Rico Department of Transportation and Public Works and Puerto Rico Highway and Transportation Authority, 2016). Review of several other long-range planning documents reveals few port-related projects or any concerted efforts to expand MTS capability or capacity, with exception to container handling capacity in the Port of Ponce.

Hurricane damage

Ports

The hurricanes caused substantial damage to the seaports in Puerto Rico, which in some cases was exacerbated by the already deteriorating condition of some equipment. The HSOAC Team has three sources of damage information, summarized below.

- MARAD contracted with two engineering firms for extensive damage assessments, including diving teams to conduct underwater assessments at almost all piers and ports around the island. Estimated costs to make repairs at these ports total $906 million.[231] Given the thoroughness of the assessments, we believe these are the best estimates available.

[230] Cargo operations cost from DCM Architecture & Engineering (2018c). Disaster relief cost from DCM Architecture & Engineering (2018b). Ferry cost from DCM Architecture & Engineering (2018a).

[231] Based on HSOAC Team review of all costs for each pier/port, but excluding additional assessments of "resiliency" repairs and one pier on an uninhabited island.

- The PRPA conducted detailed damage assessments to four ports in its jurisdiction. We have included two assessments in the $906 million total as they were conducted at areas not covered by MARAD assessments.[232]
- The Build Back Better request included $100 million to reconstruct Berths 2, 3, and 7 and dredge additional piers to a depth of 50 feet in the Port of Ponce. Further details about how this assessment was conducted are not provided in the request (Governor of Puerto Rico, 2017a).

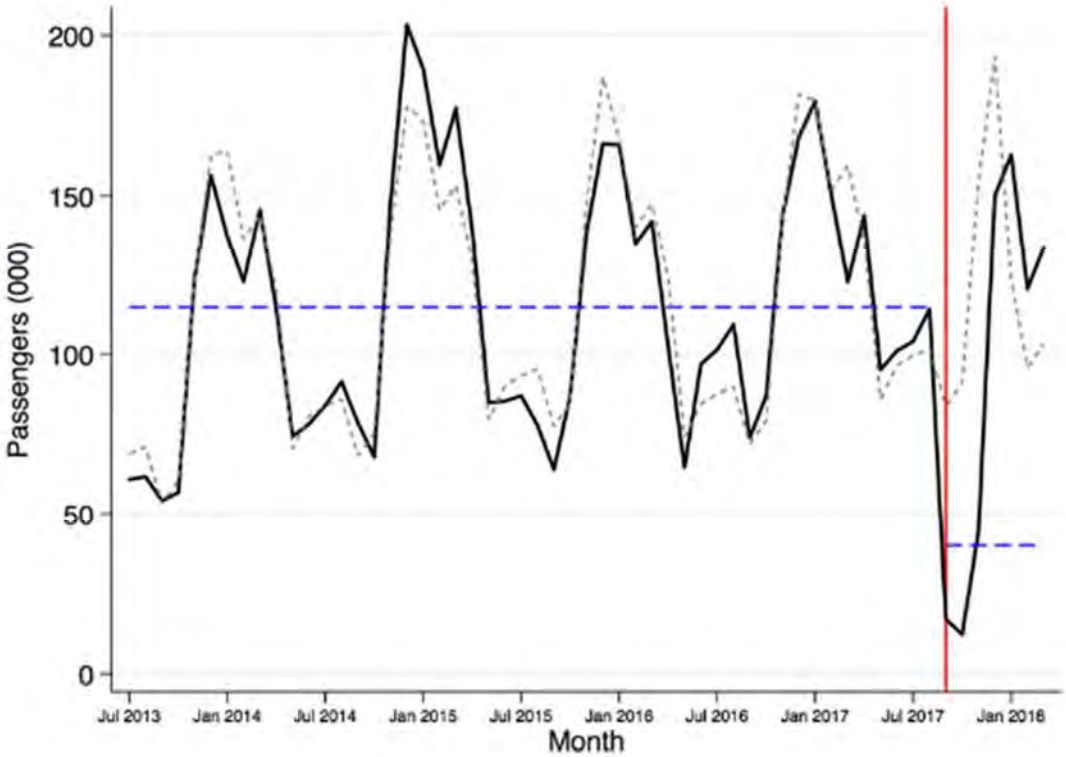
Vessels and ship traffic

A damage assessment was conducted on sea-based vessels in Puerto Rico by the interagency team of Puerto Rico Department of Natural and Environmental Resources and the U.S. Coast Guard, the EPA, the U.S. Fish and Wildlife Service, and the National Oceanic and Atmospheric Administration (NOAA). This team assessed 377 total sunken or beached vessels, removed oily water, and disposed of solid vessel waste material (U.S. Coast Guard, 2018).

To assess the effects of the 2017 hurricane season on cruise ship traffic, the HSOAC team conducted a time series analysis on the total number of cruise ship passengers, the total number of cruise ship calls, and tons of cargo processed by the Port of San Juan. Results show the number of passengers fell by 65 percent during the period September to March 2018 (Figure 14.6), and the number of vessel calls fell by 56 percent. These numbers have rebounded since early 2018.

[232] Iglesias-Vazquez Associates conducted an assessments of Villa Pesquera pier and Gvelop conducted an assessment of Buildings A through C, both at the port of San Juan.

Figure 14.6. Number of Cruise Ship Passengers Arriving to the Port of San Juan (monthly)



SOURCE: PRPA, analysis by authors. The red vertical line indicates September 2017, the month when Hurricanes Irma and Maria made landfall in Puerto Rico. The blue dashed lines correspond to pre-September 2017 and September-December 2017 adjusted means. The grey dashed line corresponds to the predicted series based on pre-September 2017 data.

Finally, there were no significant observed differences in the cargo tonnage processed by the Port of San Juan when comparing the September-December 2017 period to the previous months of data. If anything, tonnage appears to have increased by 13 percent, which could be due to increased needs for supplies for the recovery effort. More detail on the impact of the hurricanes on Puerto Rico's tourism and trade industries can be found in the Economy chapter.

Maritime public transit

Ferry service to Vieques and Culebra was unavailable for several days following the hurricane, a major hardship, given the lack of other transportation options. Some limited service became available within a week following the storm during daylight hours (U.S. Department of Transportation, 2017).

The Maritime Transport Authority (Autoridad de Transporte Marítimo, or ATM) experienced hurricane damage at many of its facilities, including the sinking of one ferry and damage to three other ferries. In addition to the ferries and terminals, the maintenance base was also damaged during the hurricanes and will impact the ability of ATM to sustain operations until repaired.

Damage to the public maritime transportation system (ferries, ferry terminals, and maintenance facilities) was reported in the Infrastructure Restoration and Assessments Workbook provided by the Federal Transit Administration (FTA) based on contractor assessments. Similar to those conducted for surface transit, the assessments included repair to code and standard or repair with mitigation/resiliency measures. Repair costs estimated for the municipalities' maritime transit systems total $38.4 million to repair to code and standard, while total costs to repair with mitigation were estimated at $140.8 million. The ferry fleet and terminals in San Juan and Fajardo were among the most costly repairs.[233]

Post-hurricane conditions

Emergency response operations

Pre-storm preparations and post-storm emergency response operations were carried out in accordance with the U.S. Code of Federal Regulations; the National Response Plan (NIMS-ICS), and state and local regulatory mandates, as well as area and individual waterfront facility contingency and incident action plans (IAP) (Department of Homeland Security, 2016). In accordance with the authority vested in the U.S. Coast Guard Captain of the Port, and in consultation with MTS stakeholders, emergency maritime operations were initiated, monitored, and documented before, during, and after each storm's passing to minimize damage to port infrastructure and protect navigable waterways. Specific activities include closing and re-opening ports for safety reasons, conducting damage assessments, emergency response to protect further damage to property, and temporary repairs to commence recovery operations.

The FTA allocated $8.4 million towards restoration of both surface and maritime public transportation services (Chirls, 2017).

Repairs and current conditions

The USCG Captain of the Port compiled a comprehensive operational assessment of the ports through January 17, 2018 (U.S. Coast Guard Captain of the Port, 2018). As of late November 2017, all ports were in an open status, but some still operated under restrictions due to shoaling. USACE had dredging operations planned or pending for many of the affected ports. Coast Guard Infrastructure Teams determined that 90 percent of all key marine terminals were available and fully operational. The report also detailed the operational status of aids to navigation, channels, waterfront facilities, and marine terminals. The only reported significant degradation to the port area critical infrastructure involved bulk liquid facilities, which reported 67 percent availability.

[233] Assessments to two ferry terminals, Fajardo and San Juan, were also conducted by a different contractor, Gvelop, working for the PRPA. Their estimated costs are significantly lower than Hill International's. HSOAC does not have complete information on the differences; presumably, this will be more apparent when Hill International's assessment is made available to the research team.

All other facilities were reported as 86 percent availability or better, with waterway and navigation systems assessed as 96 percent available or better.

However, as of this report date, many seaports remained in need of permanent repairs. Verifiable, individual port damage assessments and associated subsequent recovery repairs—including port infrastructure, maintenance of federal waterway controlling depths, and pier/dockside depth requirements—were ongoing during the drafting of this report. Further coordination with responsible government agencies, port authorities, facility owners/operators, and incident command authority is needed to ascertain the extent of both temporary and permanent repairs made to the ports.

While maritime ferry service is currently operational, the HSOAC team has not identified any information regarding the scope of any repairs already made to maritime transit facilities.

Airports

Background

History and structure

All airports are owned by the PRPA. Luis Muñoz Marín Airport in San Juan has been operated by Aerostar Airport Holdings since 2013 on a 40-year lease (Boynton, 2012). Aerostar is a jointly owned company of ASUR, which operates airports in Mexico, and Highstar, an American infrastructure investor (Aerostar Airport Holdings, 2012). It is the only major privatized airport in the United States.

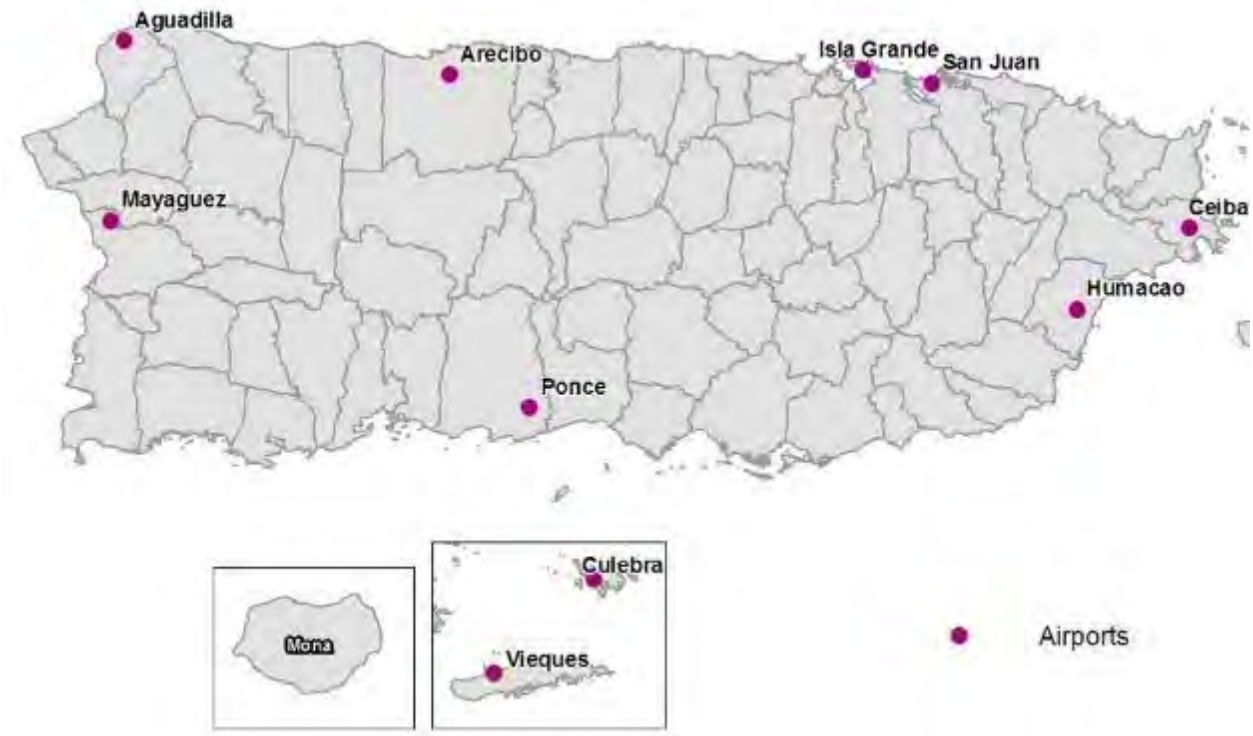
Dozens of air carriers serve Puerto Rico. In order of passenger traffic served, these are: JetBlue Airways, American Airlines, Southwest Airlines, United Airlines, Delta Air Lines, and Cape Air. A similar number of firms transport cargo to and from Puerto Rico. The United States Air National Guard and Puerto Rico Air National Guard operate out of Luis Muñoz Marín Airport. Lufthansa Technik has invested in Rafael Hernandez Airport in Aguadilla. Tourists often arrive by air, making Luis Marin Munoz International Airport important in supporting the maintenance and growth of the tourism industry.

