May 2018

Infrastructure Interdependency Assessment

Puerto Rico

Homeland Security

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Infrastructure Interdependency Assessment

Puerto Rico

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EXECUTIVE SUMMARY

Hurricane Maria caused catastrophic damage to infrastructure and communities across Puerto Rico, triggering a major disaster declaration by the President to deliver individual and public assistance resources. While response operations progressed, the Federal Emergency Management Agency (FEMA) began to transition into short- and long-term recovery operations in November 2017. The governance structure for recovery efforts prescribed in the National Disaster Recovery Framework (NDRF) includes the Infrastructure Systems Recovery Support Function (IS-RSF), led by the U.S. Army Corps of Engineers, which serves as a coordinating body for infrastructure sector-specific recovery solutions. The DHS National Protection and Programs Directorate, Office of Infrastructure Protection (DHS-IP) is a primary agency of the IS-RSF, and deployed staff to Puerto Rico in November 2017 to support the IS-RSF and recovery efforts more broadly.

This report summarizes activities that DHS-IP conducted from November 2017 through May 2018 under a mission assignment that FEMA issued to perform interdependency assessments in support of long-term economic recovery. As part of this mission assignment, DHS-IP undertook two distinct but related tasks: (1) perform a focused interdependency assessment of key industrial sectors in Puerto Rico, and (2) support the IS-RSF and newly established infrastructure sector teams in identifying and prioritizing potential recovery investments.

BACKGROUND

DHS-IP has demonstrated capabilities in analyzing critical infrastructure dependencies and interdependencies at a regional level, and sought to apply its proven techniques to Hurricane Maria recovery. When approached by FEMA to support recovery operations in Puerto Rico through an infrastructure interdependency analysis, DHS-IP leveraged its experience with regional infrastructure resilience assessments as a relevant methodological framework that could shape immediate support to federal partners and commonwealth stakeholders.

The goal of this project has been to support long-term recovery planning by FEMA and the government of Puerto Rico through an infrastructure interdependency assessment that could drive the targeting, prioritization, and packaging of recovery investments, and ultimately contribute to a resilient economy and supporting infrastructure in the commonwealth. Project objectives included the following:

- Characterizing the vital networks of activity for key industries and their dependencies on lifeline infrastructure services and resources;
- Mapping and analyzing the dependencies and interdependencies between these industries and the infrastructure, as well as among the infrastructure sectors, at both the asset and system levels;
- Assessing the balance between the supply and demand of infrastructure services and resources in light of current needs and capabilities; and
- Developing products to inform long-term infrastructure recovery investments by FEMA and other partners.

SYSTEM- AND ASSET-LEVEL ANALYSES OF INFRASTRUCTURE IN PUERTO RICO

Lessons learned from previous infrastructure assessment activities informed efforts to analyze infrastructure interdependencies in Puerto Rico and apply the results to whole-of-government efforts toward long-term recovery. The framework applied in this assessment attempted to connect top-down, system-level analysis with bottom-up, asset-level analysis to develop a comprehensive "system of systems" view of infrastructure dependencies and interdependencies. For this assessment, the "system of systems" approach focuses primarily on the assessments of interconnections between prominent industries of focus (e.g., pharmaceuticals, medical devices, agricultural biotech) and lifeline infrastructure sectors of interest. The overall approach involved five phases of effort, including top-down and bottom-up analyses of critical infrastructure:

One foundational component of top-down analysis is the process of characterizing infrastructure system operations and dynamics. This process includes defining how the system functions in general; how it functions in a particular geographical and operational context; the interdependencies between that sector and other critical infrastructure systems; and the potential consequences that could result from cascading and escalating failures. Characterizations include a mix of operational information (i.e., to understand functions and capacities of system components) and geographic data (i.e., geographic information systems [GIS] information that visualizes system within a given geographic footprint). These initial system characterizations are the basic building blocks for more advanced analyses that incorporate these inputs in models and simulations. Eight critical infrastructure sectors and subsectors became focal points for system characterization in Puerto Rico:

- Electricity (Energy Sector),
- Petroleum and other fuels (Energy Sector),
- Communications,
- Water systems (Water and Wastewater Sector),
- Wastewater systems (Water and Wastewater Sector),
- Maritime transportation (Transportations Systems Sector),
- Aviation transportation (Transportation Systems Sector), and
- Road transportation (Transportation Systems Sector).

As a complement to system-level activities, DHS-IP also conducted bottom-up analysis of infrastructure dependencies to estimate the needs of both industry and infrastructure assets for specific resources. Data collection focused on capturing the characteristics and performance of specific critical manufacturing facilities and infrastructure assets through structured interviews, facilitated discussions, and standardized dependency-related question sets. A total of 57 critical manufacturing facilities were examined as part of this process. Information was captured in a web-based environment to assess and visualize dependencies and interdependencies between lifeline infrastructure sectors and a selection of economically significant regions across the island. The Puerto Rico Infrastructure Interdependency Assessment (PRIIA) toolset includes geodatabases and relational tables that organize asset information, as well as GIS-based analytical tools that use that information to visualize first- and second-order infrastructure dependencies and interdependencies.

In addition to creating a data collection and management architecture for infrastructure data, the PRIIA toolset was also used to develop four case studies that provide a series of specific examples of how the operations of lifeline infrastructure assets affect critical manufacturing industries, food distribution networks, and broader community resilience in Puerto Rico. These case studies represent a spectrum of analytical subjects that the PRIIA toolset could be used to assess and include the following:

- Geographic cluster assessment of critical manufacturing facilities in Manatí;
- Single facility assessment of impacts to nationally significant healthcare supply chains;

- Developing industry assessment of evolving regional infrastructure dependencies; and
- Critical network assessment of life-sustaining food supply and distribution.