Key assets

The Federal Aviation Administration (FAA) Office of Airports lists 10 airports in Puerto Rico (Figure 14.7) that are Part 139 certified, meaning airports that serve commercial flights or are public facilities for General Aviation (GA) traffic (Federal Aviation Administration). The names, FAA location IDs, locations, and operational characteristics of these 10 airports are listed in Table 14.4. Three other small airports—Patillas, Santa Isabel, and Fajardo—are not currently in operation and are not discussed further.[234]

[234] According to press reports, the P3 Authority intends to sell these airports (Kuilan, 2018)

Figure 14.7. Map of Airports



SOURCE: Location data from FAA Airport Master Record Files; map by authors

Table 14.4. Characteristics of Airports in Puerto Rico

Airport Name	Location	Aircraft Operations	Average Flights (per day)
Luis Muñoz Marín (SJU)	Carolina	48% air taxi 40% commercial 10% transient gen. aviation 1% military <1% local gen. aviation	467
Fernando Luis Ribas Dominicci (SIG)	Isla Grande	45% transient gen. aviation 39% local gen. aviation 13% air taxi 3% military	262
Rafael Hernández (BQN)	Aguadilla	32% local gen. aviation 27% military 23% transient gen. aviation 10% commercial 7% air taxi	133
Benjamín Rivera Noriega (CPX)	Culebra	93% air taxi 4% transient gen. aviation 4% local gen. aviation	97
Antonio Rivera Rodríguez (VQS)	Vieques	66% air taxi 26% commercial 6% transient gen. aviation 2% military <1% local gen. aviation	85

Airport Name	Location	Aircraft Operations	Average Flights (per day)
Jose Aponte de la Torre (NRR)	Ceiba	88% air taxi 7% local gen. aviation 5% transient gen. aviation <1% military	34
Mercedita (PSE)	Ponce	66% local gen. aviation 27% commercial 7% military	17
Eugenio María de Hostos (MAZ)	Mayagüez	62% air taxi 19% local gen. aviation 10% military 9% transient gen. aviation	12
Antonio (Nery) Juarbe Pol (ARE/ABO)	Arecibo	50% transient gen. aviation 50% local gen. aviation <1% military	10
Dr Hermenegildo Ortiz Quinones Airport (HUC/X63)	Humacao	48% local gen. aviation 40% air taxi 10% military 2% transient gen. aviation	7

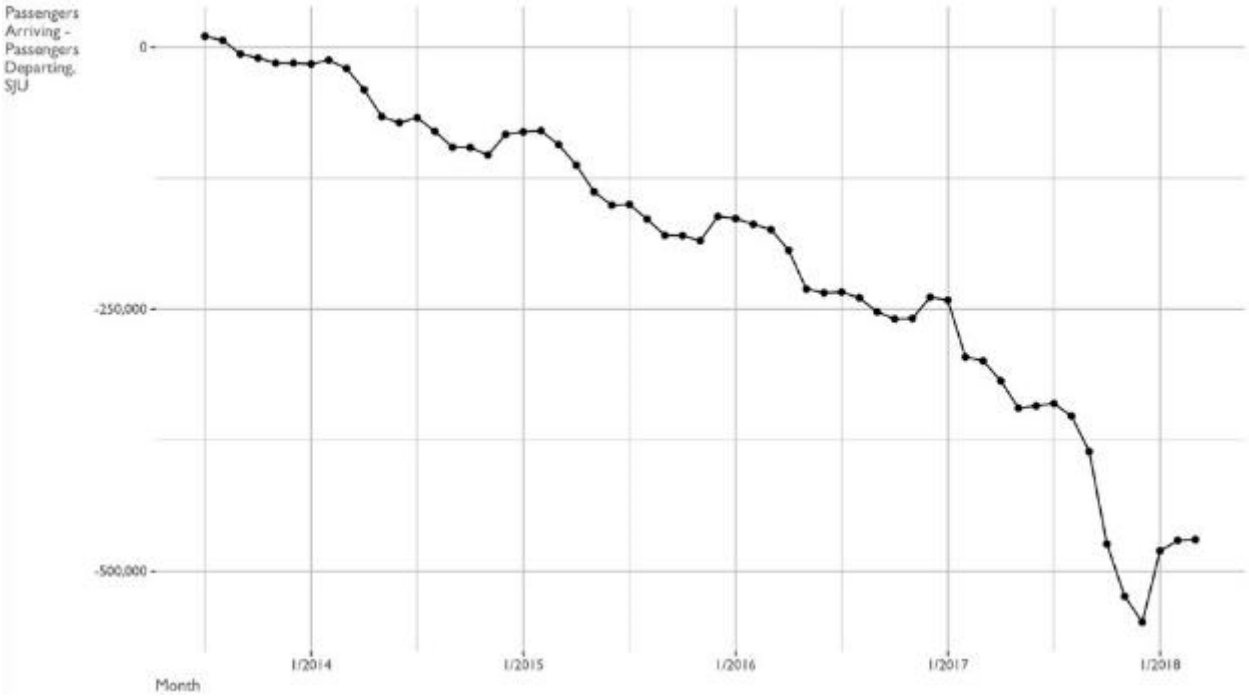
SOURCE:("AirNav.com," undated).

Pre-hurricane conditions

Luis Muñoz Marín International Airport (SJU) in San Juan is the busiest airport in Puerto Rico in terms of aircraft passengers served. Examining the flow of air traffic at SJU provides support for the demographic shifts ongoing in Puerto Rico discussed in other chapters of this report. Typically, the counts of passengers arriving at an airport and departing from the same airport over a period any longer than a few days is roughly the same. However, at SJU, more people have been departing from the airport than arriving at the airport in recent years. Figure 14.8 shows the cumulative count of passengers arriving at the airport minus the passengers departing from the airport over the period July 2013 through August 2017. During this time period, just over 350,000 more people departed from than arrived at SJU. This appears to be evidence of emigration from the Commonwealth.

Though all airports are ultimately owned by the PRPA, SJU has been operated by Aerostar Airport Holdings since 2013 on a 40-year lease (Boynton, 2012). Under the agreement, Aerostar is required to undertake airport improvement projects (Richards, 2014). Diffuse and fragmented ownership and operations at Puerto Rico's airports has challenged coordination of infrastructure maintenance and improvements.

Figure 14.8. Cumulative Count of Passengers Leaving from SJU Minus Those Arriving



SOURCE: Data provided by the PRPA; chart by authors.

Data provided by the FAA reveal a peak in air traffic in 2000, with over 200,000 passenger movements that year. Traffic declined steadily between 2000 and 2011, with nearly 50 percent fewer passenger movements in 2011 than 2000. Traffic had been slightly rebounding since 2011; however; more than 125,000 passenger movements were recorded in 2016 (Federal Aviation Administration, undated-a).

Outside of SJU, Isla Grande Airport is the busiest airport in terms of flight arrivals, followed by Aguadilla, Vieques, Ceiba, and Culebra. Many of these airports serve relatively large numbers of aircraft with relatively few passengers. Aguadilla handles the most cargo of the smaller airports, with substantially more cargo arriving than departing at this location.

The PRPA has struggled to secure the funding needed to make airport improvements. The operating agreement for SJU was, in part, an effort to mitigate this issue. According to a 2014 audit, the PRPA received an upfront payment of $615 million upon entering into the agreement with Aerostar and promptly used $525 million of this payment to repay debt and to cover transaction costs (Puerto Rico Ports Authority, 2014). The agency lowered operating expenses but also gave up operating revenue from the airport as part of the P3 agreement. Expenses continued to outpace revenue even after the arrangement; however, the difference between the two has shrunk (Puerto Rico Ports Authority, 2014).

Hurricane damage

Air travel was severely interrupted for several days following Hurricane Maria, and there were initial reports of many passengers being stranded in the airport with limited access to food and water (Calfas, 2017). Aerostar Airport Holdings, a private company that operates SJU, reported that some of the terminals at SJU "lost entire roofs" (Calfas, 2017). The airport was closed for two days immediately after Maria hit (PR Newswire, 2017) and, roughly a week after the storm, was only accepting 10 flights a day (Davila Calero, 2017). The latter restriction was attributed to "the limited signal range of the traffic control tower in San Juan" (Davila Calero, 2017).

While not on airport property, an FAA radar tower lost its power supply due to the storm and was operated on generator power. The road leading to the site, which is located in El Yunque National Forest, was inaccessible to truck traffic due to storm damage, so fuel was provided by all-terrain vehicles and helicopter (PRPA, 2018).

Damage was particularly extensive at Rafael Hernández Airport in Aguadilla. One building at the airport suffered a structural collapse while many others "building envelope breakage and loss" (Gvelop, 2017) including the FedEx™ hangar (Figure 14.9). Many infrastructure assets exposed to the elements, including antennae, solar panels, air conditioning units, and perimeter fencing, have been lost.

The total cost of repairs needed based on summaries of damage at individual airports is approximately $237 million. In addition, some privately held or managed assets such as the Lufthansa Technik facility at Rafael Hernandez International Airport (BQN) have received only superficial assessments.

The BBB report includes two projects focused on airports. It seeks $540 million for "Rafael Hernandez International Airport (BQN) Rehabilitation" and an additional $24.5 million for "Regional Airports Optimization." Note that both projects are considerably more expensive than the costs of repairs identified in damage assessments conducted to date. The BQN project in particular seems to be based on a long-standing desire to improve the airport and attract additional traffic to the area that was evident at least as far back a 2005 Master Plan for the airport (Team ERA, 2005).

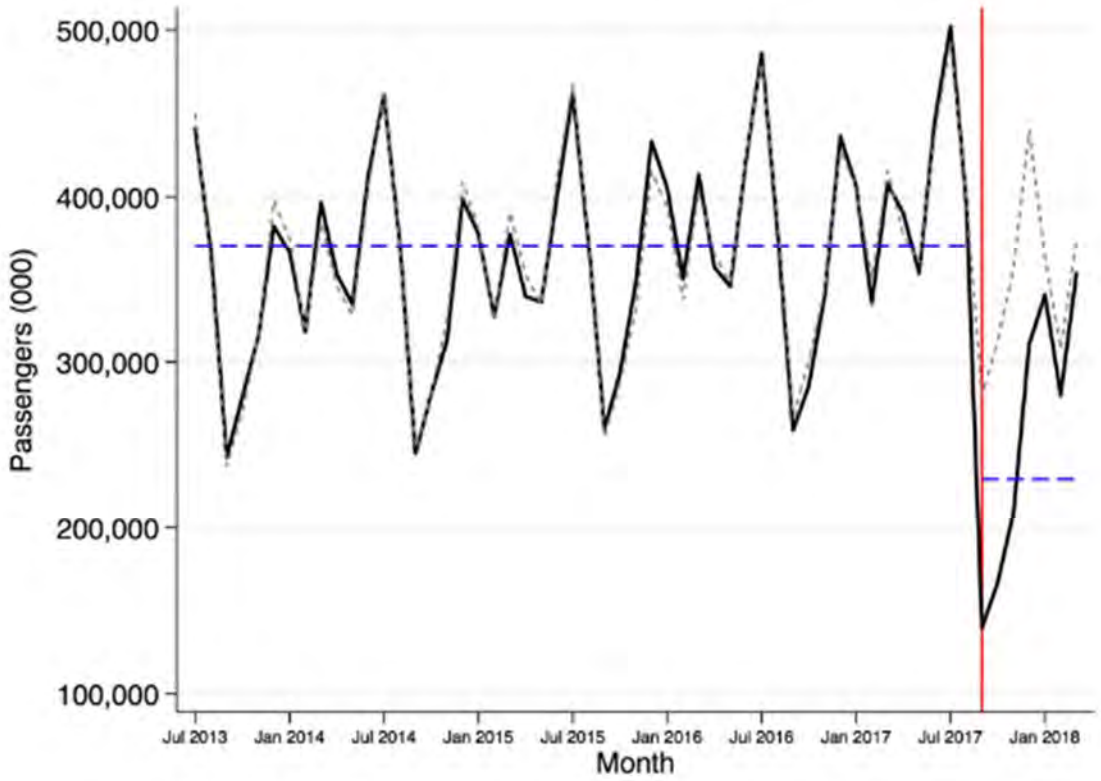
Figure 14.9. Damage to FedEx Hangar at Aguadilla Airport

Source: (Gvelop, 2017)

Damage impact: passengers

To the best of our knowledge, no airport suffered damage so severe that it is not able to resume flight operations at levels similar to before the 2017 hurricanes. To evaluate the extent to which Hurricanes Irma and Maria impacted Puerto Rico's airports, however, HSOAC compared the trends in passenger traffic before the hurricanes took place to trends during the month of, and after, the storms. This analysis relies on time series regression analysis of unpublished, monthly data provided by PRPA from July 2013 through March 2018 (Figure 14.10). Results shows that post-storm passenger and cargo movements were substantially lower through December 2017. Specifically, the HSOAC analysis shows an approximately 38 percent reduction in arriving passengers during the September through December period, approximately 140,000 passengers per month. Further detail on the impact of the 2017 hurricanes on passenger traffic is available in the Economy chapter of this report.

Figure 14.10. Number of Arriving Passengers to Luis Muñoz Marín International Airport (monthly)



SOURCE: PRPA, analysis by authors. The red vertical line indicates September 2017, the month when Hurricanes Irma and Maria made landfall in Puerto Rico. The blue dashed lines correspond to pre-September 2017 and September-December 2017 adjusted means. The grey dashed line corresponds to the predicted series based on pre-September 2017 data.

Damage impact: flight operations

The Federal Aviation Administration's (FAA) Air Traffic Activity System (ATADS) provide daily information for the total number of flights arriving and departing from two airports, SJU and BQN, based on radar tower data. HSOAC team analysis of this dataset from January 1, 2017 through April 30, 2018 shows an average of 52 fewer flights per day at SJU, an approximately a 11.3 percent reduction, although the number of flights appears to have stabilized as of early 2018. BQN, a joint civilian-military airport, saw an average reduction of approximately 33 flights per day over this period.

Damage impact: cargo

HSOAC also conducted an analysis of cargo tonnage arrivals and departures to and from Puerto Rico's airports from September 2017 to March 2018, based on data provided by the PRPA. In total, the hurricane seems to have had somewhat smaller effects on cargo arrivals and departures, with average estimated reductions of 20 percent and 25 percent, respectively. However, certain airports seem to have been dramatically impacted (such as Fernando Ribas Dominicci Airport in

Isla Grande, which saw an estimated 93 percent reduction in arrivals and 92 percent reduction in departures). However, it is important to note that PRPA data on cargo coming through SJU only span 13 months, from January 2017 to January 2018. Because of this limited sample, HSOAC could not adjust the data to account for seasonality or annual trends, making hurricane impacts more difficult to estimate.

Post-hurricane conditions

Emergency response operations

The SJU airport was closed for roughly two days after Maria hit (PR Newswire, 2017). Travelers without reservations were urged not to travel to the airport. Emergency and relief flights were given priority in the immediate aftermath of the storm. JetBlue reported that it was transporting relief supplies and allowing relief personnel to fly to Puerto Rico at no cost (JetBlue, 2017b). The SJU airport operator used 21 emergency generators to power the airport when the power would otherwise have been out (Kantrow, 2018), and there were restrictions on flights after dark at Rafael Hernandez Airport in Aguadilla and at Mercedita Airport in Ponce (JetBlue, 2017a).

Repairs and operational restoration conducted to date

All airports are currently operational as of this report date. At Rafael Hernández Airport in Aguadilla, the most expensive items of emergency work identified include stabilization and installation of new perimeter fencing and building debris removal and disposal (Gvelop, 2017). Other emergency works include installation of tarps to cover damaged roofs and "mitigate water infiltration" issues, with the expectation of future, more permanent work to repair or rebuild the roofs.

The Port Authority of New York and New Jersey sent volunteers to help remove debris and make repairs at SJU, in particular helping repair the damaged terminal roof mentioned in this report (Alba, 2017). According to statistics provided by the PRPA, passenger and cargo flights have resumed at all the airports covered in this report, though at potentially reduced levels (see above).

One barrier to recovery at SJU is that its operator, Aerostar, is probably not eligible to apply for assistance through FEMA, as FEMA is only able to assist public entities. The facility owner, the PRPA, will likely need to formally request assistance to secure future recovery funds.

Remaining critical needs and priority challenges to address during recovery

Given the damage sustained by Puerto Rico's transportation sector from Hurricanes Irma and Maria, repairs that have been completed to date, and pre-hurricane challenges, a number of critical needs and challenges will need to be addressed in the recovery process.

Short term

Short-term challenges are those associated with immediate safety concerns and the reliable restoration of mobility options within the next one to 12 months.

- *Repairs to critically damaged roads and bridges*. FEMA's short list of critical projects for roads and bridges include severe damage to the road (off PR-184) that serves a major weather radar installation; a retention pond draining under a major north-south road (PR-10) that could lead to collapse; a bridge weakened from debris in the water underneath that could result in collapse; and a small number of other roads that remain closed for safety reasons.
- *Remaining restrictions on maritime facility and vessel operations*. As noted above, all ports were open as of November 2017, but some had restrictions pending dredging operations. In addition, other facilities are still operating at limited capacity due to storm damage affecting Maritime Transportation Security Act (MTSA) compliance or because they are pending a full assessment by Coast Guard personnel.
- *Repairs to terminal damage at Luis Muñoz Marín International Airport.* Repairs are expected to cost roughly $30 million (Kantrow, 2018). This can be categorized as a critical need given the economic importance of the airport.
- *Repairs to FAA radar tower in El Yunque and restoration of its electricity supply*. The tower is currently operating on generator power.

Longer term

Over the next one to ten years, looking beyond immediate needs toward the development of a modern, efficient, and resilient transportation system will require prolonged investment in infrastructure and the reform of management practices and operations. Recovery actions funded by FEMA and other federal agencies can establish a foundation for future development of the sector.

- *A more resilient road network.* Given the extent of the road network in Puerto Rico, and the relative dearth of non-automotive travel options, maintaining the roadway network in a way that makes it resilient to future storms is of great importance. This involves:
    - consideration of sea level rise and road resilience for Puerto Rico's perimeter roads
    - consideration of risks to bridges
    - Addressing traffic congestion and safety
    - Improving options for Puerto Ricans who do not drive.
- *Accessible, high-quality information about transportation assets and ownership.* Maintaining high-quality information about transportation assets and ownership is needed to best manage their maintenance in a cost-effective way
- *Strategies to address low ridership and high costs for public transit systems.* Tren Urbano suffers from high operating costs, low farebox recovery, declining ridership, and an unreliable power supply that could leave the system vulnerable to lengthy outages during future storms. The provision of bus and publico service has also been declining, and ridership on these modes is declining as well. The transit system may have already

entered a downward spiral in which declining ridership leads to lower service, which in turn depresses ridership.

- *Strategies to help reduce dependence on driving for mobility needs*. Puerto Ricans are generally dependent on driving for mobility needs, and many persons who do not drive have reported that they seldom leave their home.[235] The Commonwealth enjoys very few of the emerging mobility options that are enabled by widespread technology, such as bike-sharing, that could ease the dependence on driving. A lack of options can contribute to congestion, as more residents have no choice except driving; social isolation, of those persons who cannot easily access jobs, groceries, or other daily needs; and air pollution, if people drive instead of using less-polluting modes.
- *Reduced dependence on the Port of San Juan*. Loss of the Port of San Juan's capability to receive petroleum products and food supplies would to have significant effects on the island's energy supplies and ability to feed its population. Planning efforts have not yet fully addressed the effects of the loss of these shipments in the event of another major hurricane and subsequent port closure; in such an event, most goods would likely need to arrive via other ports, or to a lesser extent by air. Due to just-in-time inventory policy and limited emergency storage capacity, perishable food supplies could again be significantly impacted.
- *Improved maritime public transit system service*. The populations of outlying islands were cut off from the rest of Puerto Rico for four days following the storm, suggesting that the system needs to improve its reliability for emergency operations. Also important is to balance the needs of residents against the desire to promote tourism in Puerto Rico with regard to the amount and cost of ferry service.

[235] Personal communication, PRHTA staff.

15. Public buildings

Overview

This section documents the damage experienced by Puerto Rico's public buildings sector in the wake of Hurricanes Irma and Maria, and the needs within the sector to address long-standing challenges of ownership issues, building vacancies, and deferred maintenance. Additional information on the methods, data sources, and damage and needs assessment results described here can be found in a forthcoming HSOAC "Public Buildings" Sector Report.

"Public buildings" is a broad term that could encompass a variety of structures, and the scope of the public buildings sector depends on perspective. One view is that public buildings include those buildings that house the array of essential government services, such as emergency services, education, the judicial system, corrections, National Guard, tax collection, state department, and many more. A second view is to consider all buildings owned by the government. While these two perspectives largely coincide, there are some important differences. For example, one of the largest building owners in the government, the Puerto Rico Industrial Development Company (PRIDCO), leases most of its buildings to private sector companies to support economic development. At the same time, many facilities that provide government services more naturally fall under other sectors, such as many energy, health care, and transportation facilities. There may also be government services housed in buildings leased from the private sector.

For the purposes of managing Public Assistance funding requests, FEMA has defined public buildings according to building ownership. From this perspective, public buildings include buildings owned by most Puerto Rico Territorial government agencies. However, the responsibility for facilities owned by certain agencies has been allocated to other sectors. Buildings owned by the Departments of Education, Health, and Public Works and Transportation; the Puerto Rico Electric Power Authority; and the Federal and Municipal Governments fall under other sectors. Complicating the situation, many buildings in Puerto Rico are not owned by the agency that operates the activity in the building. For example, while the FEMA Public Buildings Sector excludes the Departments of Education and Health, it nonetheless includes hundreds of public schools and health care facilities that are owned by other agencies. The collection of data and the processing of claims follows this fragmented, ownership-driven perspective, making it difficult to clearly define the public buildings sector according to the purpose of the building.

For the purposes of a long-term recovery plan, however, it is useful to think about public buildings both in terms of ownership, and activities and operations. A long-term planner is concerned with the provision of services, and for this reason cares about the number and location

of schools, fire stations, judicial buildings, and other buildings that support the provision of public services, regardless of who the building housing that service is owned by. This damage and needs assessment therefore presents results from both perspectives. Some data are in presented in terms of building owner, while others are presented in terms of building purpose. This dual approach makes it possible to understand damage from both perspectives.

Considering building ownership and building purpose and coordinating with the other sectors, the scope of public buildings for the purposes of long-term planning is summarized in Figure 15.1. Of the excluded categories, most are covered by other sectors (municipalities, housing, natural and cultural resources, transportation, energy, water). In the case of schools and hospitals, the education and health and social services sectors consider the provision of the services while public buildings considers issues surrounding the physical building infrastructure. In those cases, the two long-term planning sectors are working together to ensure the plans for the physical building support the plans for the service.

Figure 15.1. Building Classification

Background

History and structure

The essential governmental agency responsibility related to public buildings is building ownership. While the building owner tends to be responsible for the service provided in the building, in many cases the building owner has no association with the organization occupying the building. For example, two of the largest public building owners in Puerto Rico, the Public Buildings Authority, PBA, and PRIDCO, act only as building owners; activities in the buildings

are operated by other government agencies or private business tenants. Building ownership is complex and a clear inventory of public building owners in Puerto Rico is difficult to compile. Inventories of public buildings are maintained by owner rather than user, and inventories are not available from every owner. The best source of information on agencies that own public buildings is requests to FEMA for PA funding. As of May 3, 2018, there were 43 applicants for PA funding assigned to the Public Buildings sector. These applicants are listed in Table 15.1. Details of these applications are discussed further below.

Table 15.1. Public Assistance Applicants in Public Buildings Sector

911 System Government Board	PR Convention Center
Admin De Compansaciones Por Accidentes De Auto	PR Department Of Consumer Affairs/Daco
Administration Of Corrections & Rehabilitation	PR Department Of Labor
Centro De Recaudaciones De Ingresos Municipales	PR Fire Department
Comision Industrial De Puerto Rico	PR Horse Racing Sports Industry Administration
Cooperative Development Commission Of PR	PR Land Administration
Corp. Projecto Enlace Cano Martin Pena	PR Land Authority
Corporation For Supervision And Insurance Of Cooperatives Of PR	PR National Guard
Department Of Economical Devel. And Commerce	PR Police Department
Department Of Treasury	PR Public Broadcast Corp.
Economic Development Bank For Puerto Rico	PR Retirement And Adjudication System
Ethics Government Office	PR State Department
General Services Administration	PR State Emergency Management Agency
Labor Relations Board Of Puerto Rico	PRIDCO
Metro	Public Building Authority
Office for Socioeconomic and Community Development	Public Diffusion Corporation PR
Office Of Management & Budget	Public Service Commission
Office Of The Election Comptroller	Regulatory Board Of Telecomunications
Office Of The Governor	Solid Waste Authority
Office/Commissioner For Financial Institutions	State Insurance Corporation Funds
Parole Board	Trade And Exports Company
PR Admin. & Transf.Ofc. For Human Resources	

Key assets

Due to the fragmented ownership of public buildings in Puerto Rico, it is difficult to ensure an inventory list for any given type of public building is complete. For this reason, HSOAC focused on obtaining inventory and damage information from the largest owners of public buildings. In a few cases, HSOAC was able to compile numbers and locations of buildings from multiple sources. PBA and PRIDCO provided inventories of their properties as part of their damage assessments. HSOAC has also been able to ascertain numbers of buildings for a subset of building purposes from different sources. Numbers of buildings by owner or building purpose

are listed in Table 15.2. Data on the number of buildings for most of the applicants listed in Table 15.1 are not available.