Together, the case studies highlight several important themes related to infrastructure resilience in Puerto Rico:

- Redundancy: facilities and service areas pursue multiple connections to lifeline infrastructure to offset the potential consequences of losing service through a single connection.
- Alternatives: a lack of diversity in available options results in critical dependencies on infrastructure assets that are potential single points of failure during emergencies.
- Independence: inadequate reliability in infrastructure services and resources has led many entities to consider options that would provide local autonomy over infrastructure management.
- Coordination: communities and industries have been unsuccessful in their attempts to collaborate with utilities on proposed changes that would better meet needs.
- Confidence: reliability and costs associated with lifeline infrastructure operation have a direct effect on business confidence, which will be crucial to the economic recovery.

NEXT STEPS

In this process, DHS-IP and its National Laboratory partners leveraged more than a decade of experience conducting infrastructure assessments across the United States to implement this infrastructure interdependency methodology and develop this preliminary assessment for Puerto Rico. This material is intended to provide recovery planners with a foundational understanding of infrastructure interdependencies and how these could inform the development of unified solutions for long-term recovery planning. In the next phase of this project, DHS-IP seeks to continue its support for the IS-RSF through additional interdependency analysis that would assist the Infrastructure Sector Solutions Teams on topics such as analyzing additional geographic clusters in Puerto Rico where a density of critical manufacturers exists; evaluating critical supply chains; conducting sector-specific dependency and interdependency analyses; supporting analyses of other essential services (e.g., hospitals, first responder facilities, or government facilities); and contributing to other ongoing recovery planning efforts.

Project Overview

1 PROJECT OVERVIEW

1.1 INTRODUCTION

1.1.1 Background

Hurricane Maria, which made landfall as a Category 4 hurricane on Puerto Rico on September 20, 2017, is a federally declared disaster (DR 4339-PR). While response phase activities continued, the U.S. Federal Government began transitioning into the recovery phase in November 2017, and established the Maria Recovery Office under the leadership of the Federal Emergency Management Agency (FEMA). The stated purpose of this office includes the following:

- "The Maria Recovery Office will partner with the government of Puerto Rico, other federal agencies, the private sector, non-profits and academic institutions to *develop and implement an economically viable and sustainably resilient recovery.*
- Using financial, technical, and intellectual resources the recovery will use a sector organization to enable the whole community to work toward the *unified outcomes that better position Puerto Rico to build back stronger and more resistant.*
- The Recovery Office and the government of Puerto Rico will match the optimum funding and technical solutions to the elements of a pre-determined and agreed-upon end state that will result in a Puerto Rico with the *infrastructure and economy that will provide the foundation of a strong vibrant and resilient Puerto Rico* of the twenty-first century." [1]

The Recovery Office structure prescribed in the National Disaster Recovery Framework (NDRF) includes the Infrastructure Systems Recovery Support Function (IS-RSF), which the U.S. Army Corps of Engineers leads.[2] The DHS National Protection and Programs Directorate, Office of Infrastructure Protection (DHS-IP) is a primary agency of the IS-RSF, and deployed staff to Puerto Rico to support the IS-RSF and the recovery effort more broadly.

In November 2017, DHS-IP personnel initiated a pilot project assessing the dependencies of a cluster of manufacturing facilities (e.g., pharmaceuticals, medical devices, and agrochemicals) in Manatí, Puerto Rico, on critical infrastructure assets (e.g., electricity, fuels, communications, water, wastewater, and transportation), as well as the interdependencies among those critical infrastructure assets. DHS-IP presented this proof-of-concept effort to the Recovery Coordination Group and government of Puerto Rico representatives in December 2017. Its presentation illustrated the value of interdependency assessment in identifying infrastructure resilience gaps and potential solutions that can be addressed through federal recovery programs, contributing to the achievement of the Recovery Office's purpose.

As a result of the pilot project, FEMA amended the mission assignment for DHS-IP in December 2017 to expand its support to the IS-RSF, specifically to perform interdependency analysis of key industrial sectors across Puerto Rico.[3] In January 2018, a team of DHS-IP personnel arrived in Puerto Rico to support the IS-RSF and begin the expanded dependency analysis that FEMA requested.

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1 FEMA (Federal Emergency Management Agency), 2018, "FEMA-4339-DR-PR Integrated Operating Concept: A Sector Based Approach to Recovery Operations," January 1 (emphasis added).

2 FEMA, 2016, *National Disaster Recovery Framework*, https://www.fema.gov/national-disaster-recovery-framework,accessed May 17, 2018.

3 See Mission Assignment 4339DRPRNPPD0600 for more details.

In early January 2018, the Federal Coordinating Officer (FCO) modified the standard NDRF organizational structure and processes. The FCO established a sector-based operational concept, reorganizing the RSF structures into sectors and breaking the IS-RSF into six distinct infrastructure Sector Solution Teams.[4] These teams lead the development of sector recovery solutions (i.e., infrastructure projects) with an emphasis on resilience and *building back better*. With the establishment of separate infrastructure sector teams, the role of the IS-RSF changed to become one of facilitating cross-sector coordination, identifying cross-sector issues, developing cross-sector solutions, and advising on infrastructure resilience strategies.

This report summarizes activities that DHS-IP conducted from November 2017 through May 2018 as part of this mission assignment. During this time, DHS-IP undertook two distinct but related tasks: (1) perform a focused interdependency assessment of key industrial sectors in Puerto Rico, and (2) support the IS-RSF and newly established sector teams in identifying and prioritizing recovery investments. DHS-IP's knowledge and experience contributed considerably to the efforts of the sector teams to develop comprehensive solutions that address interdependencies and enhance resilience, and identifying and resolving cross-sector issues. DHS-IP's interdependency assessment provides specific insights into asset, regional, industrial sector, and system-level issues and potential resilience solutions that will directly inform sector solutions and plans.