Table 15.2. Numbers of Public Buildings for Selected Owners and Building Purposes

Owner or Purpose	Number of Buildings[a]	Source
PBA	735	PBA PA request to FEMA
PRIDCO	788	PRIDCO PA request to FEMA
Schools	1131	USACE[b] damage assessment
State police stations	196	USACE[b] damage assessment
State fire stations	95	FEMA Caribbean Area Division, compiled by FEMA Public Buildings Sector team
Emergency Operations Centers	82	HAZUS[C], compiled by FEMA Public Buildings Sector team

[a]Numbers are not additive because PBA buildings are also included in other categories
[b]U.S. Army Corps of Engineers
[c](Federal Emergency Management Agency, 2018b)

Data sources and methods

Data sources

Table 15.3 provides an overview of the data HSOAC has obtained to date on damage to public buildings from Hurricanes Irma and Maria. In some cases, building owners or tenants are still completing damage assessments or applications for public assistance, meaning further information will continue becoming available over the course of months or years. Few reliable sources of data are available to provide insight into inventories of and the extent of damage to public buildings; this information can be updated as additional data become available. HSOAC also pursued and acquired data derived from NASA satellite imagery and Google Maps, but ultimately found those sources were not designed or well-suited for purpose of recovery planning.

HSOAC has preliminary damage data from PRIDCO and PBA and expects more complete assessments in the near future. PRIDCO and PBA represent the largest stakeholders in the public buildings sector, and their combined inventory of buildings represent a large percentage of the sector. Obtaining complete damage assessments from the majority of the 43 identified stakeholders in a timely manner is unlikely. Assessments from the larger entities, such as PRIDCO and PBA, will likely serve as representative of the sector as a whole.

Table 15.3. Summary of Data Sources and Information Gaps for Public Buildings

Dataset	Source	Date Range	Pre-Storm	Post-Storm	Recovery	Data acquisition status	Evaluation Notes
Inventories of public buildings by owner and by building function			Y			Have state police and fire stations, PBA and PRIDCO; not clear what all exists	
Damage assessment reports for state police stations	U.S. Army Corps of Engineers	October–November, 2017		Y		Available–data utilized for this draft	Brief qualitative descriptions of damage
Damage assessment reports for schools	U.S. Army Corps of Engineers	October–November, 2017		Y		Available–data utilized for this draft	Mix of qualitative descriptions and coded status. Code definitions not yet available.
Damage assessment reports for fire stations	FEMA	As of April 17, 2018		Y		Available–data utilized for this draft	Brief qualitative descriptions of damage with cost estimates
Damage assessment report for PRIDCO	PRIDCO	As of March 28, 2018		Y		Available–data utilized for this draft	Cost estimates distinguished by damage type
Damage assessment report for PBA	PBA	As of March 23, 2018		Y		Available–data utilized for this draft	Cost estimates distinguished by FEMA PA category
Damage assessment reports for other types of buildings	U.S. Army Corps of Engineers, various PRG agencies			Y		Have damage inventories from 911 System Governing Board, Administration of Corrections and Rehabilitation, Parole Board, Courts and Administration, and Correctional Health	
PA funding requests	FEMA	As of March 9, 2018		Y		Available–data utilized for this draft, but much more yet to come	Includes funding for emergency work only; permanent work yet to be processed
Insurance claims	FEMA			Y		Requested, but won't be available until permanent work PA applications processed	Complement to PA funding to provide total damage
Functional status of buildings				Y		Would be very helpful–existence unknown	

Methods

Table 15.3 lists the data sources used in this report to describe damage and inventories. Analysis of this data, in addition to meetings with representatives from FEMA, PRG agencies, and other stakeholders and subject matter experts, provide the basis for the damage included this report.

Data gaps, assumptions, and uncertainties

One of the key gaps in data is the lack of comprehensive inventory of public buildings by owner and building function. Given the complex and fragmented ownership conditions in Puerto Rico, it would be helpful to understand the total population of buildings in order to place the extent of damage into context. For example, an inventory of state police stations from FEMA Caribbean Area Division includes 163 records, while the USACE police station damage assessment report includes 196 records. HSOAC was able to match only 144 of these records in both databases, indicating that both databases are missing records. Such inconsistencies make it difficult to understand the extent of damage to a particular building type. Incomplete record keeping of government real estate inventory is a known challenge in Puerto Rico, and such a comprehensive inventory does not appear to exist. In the long run, improving the recordkeeping of government real estate is an important course of action for the long-term recovery of this sector, a task which may require specific procedural or policy changes. In the short run, as noted above, the best way to assess the extent of damage to public buildings using available data is to focus on obtaining inventory and damage information from the largest owners of public buildings.

Another important gap is the data on the damage themselves. While HSOAC has obtained damage assessment reports from two of the largest public building-owning agencies and for three different building systems (schools, police stations, and fire stations), the quality of these assessments varies and there are several more building owners and systems for which no data are available other than the amount of their FEMA Public Assistance request. Further, the data HSOAC has vary considerably in format and level of detail, and there's no way to ascertain their accuracy or inter-agency consistency.

The extent of functional impairment of buildings would also have been very helpful in characterizing the impacts from the hurricanes on the public buildings sector. This is often impossible to determine from a damage assessment report. Such data would help characterize the extent to which access to key services is limited or unavailable, as well as to determine whether a structure can be repaired or must be demolished.

Pre-hurricane conditions

As noted above, a long-standing issue with public buildings in Puerto Rico has been fragmentation and confusion over building ownership. For example, school buildings are owned by at least three different agencies: the Office for the Improvement of Public Schools of Puerto

Rico, the PBA, and the Department of Transportation and Public Works. PRIDCO, a government-owned corporation focused on economic development broadly, owned almost 800 buildings but leased most of them to private sector companies to support economic development. This has made it difficult to know which building is owned by which agency. In addition to confusion over ownership, fragmentation has made it difficult to track and ascertain basic information about public buildings. According to the 2018 certified fiscal plan for Puerto Rico (Government of Puerto Rico, 2018b), "To date, with very few exceptions, the Government lacks a clear understanding of the number, type, location, legal status, and condition of the real estate assets it owns."

Another issue has been the substantial amount of underoccupied, excess building inventory, likely a result of economic recession and declining population. As a result, various initiatives to consolidate and right-size buildings have been proposed, including the School Modernization Program (Government of Puerto Rico, 2017a). This program, originally launched in 2010, was designed to respond to declining enrollment and poor conditions in Puerto Rico schools. It was initially funded by the American Recovery and Reinvestment Act (ARRA) of 2009 and envisioned as a plan to renovate or reconstruct 81 of Puerto Rico's then about 1500 schools. Since that time declining enrollment has led to calls for the closure of hundreds of schools and further consolidation. According to the 2018 certified fiscal plan for Puerto Rico, approximately 400 schools have closed over the past seven years (Government of Puerto Rico, 2018b).

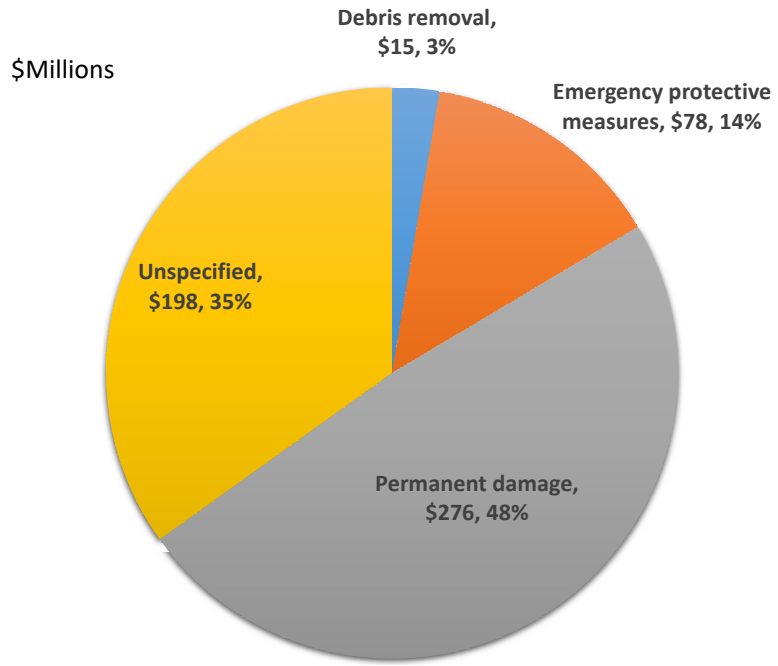
There was also an initiative to consolidate multiple government services into integrated service centers before the hurricanes, but little information is available about the "Centros de Servicios Integrados" initiative (Governor of Puerto Rico, 2016; Plan Para Puerto Rico, 2016). Informal communication with the PBA and FEMA Public Buildings sector team indicate that the proposal included plans to create about 30 Integrated Service Centers throughout Puerto Rico. Centers are intended to include services spanning insurance, business filings, police, motor vehicles, vital records, family services, and more (Government of Puerto Rico, 2016). Choosing where to house these Centers and which buildings may be rendered vacant as a result remains to be finalized.

Another major chronic issue with public buildings has been insufficient maintenance, likely a result of insufficient funding and staffing. While good documentation of the conditions of public buildings prior to the hurricanes was not available, evidence gleaned from FEMA PA applications and other sources suggest that poor maintenance was a central problem impacting building functionality. For example, lack of proper maintenance in schools has "led to the use of improvised maintenance services, the continued implementation of emergency repairs and the loss of a significant amount of school days" (Government of Puerto Rico, 2017a).

Hurricane damage

An important source of damage data is FEMA PA applications. Based on PA application data as of May 3, 2018, a total of $568 million has been requested in over 8,500 requests from 43 applicants, as shown in Figure 15.2. The majority of the applications are for debris removal, emergency protective measures (primarily security), and permanent damage to public buildings and contents (Public Assistance categories A, B and E, respectively)[236]. These values do not necessarily reflect the total cost of damage, as additional claims will continue to be processed over the following months and years, as damage assessments and applications for public assistance are ongoing.

Figure 15.2. Public Buildings PA Requests by Category



SOURCE: HSOAC calculations based on PA claims data, as of 5/3/2018.

Emergency protective services cover providing response and security after the hurricane and include $56 million to the State Emergency Management Agency, most of which supports emergency responders form other states through Emergency Management Assistance Compacts and $20 million by the Police Department. In addition, $185 million of the unspecified costs are emergency protective services provided by the Puerto Rico National Guard (personal

[236] A definition of FEMA Public Assistance categories can be found at https://www.fema.gov/media-library-data/1497559657642-a01f6ee60e25394fa9a25cae2fd289d5/PublicAssistanceFactSheetJune2017.pdf

communication with Lisa Escobales and Santos Guzman, Puerto Rico National Guard, June 7, 2018)

As noted above, 43 different agencies with a stake in public buildings have thus far been identified. Each stakeholder is responsible for their own assessment, and stakeholders are at different places in terms of completing damage reports. How many data each of these stakeholders has remains unknown. As a result, there is no uniform timeline for completed damage assessments across the sector.

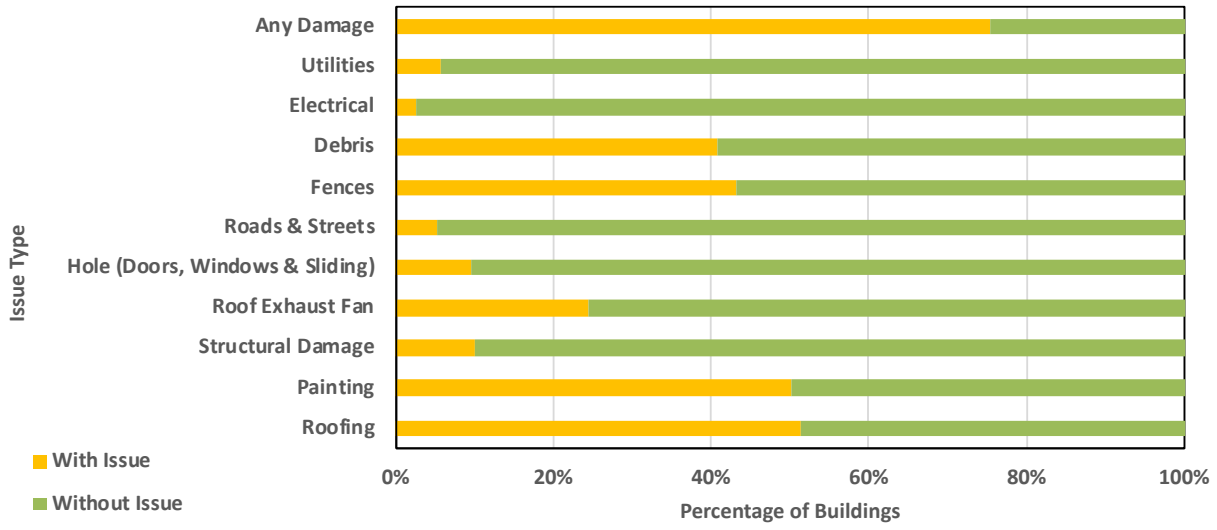
While a comprehensive inspection-based damage assessment for the entire sector is not available, we have been able to compile those assessments that are available. This information includes data by both building owner and by building type. Given the complex building ownership situation, these data likely overlap (that is, some damage may appear both in owner data and building type data), but the extent of overlap is unknown.