1.1.2 Lessons in Resilience Assessment

DHS-IP has demonstrated experience in analyzing critical infrastructure dependencies and interdependencies at a regional level and sought to apply its proven approaches to the challenge of helping Puerto Rico recover from Hurricane Maria. In particular, since 2009, DHS-IP has led the Regional Resiliency Assessment Program (RRAP), a cooperative assessment of specific critical infrastructure within a designated geographic area and a regional analysis of the surrounding infrastructure that is regionally and nationally significant. The goal of these voluntary, non-regulatory RRAP projects is to generate greater understanding and action among public and private sector partners to improve the resilience of a region's critical infrastructure.

The RRAP evolved from earlier DHS initiatives focused on the protection of high-consequence clusters of critical infrastructure. Over time, the program transitioned to address broader and more regionally based issues. Since the program's inception, DHS has conducted assessments across the country and explored infrastructure sectors such as Energy, Water and Wastewater, Transportation Systems, Communications, Commercial Facilities, and Food and Agriculture. Although stakeholder needs and research questions vary significantly by RRAP project, DHS-IP has endeavored to implement a consistent approach to these regional analyses, as illustrated in figure 1-1.

When approached by FEMA to support recovery operations in Puerto Rico through infrastructure interdependency analysis, DHS-IP leveraged its experience with the RRAP as a relevant methodological framework that could shape immediate support to federal partners and commonwealth stakeholders. The technical approach applied in Puerto Rico and reflected in this report was inspired by the RRAP and, more broadly, also illustrates the relevance of DHS-IP's infrastructure assessment expertise to emerging needs in disaster recovery.

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4 EMA, 2018, "FEMA-4339-DR-PR Integrated Operating Concept: A Sector Based Approach to Recovery Operations," January 1.

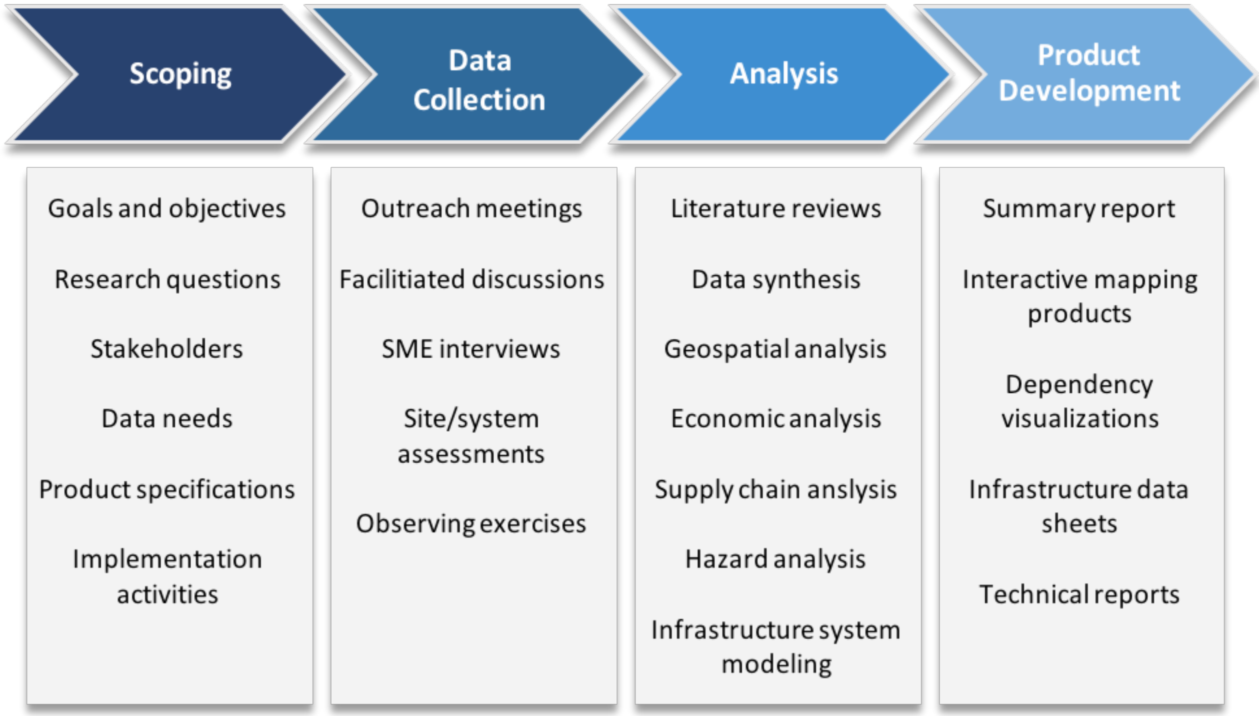

Figure 1-1: Overview of the RRAP Approach

1.1.3 Goal and Objectives

The goal of this project is to support the long-term recovery planning of FEMA and the government of Puerto Rico to achieve a more resilient infrastructure and economy by conducting an infrastructure interdependency assessment that informs the targeting, prioritization, and packaging of recovery investments related to critical infrastructure.

The objectives for this project include the following:

- Characterizing the vital hubs and chains of activity for key industrial sectors and their dependencies on lifeline infrastructure, which includes electricity, fuels, communications, water, wastewater, maritime transportation, air transportation, and road transportation.
- Mapping and analyzing the dependencies and interdependencies between these users and the infrastructure, as well as among the infrastructure sectors, and identifying vulnerabilities, stressors, opportunities for resilience enhancement, and potential future infrastructure development approaches to help meet Puerto Rico's goal of economic advancement and resilience.
- Assessing the balance between the supply and demand of infrastructure services and resources in light of current needs and capabilities.
- Developing products for FEMA partners to use to inform long-term infrastructure investments, including narrative reports and dynamic analytical capabilities.

1.1.4 Partnerships

Six Sector Solution Teams are related to infrastructure, as listed below. Each team is led by a senior FEMA employee from the FCO cadre, and team membership comprises representatives from sector-specific federal agencies (RSFs, emergency support functions, and other federal agencies); commonwealth agencies; relevant non-governmental organization, academia, industry experts and organizations; the private sector; and embedded or assigned personnel from other FEMA programs (e.g., public assistance and hazard mitigation). Conceptually, these are staffed as collaborative planning teams. Each team is tasked with envisioning the "agreed-upon end state that will result in a Puerto Rico with the infrastructure and economy that will provide the foundation of a strong vibrant and resilient Puerto Rico," as well as developing and implementing the "unified solutions" needed to reach this end state.[5]

The six Sector Solution Teams were particularly important to DHS-IP's interdependency assessment effort; the following bullets briefly outline the roles and needs of each team.

- **Energy Sector Solution Team.** This team provided access to electric grid and fuel geolocation and other data; information on sector challenges pre-, during, and post-Maria; and access to various energy studies, reports, and assessments. They also maintained awareness of ongoing developments within the sector that may influence resilience strategies (e.g., changes to Puerto Rico regulations on microgrids, privatization of Puerto Rico Electric Power Authority [PREPA]).
- **Communications/Information Technology Sector Solution Team.** This team provided access to communications infrastructure asset and system locations and other data; information on sector challenges pre-, during, and post-Maria; and access to various communications studies, reports, and assessments. They also maintained awareness of ongoing developments within the sector that may influence resilience strategies.
- **Transportation Sector Solution Team.** This team provided access to transportation infrastructure asset and system locations and other data; information on sector challenges pre-, during, and post-Maria; and access to various transportation studies, reports, and assessments. They also maintained awareness of ongoing developments within the sector that may influence resilience strategies.
- **Water Sector Solution Team.** This team, which also encompasses wastewater, provided access to water and wastewater infrastructure asset and system locations and other data; information on sector challenges pre-, during, and post-Maria; and access to various water and wastewater studies, reports, and assessments. They also maintained awareness of ongoing developments within the sector that may influence resilience strategies.
- **Municipalities Sector Solution Team.** Although not one of the key industrial sectors or dependent lifeline infrastructure systems focused on in this study, information on unique requirements of the significant population centers across Puerto Rico allowed analysts to target the geographic clusters of industrial activities and the communities in which these are situated.
- **Public Buildings Sector Solution Team.** Similar to the Municipalities Sector Solution Team, information on the locations of public buildings and other data from this team allowed analysts to examine improvements to lifeline infrastructure serving a geographic area in the context of public buildings, as well as key industrial sector assets and other relevant regional information.

DHS-IP's aim is to provide these Sector Solution Teams with an improved understanding of sector interdependencies and potential resilience solutions. The desired outcome is that individual sector plans identify and address the need for investments in the resilience of other sectors on which they depend to ensure that relevant interdependencies are reflected in every sector plan. The following bullets describe the roles of other partners in the interdependency assessment efforts.

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[5] Ibid.

- **IS-RSF Lead.** The IS-RSF Lead works in support of the deputy administrator for the infrastructure sectors to coordinate the development of sector and cross-sector solutions to further recovery efforts. The Lead functions as a member of the cross-sector creative solutions team, which relies on DHS-IP expertise in infrastructure resilience and interdependencies for various tasks and uses the DHS-IP interdependency assessment to identify sector and cross-sector concerns for IS-RSF action. The Lead facilitated access to sector teams for the DHS-IP interdependency assessment team to enable sharing of interdependency and resilience insights with sector teams.
- **Economic Sector Solution Team.** This sector team is working to analyze various economic factors in order to identify and invest in long-term economic growth industries on Puerto Rico. Such growth industries may require new infrastructure investment to support them. The DHS-IP interdependency assessment team worked closely with this team to understand the vision for Puerto Rico's resilient economy in order to assist in identifying infrastructure requirements, and resilience considerations for its design.
- **FEMA Geographical Information Systems (GIS) Teams.** The FEMA GIS Unit and the Geospatial Data and Analysis Cell (GDAC) are responsible for collecting, maintaining, creating, and sharing geospatial data and products to support the Joint Field Office (JFO) and recovery mission. These teams have extensive repositories of geospatial data collected before and since the federal response to Hurricane Maria. These data have been an essential component of the DHS-IP interdependency assessment activities to date. The FEMA GIS unit and GDAC are central partners in providing geospatial data to support the assessment.
- **Homeland Security Operational Analysis Center.** Operated by the RAND Corporation, the Homeland Security Operational Analysis Center (HSOAC) is working with FEMA to develop the long-term recovery plan for Puerto Rico. As part of this planning effort, the HSOAC team is responsible for assembling a comprehensive understanding of critical infrastructure across the commonwealth. Discussions between DHS-IP and the HSOAC team identified opportunities for further collaboration to support analyses and deliverables for both organizations, including assisting the HSOAC team in crafting and validating potential courses of action that will accompany the FEMA long-term recovery plan.
- **Puerto Rico Central Office of Recovery, Reconstruction, and Resilience (COR3)**. The Puerto Rico Public-Private Partnerships Authority promotes an ongoing collaboration between the public and private sectors in support of economic development. The authority established the COR3 and directed it to serve as the primary government of Puerto Rico representative to FEMA and the lead agency for hurricane recovery and restoration. COR3 personnel have been assigned to support/participate as part of each Sector Solution Team.