Damage by building owner

HSOAC has preliminary damage data from PRIDCO and PBA through their FEMA PA applications and may receive more complete assessments in the near future. PRIDCO and PBA represent the largest stakeholders in the public buildings sector, and their combined inventory of buildings (~1500) represent a large percentage of the sector.

PRIDCO owns 788 buildings, 586 (or roughly 74 percent) of which were reported as damaged (Source: PRIDCO data from March, 2018). Damage assessments were conducted by lessees rather than PRIDCO, and assessment approaches and scopes were not standardized. Frequencies of occurrence of different types of damage are shown in Figure 15.3. Roofing, painting, fencing, and debris removal are the most common types of damage.

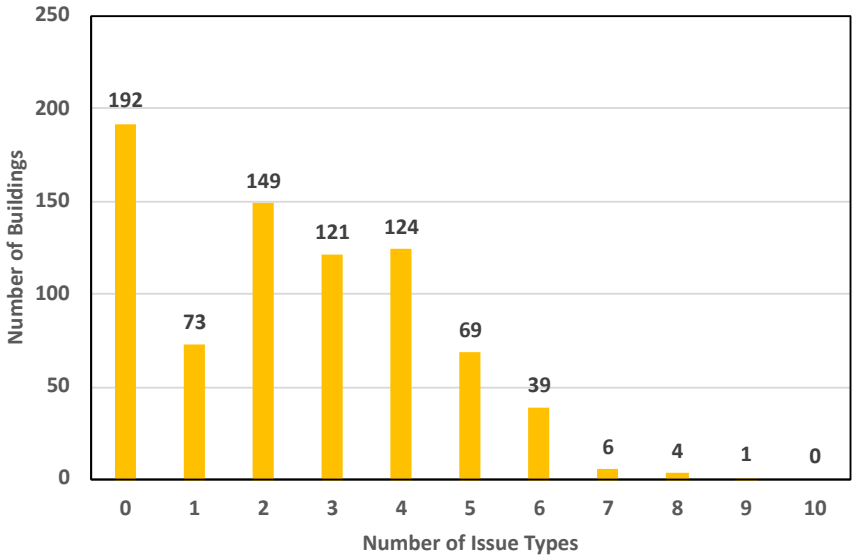
Figure 15.3. Percentage of PRIDCO Buildings with Different Types of Damage



SOURCE: HSOAC calculations based on PRIDCO data from March, 2018.

Another way to view these data is in terms of the number of damage issues recorded for each building. These results are shown in Figure 15.4. While many buildings have only a single type of damage, many more have several different types of damage.

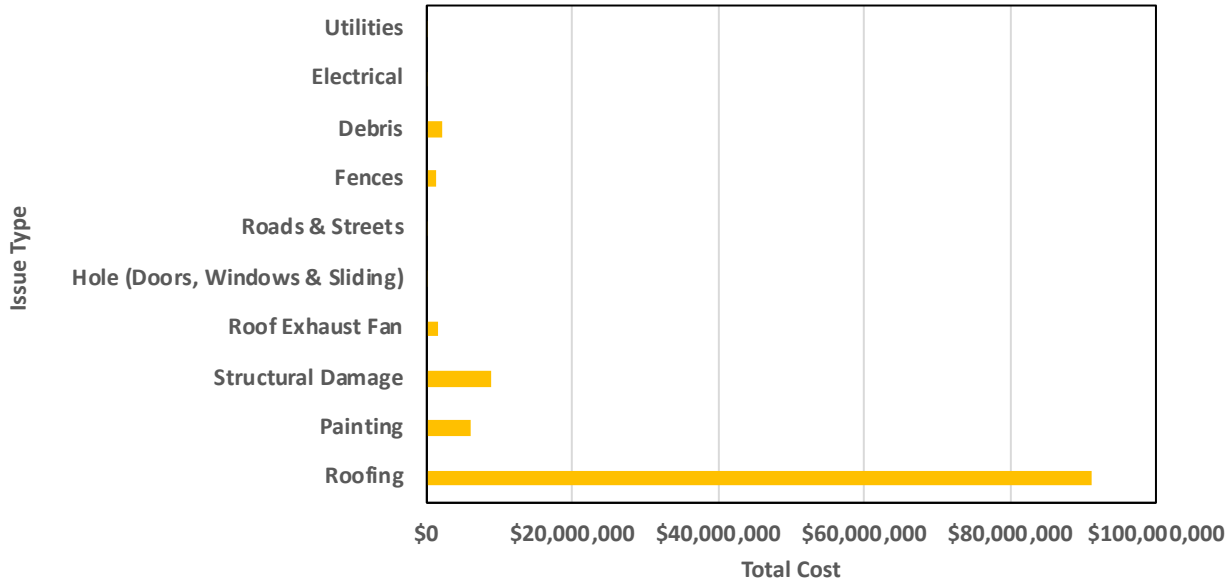
Figure 15.4. Distribution of Number of Damage Types Per PRIDCO Building



SOURCE: HSOAC calculations based on PRIDCO data from March, 2018.

The PRIDCO damage data also include cost estimates for each of the damage categories. These are presented in Figure 15.5. Costs are overwhelmingly dominated by repairs to roofing damage, and it is likely that roofing damage represents a large proportion of damage costs across the public buildings sector.

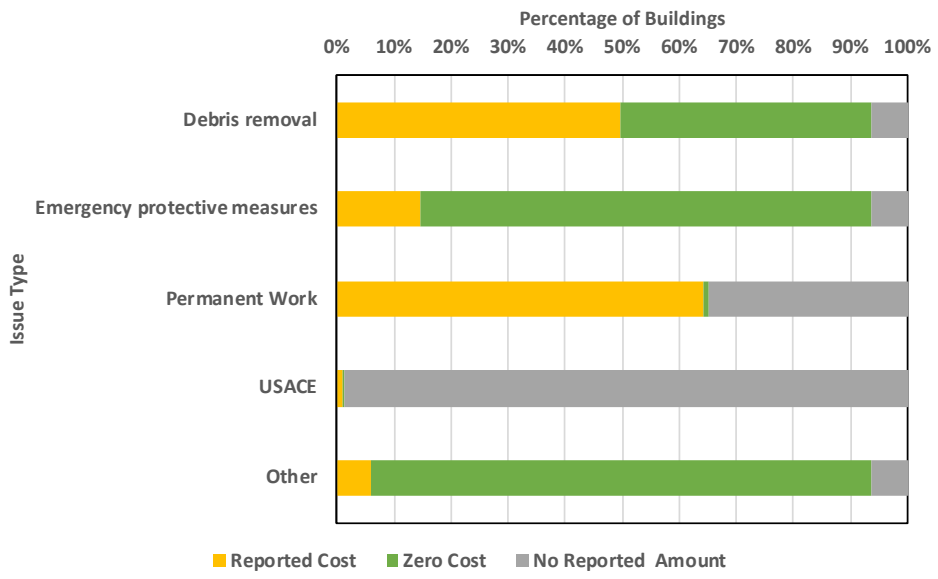
Figure 15.5. Total Cost Estimates for Different Damage Types for PRIDCO Buildings



SOURCE: HSOAC calculations based on PRIDCO data from March, 2018.

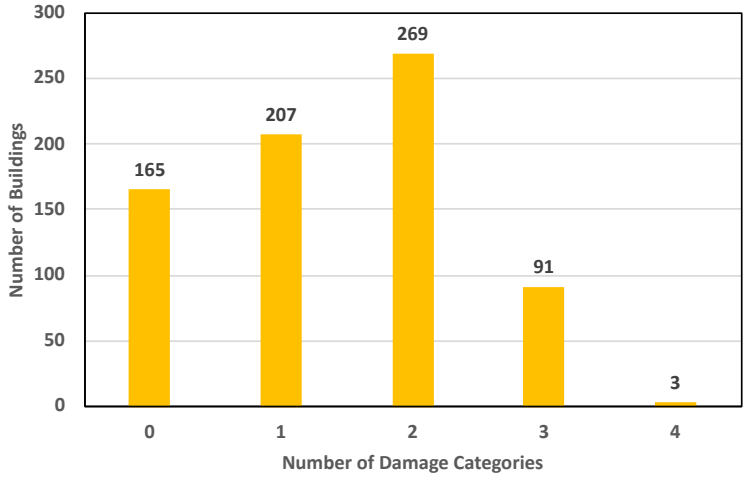
PBA owns 735 buildings, including over 400 schools, 49 government centers, 112 state police headquarters, 34 judicial centers, 17 health care centers, 12 fire stations, 7 penitentiaries, and much more. Damage data from PBA distinguish losses by only by broad category, including debris removal, emergency protective measures, and permanent damage to public buildings and contents (FEMA PA Categories A, B and E, respectively; see Figure 15.6), as well as work emergency work performed by the USACE, such as installing temporary roofs, and other damage. Frequencies of different types of damage are shown in Figure 15.6 and the distribution of the number of damage types for buildings is shown in Figure 15.7.

Figure 15.6. Percentage of PBA Buildings with Different Categories of Damage



SOURCE: HSOAC calculations based on PBA data from March, 2018.

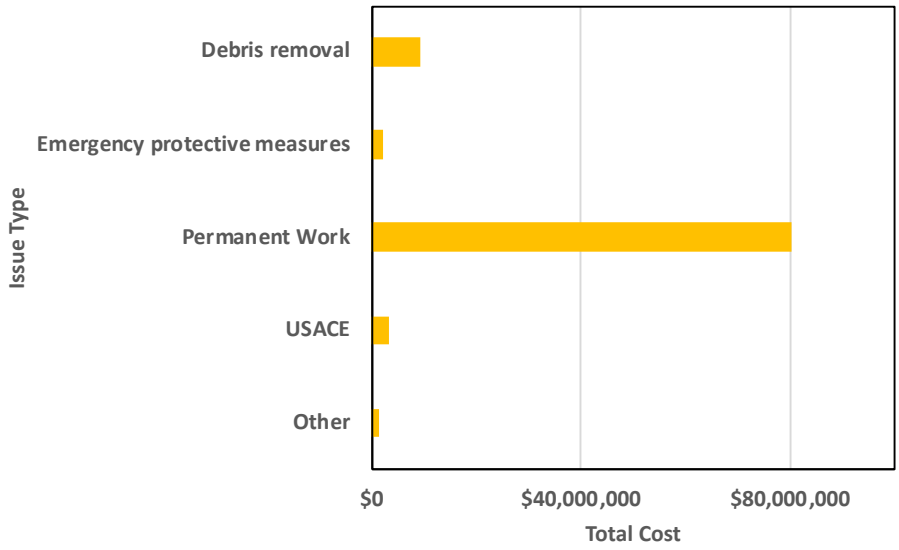
Figure 15.7. Distribution of Number of Damage Categories Per PBA Building



SOURCE: HSOAC calculations based on PBA data from March, 2018.

Cost estimates for each damage type are shown in Figure 15.8. Estimates for permanent repairs are far greater than those for emergency work. This supports the presumption that the Public Assistance emergency work cost estimates shown in Figure 15.2 far underestimate the total costs that will eventually include permanent work.

Figure 15.8. Total Cost Estimates for Different Damage Categories for PBA Buildings



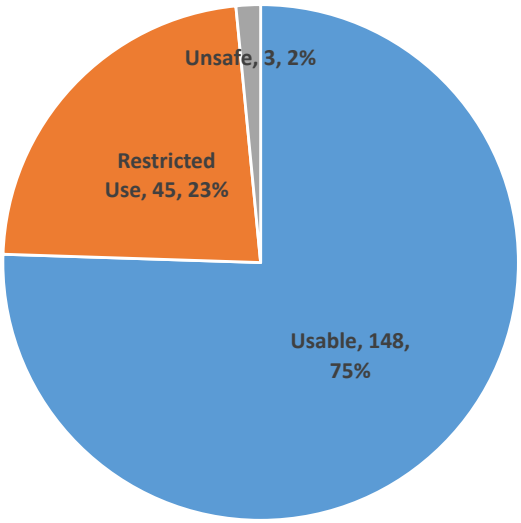
SOURCE: HSOAC calculations based on PBA data from March, 2018.