Additional Analysis of Puerto Rico's Economy and Infrastructure

Before and during the course of this project, other public and private sector partners conducted additional analysis of Puerto Rico's economy, infrastructure systems, and the extensive impacts that Hurricane Maria had on them. These reports and the partners who developed them were important foundational inputs into DHS-IP's assessment efforts and continue to inform the recovery planning process. Examples include:

- Puerto Rico Department of Transportation and Public Works, *Puerto Rico 2040 Islandwide Long Range Transportation Plan* (2013)
- Puerto Rico Broadband Taskforce, *Gigabit Island Plan* (2015)
- Puerto Rico Energy Resiliency Working Group, *Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico* (2017)
- Financial Oversight and Management Board for Puerto Rico, *New Fiscal Plan for Puerto Rico: Restoring Growth and Prosperity* (2018)

1.2 METHODOLOGY

1.2.1 Theory and Concepts of Infrastructure Interdependency Analysis

This framework prioritizes a need to couple top-down and bottom-up analyses to produce a comprehensive "system of systems" view of dependencies and interdependencies that integrates the best available data. Lessons learned from previous infrastructure assessment activities—including the RRAP—informed the development of these concepts and their application to whole-of-government efforts to support long-term recovery in Puerto Rico.

1.2.1.1 Defining Key Terms

A dependency is a unidirectional relationship between two assets where the operations of one asset affect the operations of the other. For example, a water treatment plant depends on communications services that support the supervisory control and data acquisition (SCADA) systems required to control plant operations.

An interdependency is a bidirectional relationship between two assets where the operations of both assets affect each other. For example, the water treatment plant requires communications for its SCADA system, and, in turn, provides water that the communications system uses to cool its equipment. An interdependency is effectively a combination of two dependencies—therefore, understanding an interdependency requires analysis of the one-way dependencies that comprise it.

Figure 1-2 illustrates the definitions of dependency and interdependency.[6]

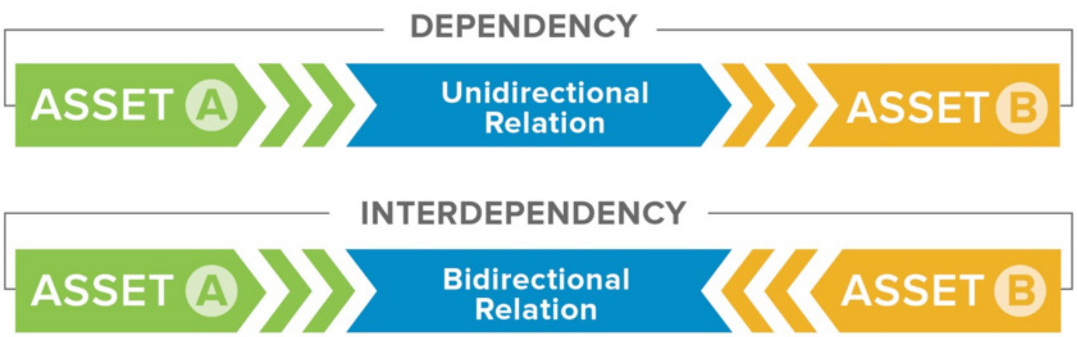

Figure 1-2: Dependency and Interdependency between Two Assets

Table 1-1 outlines four distinct classes of infrastructure dependencies and interdependencies that are helpful in scoping, executing, documenting, and communicating analysis: physical, cyber, geographic, and logical dependencies.[7]

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6 Petit, Frederic, Duane Verner, and Leslie-Anne Levy, 2017, *Regional Resiliency Assessment Program Dependency Analysis Framework*, Argonne National Laboratory, Global Security Sciences Division, ANL/GSS-17/05, Argonne, Ill., USA.

7 Rinaldi, Steven M., James P. Peerenboom, and Terrence K. Kelly, 2001, "Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies," *IEEE Control Systems Magazine*, December, https://pdfs.semanticscholar.org/b1b7/d1e0bb39badc3592373427840a4039d9717d.pdf, accessed May 17, 2018.

Table 1-1: Dependency and Interdependency Classes

Class	Description
Physical	Operations depend on material output(s) of other infrastructure through a functional and structural linkage between the inputs and outputs of two assets. A commodity produced by one infrastructure is needed as an input by another infrastructure for its operation.
Cyber	Operations depend on information and data transmitted through the information infrastructure via electronic or informational links. Outputs from the information infrastructure serve as inputs to other infrastructure; the relevant commodity is information.
Geographic	Operations depend on the local environment, where an event can trigger changes in the state of operations in multiple infrastructure assets or systems. A geographic dependency occurs when infrastructure assets are in close spatial proximity (e.g., a joint utility right-of-way).
Logical	Operations depend on the state of other infrastructure via connections other than physical, cyber, or geographical. Logical dependency is attributable to human decisions and actions and is not the result of physical or cyber processes.

The required data inputs, relevant qualitative and quantitative analytical techniques, and resulting products from dependency and interdependency analyses differ across these four classes. Other dimensions of dependencies and interdependencies that influence the scope and complexity of analysis include the following:

- Operating environment for critical infrastructure, including broader business, policy, legal, security, safety, and political considerations;
- Coupling and response behavior(s) for critical infrastructure following a disruption;
- Type(s) of failure affecting critical infrastructure;
- Infrastructure characteristics that influence the effects of a disruption; and
- State of operations for critical infrastructure (e.g., normal day-to-day operations, degraded operations).

Figure 1-3 provides a matrix of the common physical relationships among critical infrastructure systems. This matrix, which aggregates inputs from subject matter experts and data from the DHS sector-specific plans, is a starting point to illustrate physical interdependencies that an incident may exacerbate.

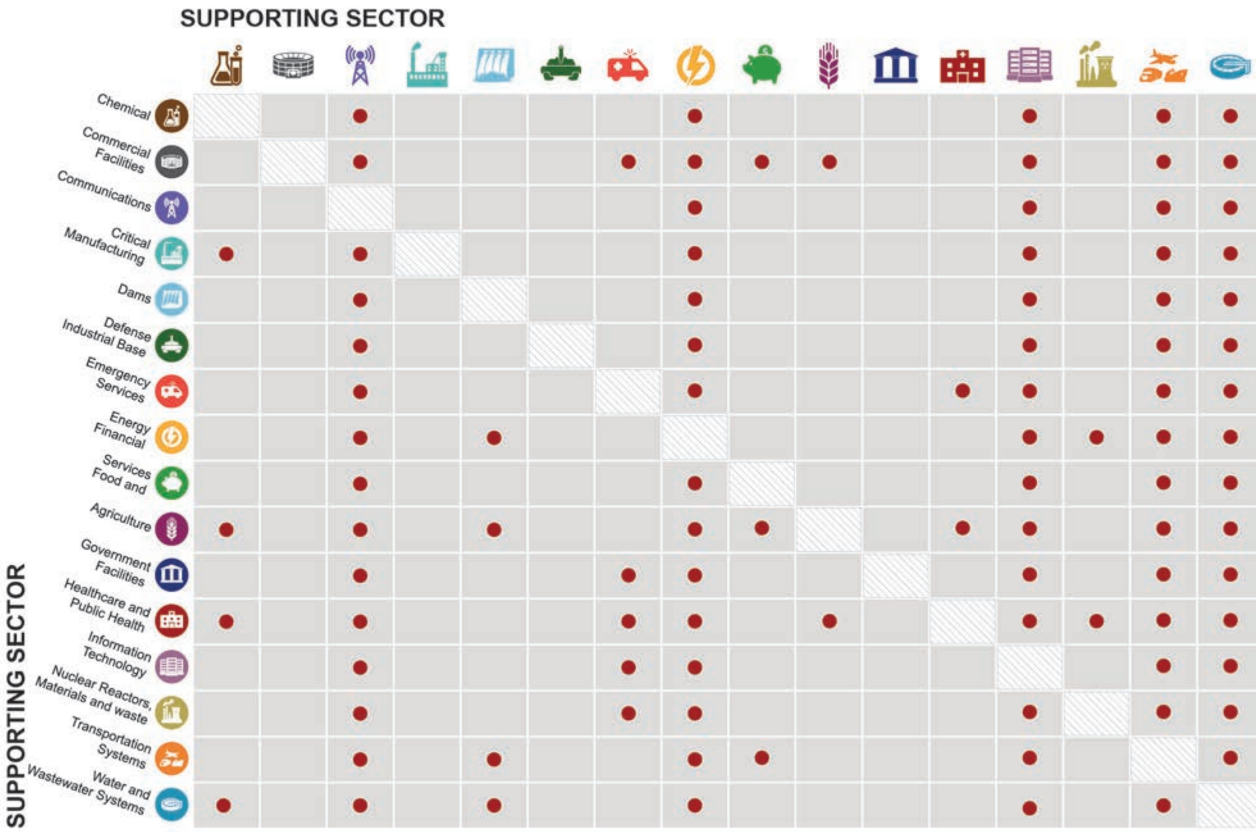

Figure 1-3: Critical Infrastructure Dependency Matrix[8]

In each *column*, red dots indicate the sectors of interest to which the supporting sector supplies goods or services. In each *row*, red dots indicate the supporting sectors that supply goods or services to the sector of interest.[9] As shown in the sector dependency matrix, five sectors provide resources or goods to all other critical infrastructure sectors; their corresponding columns show a red dot for all critical infrastructure sectors. These critical infrastructure sectors, which mostly encompass utility sectors, are often defined as “lifeline” sectors: communications, energy, information technology (IT), transportation systems, and water and wastewater systems.

1.2.1.2 Systems Approach to Infrastructure Interdependency Analysis

Infrastructure dependency and interdependency analysis can be analytically complicated, time-consuming, and costly, which, in turn, can limit stakeholders’ ability to understand and use this information to make risk-informed decisions that enhance resilience. To manage these complexities, DHS applies a process that helps partners prioritize resilience assessment efforts by adopting a “system of systems” approach to regional dependency and interdependency analysis.

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8 Clifford, Megan, and Charles Macal, 2016, *Advancing Infrastructure Dependency and Interdependency Modeling*, A Summary Report from the Technical Exchange, August.

9 At the sector level, dependencies within a sector—such as electric power’s dependence on natural gas—cannot be meaningfully displayed. Thus, those cells in the table are crossed out.

This approach is based on the assumption that a critical asset or facility can be considered as part of a broader system of infrastructure. Higher-level constructs (e.g., a community or a region) include multiple systems. As such, a community or a region operates as a "system of systems." Viewed within this framework, high-level systems analysis—using proven and scientifically sound tools—can help identify the most critical lower-level systems. This information, in turn, can help determine where to conduct more detailed site assessments, focusing only on the most critical asset-level components.[10]

A "system of systems" approach can help establish the appropriate scope of a dependency analysis, as well as the specific assets and/or subsystems for which resilience-related information should be collected.[11] Using this approach, analysis would consider the high-level context (e.g., a geographic region or an industry sector) and the associated states of these systems, ultimately represented by the most critical assets that will inform the scope and focus of a resilience assessment, including the most critical assets from which to collect dependency data.