Damage by building type

Police stations

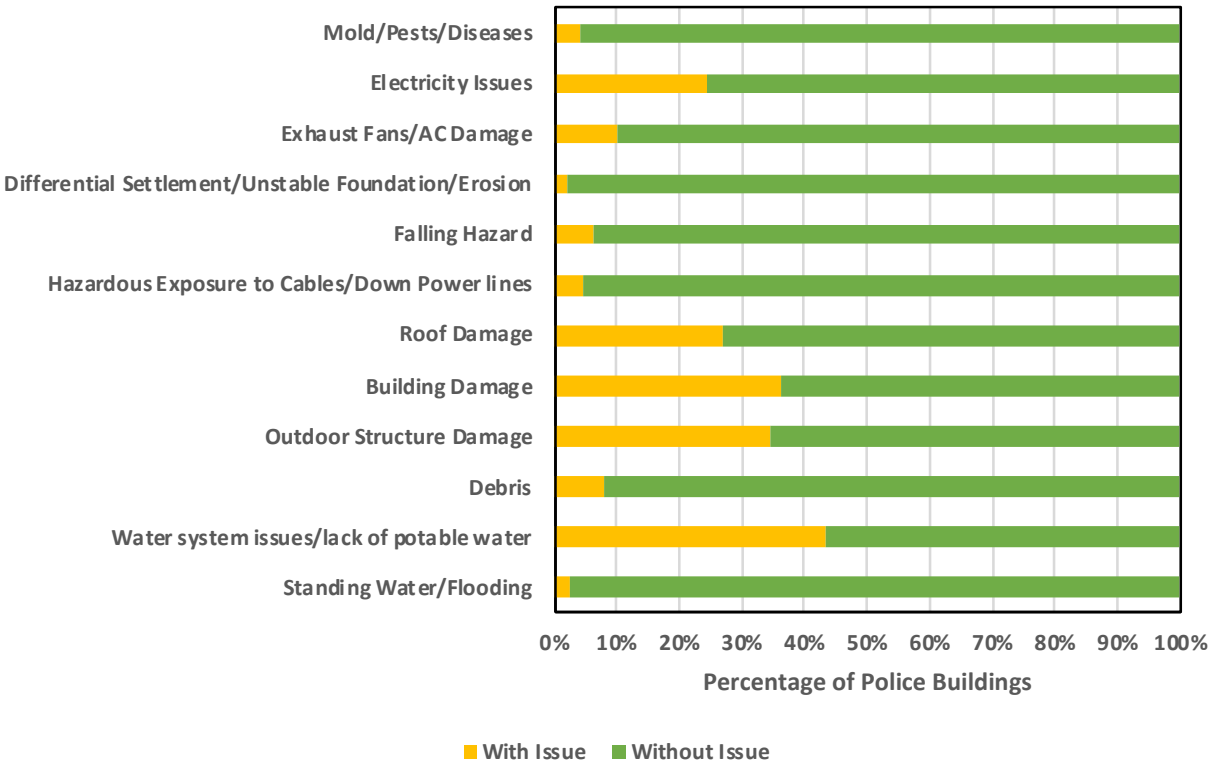
An additional source of damage data is from the USACE. USACE provided emergency assessments of 196 police stations. The status of the stations as of November 2017 is shown in Figure 15.9. This figure shows that the vast majority of stations are operational—only 3 were closed and less than a quarter had some (unspecified) restrictions on their functionality. The data do not include cost estimates, images, or other details. Figure 15.10 illustrates the presence of particular issues, and the percentage of police stations affected. The most common damage issues are problems with water systems, general building damage, outdoor structural damage, and roof damage. While there is no information available on the severity of each issue. Figure 15.11 shows how many issues each station has.

Figure 15.9. Functional Status of State Police Stations as of November, 2017



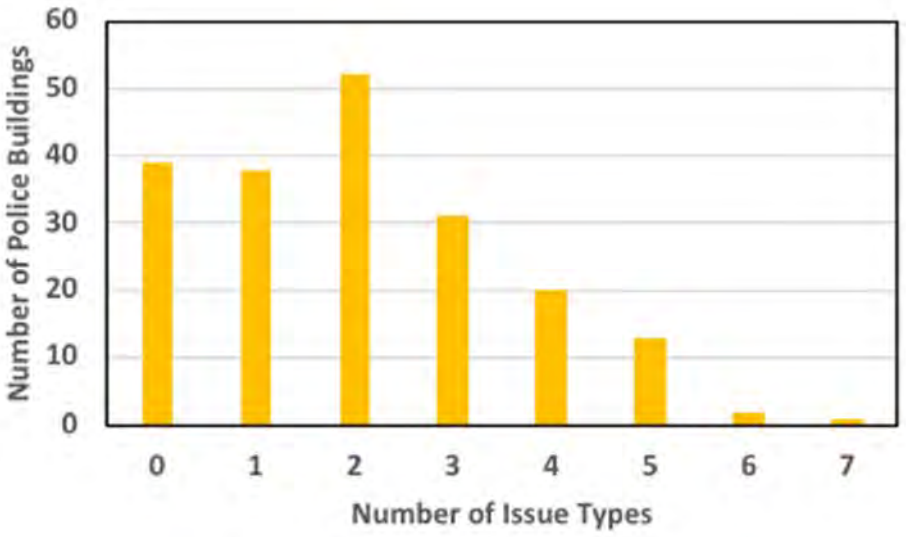
SOURCE: HSOAC calculations based on USACE data from November, 2017.

Figure 15.10. Percentage of Police Stations with Different Types of Damage



SOURCE: HSOAC calculations based on USACE data, as of November, 2017

Figure 15.11. Distribution of Number of Issues per Police Station



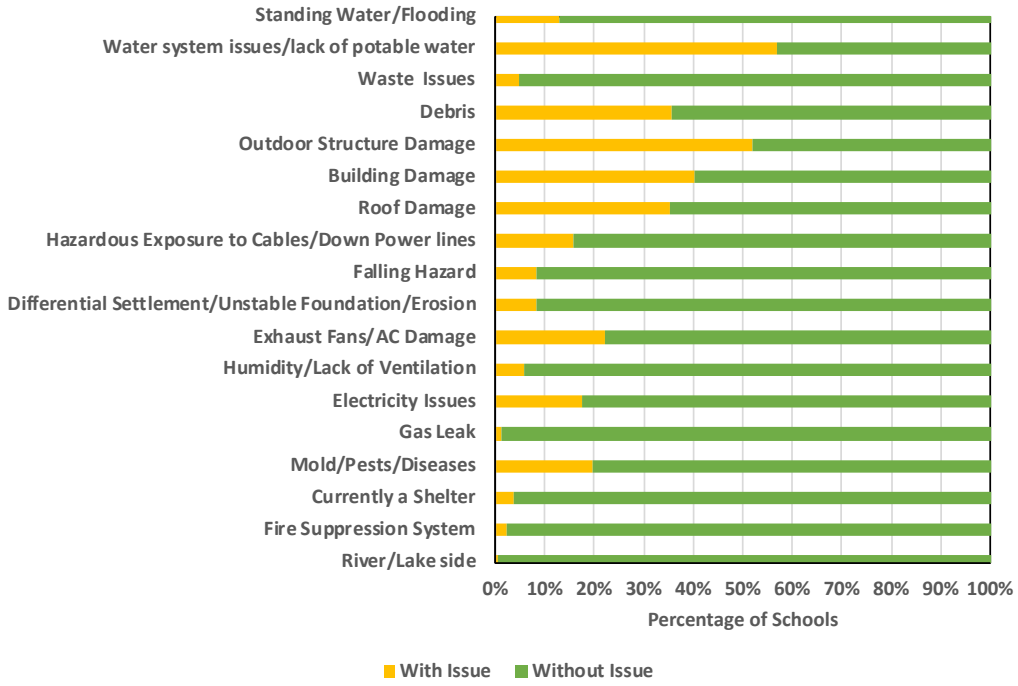
SOURCE: HSOAC calculations based on USACE data, as of November, 2017

Schools

The USACE similarly provided emergency damage assessments for 1,131 public schools in Puerto Rico.[237] Similar to police stations, these damage data include brief descriptions of damage, but do not provide information on functional impairment, cost estimates, images, or other details. While these assessments do not indicate the functional status, the Puerto Rico Department of Education reported that 1094 schools were open as of December 20, 2017 (Puerto Rico Department of Education). Results of coded text descriptions are summarized in Figure 15.12, and the number of damage issues recorded for each school are shown in Figure 15.13. The most common issues are again problems with water systems, general building damage, outdoor structural damage, and roof damage.

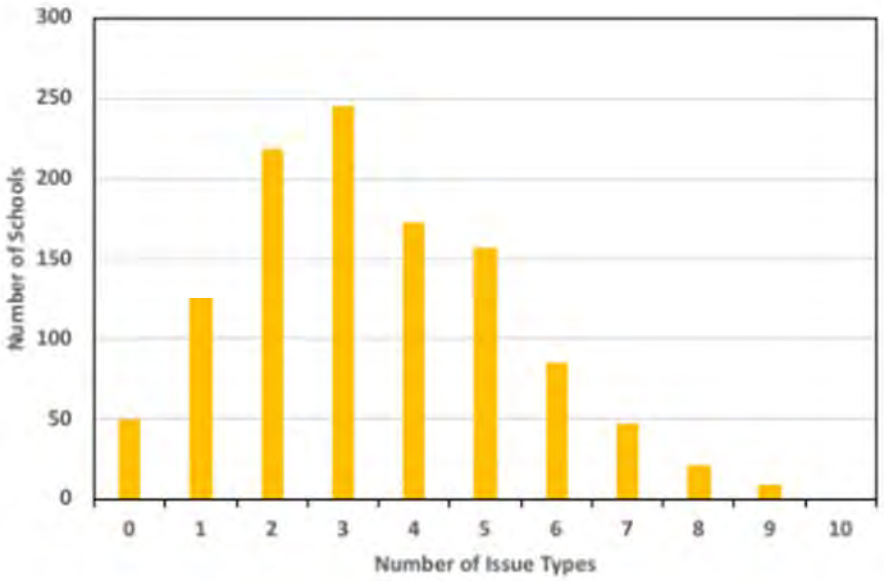
[237] Puerto Rico previously had approximately 1,500 public schools, but up to 400 schools have been closed since 2010 through the School Modernization Program. Current information available suggests that the number of schools open prior to the storm is approximately equal to the number of USACE damage inspections conducted (Government of Puerto Rico, 2017a).

Figure 15.12. Percentage of Schools with Damage and Other Issues



SOURCE: HSOAC calculations based on USACE data, as of November, 2017

Figure 15.13. Distribution of Number of Issues per School



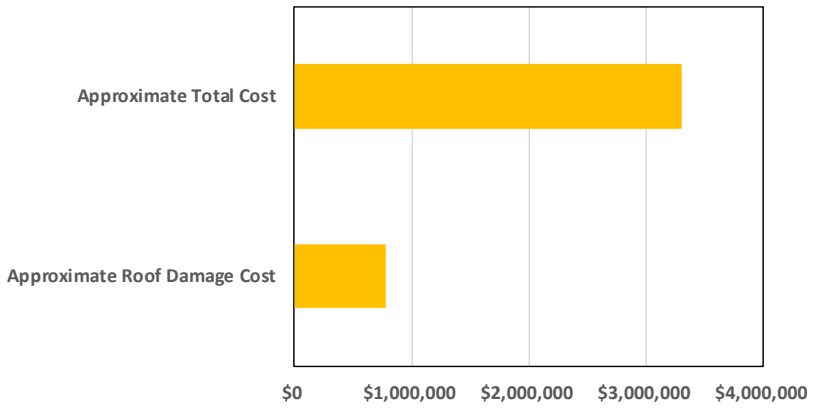
SOURCE: HSOAC calculations based on USACE data, as of November, 2017

Separately, the Governor's Build Back Better Puerto Rico report identifies $8.4 billion in damage to schools (Governor of Puerto Rico, 2017a). This estimate was produced in November 2017 using preliminary damage percentages estimated at the zip code level. The extent to which this is a reasonable proxy for the degree of damage at individual schools in those zip codes is unknown.

Fire stations

HSOAC also obtained some further details from FEMA on the PA applications for fire stations. Stations suffered a wide range of types of damage, with roof damage again being one of the most common types. Figure 15.14 shows the relative proportion of roof damage compared to total damage for 99 fire stations submitting PA applications. The sum of damage for all stations was about $3.3 million. In contrast to the case for PRIDCO buildings, where roof damage accounted for 70% of the total damage (Figure 15.3), roof damage is about 23% of the total for fire stations. Part of the reason for this difference may be that a large proportion of the loss estimates for fire stations consist of building contents, while the PRIDCO loss estimates are for the building envelope only and do not include contents.