Executing this "system of systems" approach to fully consider regional infrastructure dependencies and interdependencies requires the application of system science methodologies and a combination of top-down and bottom-up data collection and analysis methods (figure 1-4).[12]

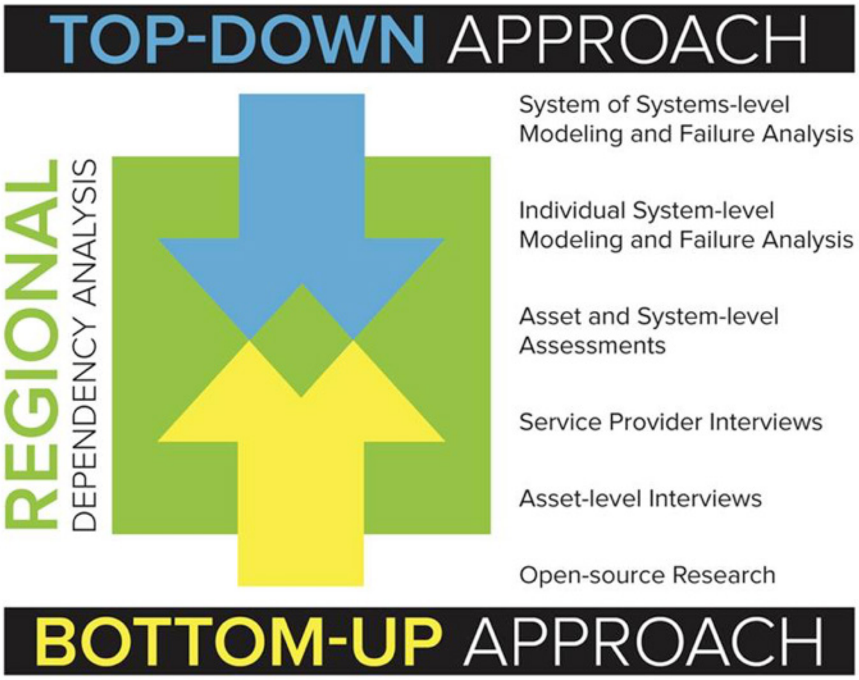

Figure 1-4: Top-down and Bottom-up Approaches to Regional Dependency Analysis

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10 Carlson, Lon, Gib Basset, William Buehring, Michael Collins, Steve Folga, Rebecca Haffenden, Frederic Petit, Julia Phillips, Duane Verner, and Ronald Whitfield, 2012, *Resilience Theory and Applications*, Argonne National Laboratory, Decision and Information Sciences Division, ANL/DIS-12-1, Argonne, Ill., USA, http://www.ipd.anl.gov/anlpubs/2012/02/72218.pdf, accessed May 17, 2018.

11 Ibid.

12 Petit, Frederic, Duane Verner, and Leslie-Anne Levy, 2017, *Regional Resiliency Assessment Program Dependency Analysis Framework*, Argonne National Laboratory, Global Security Sciences Division, ANL/GSS-17/05, Argonne, Ill., USA.

Dependencies and interdependencies exist at individual levels (e.g., assets are interconnected with other assets) and between levels (e.g., assets are interconnected with systems, systems with other systems, and so on). Table 1-2 presents attributes of bottom-up and top-down approaches to critical infrastructure dependencies and interdependencies assessments.[13]

Table 1-2: Comparison of Bottom-up and Top-down Approaches

Bottom-Up Approach	Top-Down Approach
Decentralized	Centralized
Targets data collection at asset level	Targets data collection at system level
Based on actual operations and conditions	Often based on models and large datasets
Identifies facility-level interdependencies	Identifies system-level interdependencies
Moves from the specific to the global	Moves from the global to the specific

1.2.1.3 Scoping Data, Analysis, and Products

Assessing infrastructure dependencies and interdependencies to improve regional resilience requires a scalable approach that can be tailored based on decision support needs, stakeholder requirements, and relevant critical infrastructure. Performing dependency and interdependency analyses is not a one-size-fits-all activity. Stakeholder goals, available data, time, budget, and analytical sophistication all combine to influence the scope and complexity of potential dependency analysis. Thus, the core concept of the framework outlined here is to establish a flexible approach that covers a broad spectrum of options, starting with relatively simple and tightly scoped efforts and culminating in more complex, integrated evaluations.

Data collection and analyses are expanding from traditional evaluations of physical dependencies to include cyber and geographic dependencies, as well as visualizations of first-order cascading failures. However, many existing tools and models operate in silos. Over time, more advanced infrastructure interdependency analysis can consider all dimensions of critical infrastructure dependencies and interdependencies, including operating environment, coupling and response behaviors, types of failure, infrastructure characteristics, and state of operations.[14] These advanced approaches require new data-collection mechanisms and the integration of independent, but complementary, tools and models. The more advanced analysis enables stakeholders in public and private sectors to move from traditional analysis—centered on individual facilities—to broader systems-level evaluations of infrastructure dependencies and interdependencies and identification of key failure points, as illustrated in table 1-3.

[13] Ibid.

[14] Petit, Frederic, Duane Verner, David Brannegan, William Buehring, David Dickinson, Karen Guziel, Rebecca Haffenden, Julia Phillips, and James Peerenboom, 2015, *Analysis of Critical Infrastructure Dependencies and Interdependencies*, Argonne National Laboratory, Global Security Sciences Division, ANL/GSS-15/4, Argonne, Ill., USA, https://www.osti.gov/scitech/biblio/1184636-analysis-critical-infrastructure-dependencies-interdependencies, accessed May 17, 2018.