Figure 15.14. Total Losses and Roof Losses for Fire Stations

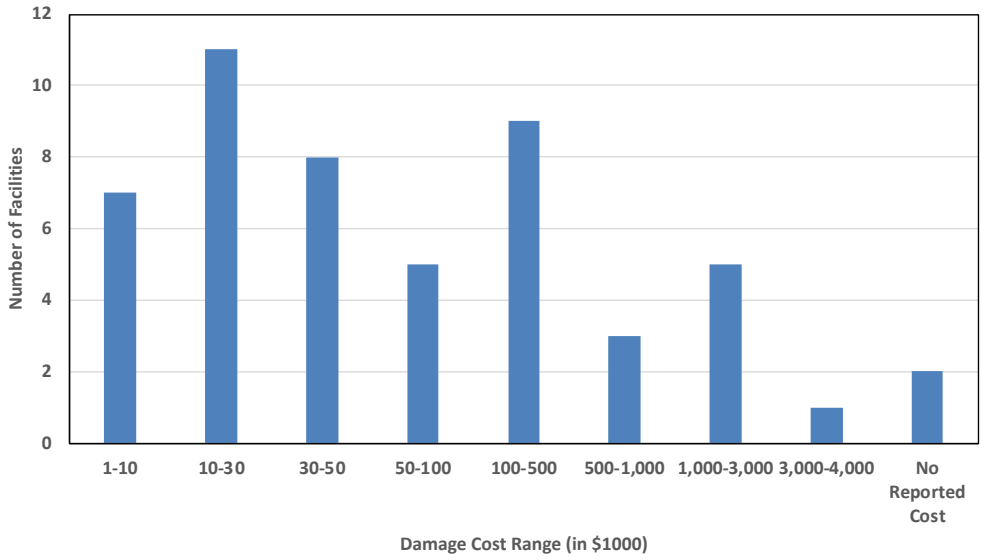


SOURCE: HSOAC calculations based on FEMA PA data, as of May 3, 2018

Corrections facilities

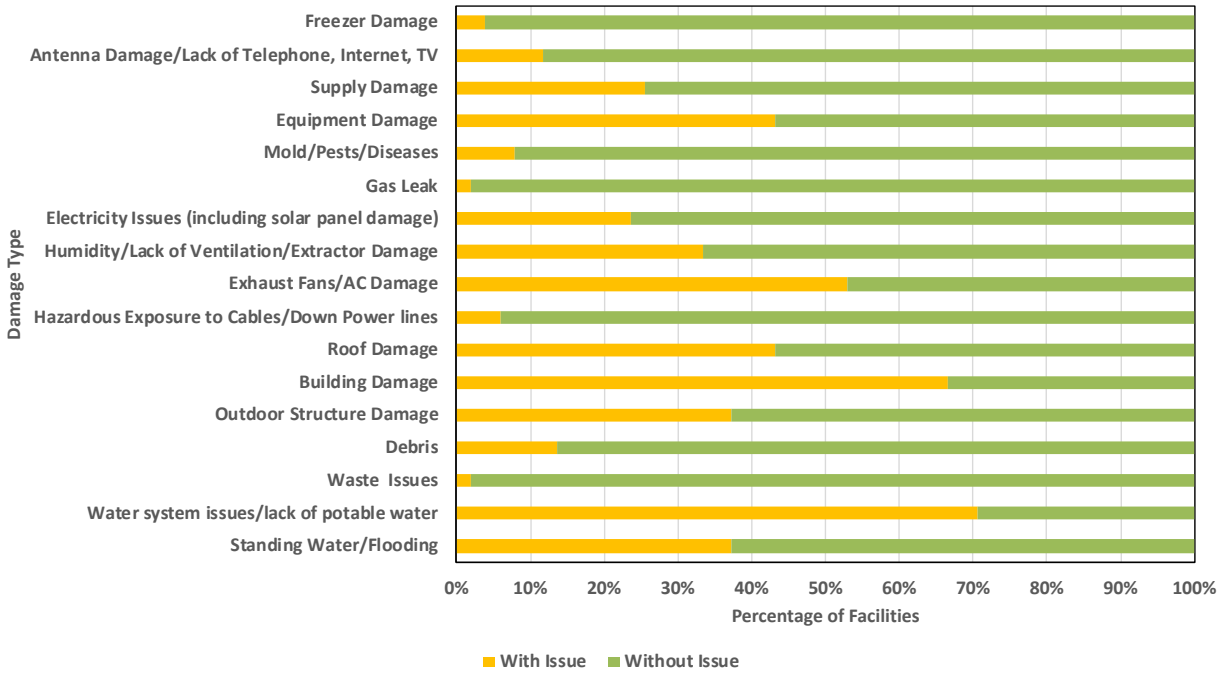
Damage to corrections facilities, as reported by the Department of Corrections and Rehabilitation, are summarized in Figure 15.15 and Figure 15.16. Damage to individual facilities range from under $10,000 to over $3 million (Figure 15.15), with total reported damage of $15.2 million. The distribution by facility of different types of damage is summarized in Figure 15.16. The most common types of damage include water system issues, general building damage, air conditioning, roof damage, and damage to equipment.

Figure 15.15. Range of Damage for Individual Corrections Facilities



SOURCE: HSOAC calculations based on Correctional Health Damage Inventory, as of March 30, 2018

Figure 15.16. Percentage of Corrections Facilities with Different Types of Damage



SOURCE: HSOAC calculations based on Correctional Health Damage Inventory, as of March 30, 2018

Aside from the case of police stations (Figure 15.10), HSOAC has little insight into the degree of damage in terms of impact on buildings' functionality. As noted above, 1094 of the 1131 schools

had reopened by the end of 2017, although reopening doesn't necessarily indicate that all damage have been repaired. HSOAC does not yet have a full count of how many public buildings exist, regardless of whether public buildings are defined as buildings owned by the PA applicants or a selection of specific categories of buildings. It seems the number of buildings owned by the territorial agencies is on the order of several thousand. The amount of damage to many of these buildings is unknown. Approximately 70% of PRIDCO's buildings and about 65% of PBA's buildings are damaged, although the extent of damage remains unknown. Even with declines in population reducing needs, Puerto Rico is looking at the cost of repairing thousands of public buildings. The total cost of that is likely into the billions of dollars. The department of education has made initial awards of $589 million to the Puerto Rico Department of Education. New Orleans spent $1.9 billion on schools in the years following Katrina. There are more than 10 times as many schools in PR as there are in New Orleans.

Post-hurricane conditions

HSOAC has almost no insight into post-hurricane response activities. The majority of the FEMA PA application data do not indicate the extent to which the work has been completed. The USACE damage data for police stations and schools indicate that public buildings sustained a substantial amount of structural damage requiring repair. It is possible that some of this work is underway. To date, the majority of response work for which information is available involves emergency protection, debris removal, and damage assessment inspections.

Decisions about what to do with damaged and excess public buildings continue following the storms. Education is one area in which specific plans have been announced. The Government of Puerto Rico has reported that "student population has declined by over 40% since 2000 with an additional 16% decline expected by FY22" (Government of Puerto Rico, 2018b). The plan projects that Hurricanes Irma and Maria will cause student population to drop by 10% in FY18–19 alone. The plan calls for a consolidation from the current approximately 1130 schools to 805 schools by 2022. In fact, the Department of Education recently announced plans to close 283 schools at the end of the 2017–2018 year. These consolidation plans were authorized in the recently passed education reform bill (Ujifusa, 2018). Choosing what to do with the hundreds of closed school buildings is a major public buildings issue that remains to be addressed. Discussions are ongoing related to the other types of public buildings.

Remaining needs and recovery priorities

Key public buildings challenges to be addressed as part of Puerto Rico's recovery include issues directly related to the storm damage as well as preexisting issues that hinder the recovery process.

Short term

Short-term challenges are those associated with remaining repairs to be made, understanding the assets that exist within this sector, and urgent emergency preparedness needs. These needs should be addressed within the next one to 12 months.

- *Repairs to remaining damage from the 2017 hurricanes to fully restore critical services to the Commonwealth.* Public buildings remain in various levels of disrepair, though specific data on the functional status of Puerto Rico's public buildings is unknown. Continuing repair activities is an ongoing need to fully restore critical services to the Commonwealth.
- *Data collection to consolidate information on Puerto Rican government-owned buildings and systematically document the Commonwealth's public building stock.* A key challenge pre-dating the 2017 hurricane season was a lack of awareness of which buildings were owned by the Commonwealth, leading to deferred maintenance and challenging application for PA funds in the aftermath of the storms. Continuing to systematically document the Commonwealth's public building stock.
- *Improvements to building backup power sources to avoid extensive loss of electricity to public buildings in future emergencies.* The loss of electricity to public buildings was a key challenge following Hurricane Maria. Due to the critical services operating out of public buildings, including public safety functions, secondary power guidelines should be developed to improve the capacity, siting, and resiliency of backup generators.

Longer term

Longer term investments will make Puerto Rico's public building stock less vulnerable to natural disasters and improve overall resilience moving forward. These remaining needs to be considered over the next one to ten years.

- *Enhanced structural resilience to natural disasters to reduce structural damage in the face of future disasters* To reduce damage that occur during inevitable future disasters, and to reduce maintenance costs, public buildings should be retrofit to meet current building safety codes for wind, flood, and seismic risk. In addition, policies should be introduced that incentivize building technologies and practices that increase energy and water use efficiency and resilience to natural hazards.
- *Adjustments to critical government activities in flood hazard zones to reduce water damage in the future.* Flood risk should be reduced by moving critical government operations currently located in flood risk areas to vacant or new buildings outside flood risk areas, or by elevating or otherwise mitigating buildings to reduce flood risk.
- *Utilization of vacant or destroyed buildings to address the stock of public buildings that are unsafe to remain in use.* Puerto Rico owns more public building space than can be affordably maintained. Mandated government consolidation (Government of Puerto Rico,

2018) and population projections do not suggest this excess building stock will be needed. At the same time, in some cases public agencies rent building space from the private sector. Government services should be relocated to public buildings where appropriate, and buildings that cannot be efficiently used should be repurposed or demolished.

16. Recovery and Resilience Needs

Pre-storm conditions, extensive storm damage to critical infrastructure systems, and significant barriers to response and recovery have had impacts across sectors. Focusing on the potential of cascading impacts may offer insight into priority recovery activities and courses of action. In this concluding chapter, we highlight selected cross-sectoral challenges that have exacerbated the duration of the disaster and impeded the transition to disaster recovery. We then draw from the sector-specific recovery needs described in the chapters above and highlight priority near- and longer-term needs that Puerto Rico must address in its economic and disaster recovery plan.

Cross-sector impacts in Maria's aftermath

Impacts of economic decline on hurricane response and recovery

In addition to being a primary pre-storm challenge, Puerto Rico's debt crisis presented a barrier to immediate response and recovery. Initial assessments, inspections, repairs, and overall recovery were significantly affected by reduced funding from the Commonwealth government due to its precarious economic situation. As discussed above, many assets were past their useful life even before the storm, which may have made it difficult to prioritize reconstruction activities when the needs were so widespread. Moreover, the demand for damage assessment and repair efforts, across sectors significantly strained the Commonwealth's workforce, including qualified engineers and technicians, necessary to restore essential services. Economic challenges that may have precipitated the loss of medical and mental health professionals starting before the storm, has led to access issues even as mental and physical health issues have increased following the storms.

Cascading impacts of power loss

In the wake of Hurricane Maria, a key barrier to response for all critical infrastructure sectors, particularly in the water, communications, and health services sectors, was the loss of electrical power to facilities. The lack of electricity meant that even facilities that were not damaged directly by the hurricane were still inoperable. The widespread nature of the electricity outage, and its persistence, constrained the ability of facilities that escaped damage to absorb the excess demand from those that were damaged. Moreover, as the electrical grid has still not reached a steady state of reliability (as evidenced by a grid-wide outage on April 18), and a number of critical facilities, including hospitals, water treatment plants, and telecommunications sites, are still running on generator power. Additionally, not all facilities have been able to rely on generators as hurricane damage to generators was common. In particular, from the health sector, there is a concern that remains regarding the interruption of essential services (e.g., cold chain

for vaccines, storage of insulin) and power loss to public health labs at the same time as infectious disease risk has increased post-storm.

Documentation of asset ownership and responsibility

Following the storms, damage assessment was fragmented by the variety of owners within some sectors. Assessment often required access to facilities and buildings, and this fragmentation has made it difficult to track and ascertain basic information about those facilities to gain access and gather information. For example, a systematic assessment of damage to Puerto Rico's airports and public buildings has been challenged by a lack of transparency and coordination across parties. Additionally, since it is sometimes difficult to determine which facility owner is responsible for which repair, access to public assistance funds may be delayed or may not be sought at all. Finally, the widespread destruction associated with Maria often impacted adjacent infrastructure that was owned by many different parties (e.g., a landslide on a road owned by the Commonwealth, but lined with privately owned houses), resulting in ambiguity over responsibility and scope of debris clearance and repairs.

Impact of communication infrastructure failures on hurricane response

The impact of the destruction caused by Hurricane Maria to Puerto Rico's communications networks was unprecedented, widespread, and devastating. Critical emergency services were delayed at a time when such services were a necessity for many. First responders were challenged to manage dispatches, and coordination between Federal and Commonwealth agencies to transport materials and conduct critical emergency repairs was hindered by the failure of communication infrastructure.

As recovery proceeded, the lack of commercial communications also had a profound impact on daily life for the citizens of Puerto Rico. Even as commercial communications were restored, progress was likely slow for many of Puerto Rico's citizens. For example, in some cases, voice and text messaging services were restored before data services. FEMA officials noted that these limitations, including a lack of access to the internet, limited citizens' ability to apply for important relief through FEMA. Just as the communications system is dependent on electrical power, individuals without power could not fully benefit from restored communications networks if their mobile devices were not charged. Finally, the government of Puerto Rico had limited means by which to communicate essential information to its citizens.

Storm debris impacts on response and damage assessment

FEMA has estimated that Hurricane Maria generated over 7.45 million cubic yards of debris (Carrasco, 2018; Kornacki, 2018b). FEMA considers debris assessment and removal critical to disaster response (Category A of emergency work; see Chapter 4). Immediately following the storm, debris in roadways made the initial assessment of damage to other critical infrastructure and assets (energy, water) difficult. Once access was secured, storm debris was found to be the

cause of damage to systems across sectors. In addition, the need to clear debris and repair roads to gain access to facilities slowed the rate at which response actions could be conducted. For example, it was almost a month after the storms hit when fuel supplies were considered sufficient to meet demand, largely due to transportation issues stemming from storm debris. Many residents, especially in rural areas without a redundant road network, were unable to get to medical appointments, or seek help for mental health issues due to blocked roadways.

Priority recovery and resilience needs

Below, cross-sectoral recovery needs drawn from this assessment are presented, building on the sector-specific needs summarized in the other chapters of this report. As before, these needs are separated into two time periods—short-term (one to two years) and long-term (three to ten years)—corresponding to the rough timeframe needed to implement courses of action to address or resolve these needs. A subset of cross-sector needs are highlighted in this summary document.

Across sectors, short-term priorities include continuing damage and needs assessments, continuing repairs, shoring up emergency preparedness protocols, and addressing a lack of clarity around jurisdiction and asset ownership.

Over the next three to ten years, the Commonwealth will need to address a number of both sector-specific and cross-sectoral challenges, including pre-storm economic decline, infrastructure vulnerability and degradation, asset management and governance challenges, and a lack of information about the most appropriate long-term resilience investment decisions for the future of Puerto Rico.

Short-term cross-sectoral needs

Damage and needs assessment are incomplete as of June 2018.

Charting Puerto Rico's path forward successfully requires a comprehensive assessment of damage to its infrastructure and environment as well as continuing social service needs. Although significant work has been done to date, damage and needs assessments are ongoing by various public, private, and non-profit groups in most sectors. Communication and coordination between FEMA and the Puerto Rico government will be essential to use this information for recovery planning and implementation.

Some critical infrastructure remains non-functioning or in disrepair nine months after the hurricanes.

Reestablishing power, communications, and water utilities across Puerto Rico to the entire island remains a priority; the lack of power and persistent poor water quality has affected overall government and utility services and contributes to worsening economic, health, employment, and housing outcomes (U.S. Department of Housing and Urban Development, 2018a). It is critical to reenergize the five percent of Puerto Rico still without power and create an energy grid that is

reliable enough to get other critical infrastructure such as water treatment plants and hospitals off of emergency generators and make them less vulnerable to accidents, technical outages, or future storms. Damage to Puerto Rico's economy, public life, public health, and well-being will continue as long as critical infrastructure remains inoperable or unreliable.

Post-disaster assistance is only beginning to flow to Puerto Rico.

The diverse set of funding mechanisms available in Puerto Rico following the President's disaster declarations include federal grants and aid, federal loans, insurance payouts, Commonwealth grants and aid, Commonwealth loans, foundation aid, private-sector loans, and public-sector corporation revenue. The likely largest source of funding will originate from federal grants and aid, in particular, Community Development Block Grant Disaster Recovery assistance provided by the Department of Housing and Urban Development and FEMA-DHS PA funds. Many of these sources have yet to be released, or assistance to date has been largely limited to response.

There is lack of ready access to comprehensive information about infrastructure asset inventory, ownership, and functionality.

Prior to the storms, no comprehensive asset inventory or management system existed for many sectors. As Puerto Rico enters the next hurricane season—with many vulnerabilities still present—emergency response will continue to be hampered by a lack of access to complete information regarding ownership and status of assets. Next steps for the housing, energy, transportation, and public buildings sectors in particular should involve creating a comprehensive inventory and clarifying parties responsible for maintenance and repairs in asset management systems.

Deficiencies in emergency preparedness protocols must be addressed.

A number of gaps in Puerto Rico's emergency preparedness infrastructure were identified during the recovery period. Municipal-level emergency response and mitigation plans were found to be inadequate, with an estimated 20 percent of plans not up to date when Hurricane Maria made landfall. Coordination of parties responsible for emergency response, as well as stockpiling of materials, resources, and personnel, are near-term priorities.

Longer-term cross-sectoral needs

Economic challenges that precipitated population loss, worsened storm damage, and currently inhibit recovery must be addressed.

Economic contraction has been ongoing since approximately 2006, and related outmigration has been a significant factor in Puerto Rico's recent population decline (losing over 300,000 people since 2010). With this loss of tax base, and other financial and management challenges, many of Puerto Rico's utilities and public agencies are financially insolvent. As a result, fiscal capacity to

provide long-term operation and maintenance of rebuilt or replaced assets is limited. Efforts to attract businesses, incentivize formal employment, and stimulate the return of the displaced, along with efforts to restructure public debt and reduce the cost of services and materials in Puerto Rico, will be critical longer-term steps toward recovery.

Timely and accurate data on the Commonwealth's economic and fiscal status is required.

Both the public and private sectors require timely, accurate, and comprehensive information to make effective strategic decisions regarding both recovery and day-to-day operations (Congressional Task Force on Economic Growth in Puerto Rico, 2016b). Puerto Rico's outdated methods of national income accounting and lack of participation in some U.S. Census Bureau, Bureau of Labor Statistics, Bureau of Justice, Health and Human Services, Energy Information Administration, National Center for Education Statistics, National Center for Health Statistics, and U.S. Department of Agriculture data programs limits the quantity of information available relative to U.S. states. While the Puerto Rico Institute of Statistics has been recognized as an exemplar of good statistical practice, it cannot be expected to fill this gap at historical funding levels (Congressional Task Force on Economic Growth in Puerto Rico, 2016b).

Infrastructure in Puerto Rico is vulnerable to natural hazards and needs to be built to 21st century standards.

Puerto Rico's infrastructure is threatened by degradation due to many years of deferred maintenance, resulting in lost revenue and higher repair costs, which further draw public utilities and agencies into debt. Many of the systems in Puerto Rico lag behind the continental U.S. and are not built according to the latest standards. This reduces the attractiveness to businesses and to potential immigrants (or returning migrants) and impacts the Commonwealth's tax base.

In addition, Puerto Rico will soon enter another hurricane season, and other natural hazards such as drought and sea level rise continue to threaten the Commonwealth's infrastructure and residents. Understanding vulnerabilities and creating robust and flexible systems will take significant investment moving forward. In addition, Puerto Rico might need to consider more dramatic policy actions, such as property acquisitions in high-risk floodplains, in order to reduce disaster vulnerability and losses.

Management challenges and code enforcement gaps reduce the effectiveness of Puerto Rico's utilities and perpetuate activity in the informal sector.

A substantial informal construction sector was prominent in Puerto Rico before the storm. Informal building construction, unmetered water connections, and inconsistent electricity metering were common, for example, and laws and regulations governing these activities were not rigorously enforced. As Puerto Rico rebuilds, clarity will be needed regarding which entities are in charge of operating and regulating sector assets, as well as how codes and standards will evolve and enforcement improved during hurricane recovery.

Informal employment negatively affected Puerto Rico's economy and tax base.

Many Puerto Ricans were employed in jobs outside of the formal economy before the storms, which had implications for tax revenue and other economic drivers. Estimates place the size of the informal economy in Puerto Rico over 20 percent of its GNP (Congressional Task Force on Economic Growth in Puerto Rico, 2016b; Enchautegui and Freeman, 2006; Estudios Tecnicos Inc, 2017a; Federal Reserve Bank of New York, 2014a). The existence of a large informal economy has a number of negative effects, chief among them the erosion of Puerto Rico's individual and corporate tax base, which has contributed to its large ratio of public debt to revenue.(Congressional Task Force on Economic Growth in Puerto Rico, 2016b)

Social service and infrastructure systems must be scaled for the current and future population.

Across sectors, social service systems, financial planning, administrative functions, and physical infrastructure have not been appropriately scaled and adjusted to sustainably meet the needs of Puerto Rico's citizens. As the Commonwealth continues to face outmigration and the remaining population ages, education, health, and social services reforms will be required. Additionally, an elderly population may be less able or willing to drive, suggesting a need to provide a wider variety of mobility options. Finally, public utilities must be reconfigured to become financially solvent despite a shrinking customer base.

Additional information is needed to help inform long-term resilience decisions.

As Puerto Rico turns from immediate recovery to "building back better," improving the assessment and understanding of hazard vulnerability under future uncertainty will be a critical next step. Additionally, there will be value in understanding the potential for cross-sector interventions to achieve broad benefits (e.g., watershed management and protection of natural resources; improvements to energy grid reliability and resilience of other critical infrastructure; and waste-to-energy solutions to landfill overcrowding and high energy prices).

17. Limitations of this assessment

Because of the widespread and entrenched pre-storm challenges to Puerto Rico's economy and population, HSOAC undertook an assessment that not only analyzed damage due to the storms, but also collected information on the pre-storm conditions that were exacerbated by (or exacerbated) the damage from the storms themselves. This analysis required the team to utilize a broader set of data for this analysis (over 100 separate data sources), including traditional damage assessment data sources like individual and public assistance requests, data directly from public agencies, and FEMA's CCA, but also sources like OpenStreetMaps, demographic and economic data from the U.S. Census Bureau, the EPA, and primary quantitative and qualitative data collected via survey, interview, and focus groups.

Limitations of this assessment

There were a number of challenges to working in Puerto Rico related to the post-disaster recovery environment, as well as data and capacity issues that preceded the 2017 hurricanes. Comprehensive damage assessment was primarily challenged by data gaps, summarized in the next section, that remain at the time of writing. As described previously, confusion over asset ownership inhibited data collection, since HSOAC often did not know which entities owned data within sectors. Often it was not feasible to collect data from all possible data stewards within a sector, so some sectors relied on data from a few providers to represent the state of the sector (e.g., the public buildings sector relied on data from PRIDCO and PBA, though many other public building owners exist).

To attempt to fill gaps in data, the team relied on subject matter experts, FEMA RSF contacts, community members, and press accounts of conditions before and after hurricanes Irma and Maria. These accounts should be interpreted with caution, though they were often the only sources of information on pre-storm challenges and barriers to recovery when systematic data had not been collected or released publicly. Additionally, the pace at which recovery activities were proceeding and the influx of recovery capacity in the island created a number barriers to systematic data collection and timely communication.

Since the analyses presented in this report rely heavily on existing data, this analysis is subject to the assumptions and limitations of the primary data sources. These including a lack of systematic data collection in many sectors (e.g., select habitat damage assessment in natural resources), data lags (e.g., economic impacts), and limitations of using IA and PA requests to estimate costs, such that estimates are based on costs to bring structures into a "habitable state" rather than a state of improved condition or resilience. Detailed assumptions are noted in the sector-specific chapters above and forthcoming sector-specific reports.

Finally, related to the limited sources of data upon which this assessment is based, the team did also not have access to detailed information on the needs of, and the assistance provided to, potentially marginalized populations in the aftermath of Hurricanes Irma and Maria, including the elderly population, women, children, disabled people, undocumented persons, and people living in informal housing. These populations are considered to be at potentially greater vulnerability than the general population due to their preexisting risk factors.

Critical information gaps

This report is based upon the best available data at the time of writing. Thus, there are a number of crucial information gaps that we hope to at least partially fill as the document evolves up until the final recovery plan for Puerto Rico is released.

- Municipalities, public buildings, natural resources, and health and human services lack comprehensive asset inventories
- Communications/IT, energy, water, and health and human services are subject to the limitations of sharing FOUO and proprietary data
- HSOAC relies on statistical estimates of the informal sector's impact on economy, housing, workforce, which has implications for damage reported by the economics, housing, and health and human services sectors
- As described above, data are still not available on ODSEC special communities and PDADs

Recommendations for future research

[Forthcoming]

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