Table 1-3: Characteristics of Advanced Dependency and Interdependency Analysis

Data	Analysis	Products
Considers all classes of dependencies (e.g., added detail on physical and cyber dependencies, with initial efforts to integrate/analyze logical dependencies) Captures new characteristics of dependency dimensions (e.g., operating environment, type of failures) Includes multiple data sources (e.g., open-source information, proprietary and protected databases, surveys, and facilitated discussions with stakeholders), with flexibility to ingest new data collection mechanisms as they emerge	Uses top-down, system-level models and bottom-up approaches (e.g., interviews, facility assessments) Initiates integration of system-level and facility-level models and assessments Addresses conditions during normal steady-state conditions and degraded operations Refines analysis of cascading failures and initiates analysis of escalating failures	Provides a refined visualization of system-level dependency links and degradation propagation Reflects an understanding of first-order cascading failures with some notion of system-level temporal aspects Reflects use of operational tools for characterizing interaction between infrastructure and its environment Provides a refined cascading and escalating visualization, including first-, second-, and third-order cascading failures Incorporates temporal and spatial visualization

1.2.2 Applying the Methodology in Puerto Rico

For this Puerto Rico assessment, the “system of systems” approach focuses primarily on the assessments of interconnections between the industries of focus (i.e., pharmaceuticals, medical devices, agricultural biotech) and lifeline sector systems of interest (i.e., energy, communications, water, wastewater, and transportation). The objective of this assessment process was to characterize the vulnerability and resilience of major industries and lifeline sectors and to better understand how existing dependencies and interdependencies could generate cascading or escalating failures across the island.

This section outlines the general approach applied in the Puerto Rico analysis to understand infrastructure interdependencies in order to inform long-term recovery. Figure 1-5 illustrates the five phases of the approach listed below, which were applied to varying degrees in Puerto Rico:

1. Identification of stakeholder needs;
2. Identification of major assets constituting industries of focus and systems of concern;
3. Data collection;
4. Infrastructure analysis; and
5. Development of tools and final products.

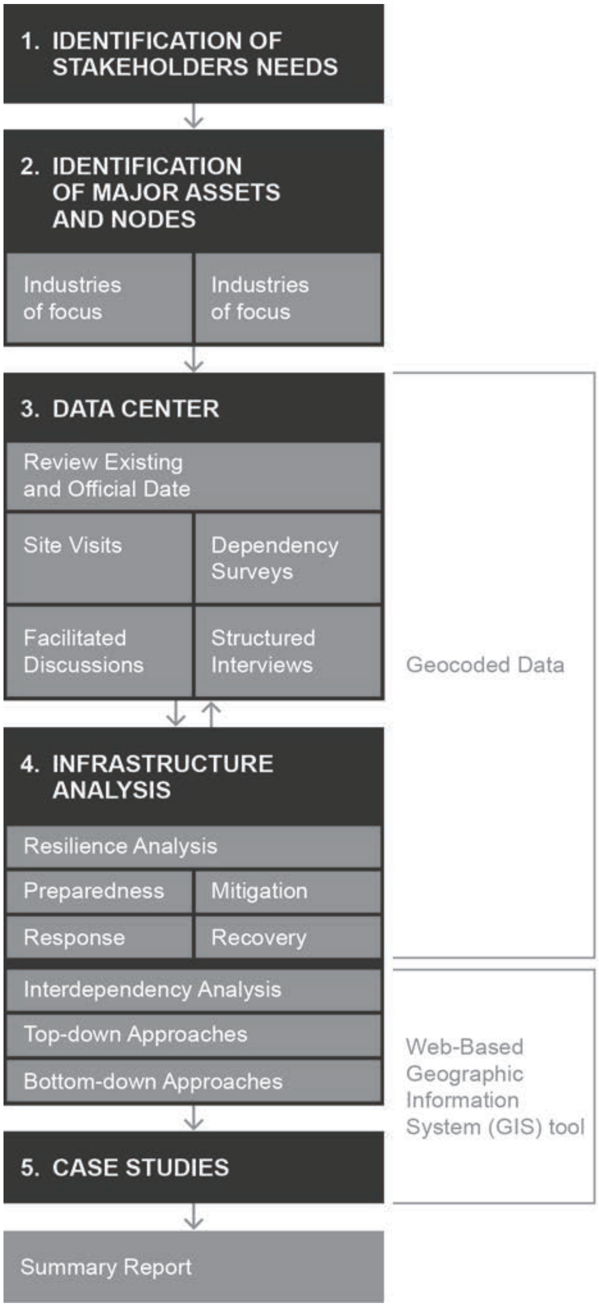

Figure 1-5: Infrastructure Interdependency Assessment Methodology

1.2.2.1 Phase 1: Identification of Stakeholder Needs

Defining the primary stakeholders in Puerto Rico (including federal partners supporting recovery operations, the government of Puerto Rico, and key private sector partners), their requirements, and the information they need to make decisions was a first step in conducting infrastructure interdependency analysis to support long-term recovery. A solid understanding of the information needs of decision makers and the business processes in which these decisions occur was essential to scoping the critical infrastructure systems for assessment and the required level of analysis, particularly because interdependency assessments of critical infrastructure can be tailored to different levels (i.e., asset, system, network, or functions).

This phase involved an initial review of existing documentation (e.g., previous assessments and characterizations of the island's infrastructure, existing plans, GIS data, and other available information) to refine the project scope and identify a preliminary list of industries of focus and systems of concern. This phase also involved coordination with the emerging governance structures in place to oversee federal support to long-term recovery in Puerto Rico. These engagements included integration with response and recovery personnel in the JFO in San Juan; coordination with the IS-RSF; and research into the public assistance process and related investments opportunities for infrastructure systems on the island.

1.2.2.2 Phase 2: Identification of Major Assets in the Industries of Focus and Infrastructure Systems of Concern

The next phase centered on identifying and prioritizing economically significant regions throughout Puerto Rico and defining the most critical assets (including those in industries of focus, as well as nodes and links in lifeline infrastructure systems) that would have detrimental economic or social impacts in Puerto Rico if disrupted. As outlined in Section 1.3 on industries of focus, initial emphasis included pharmaceutical manufacturing, medical device manufacturing, and agricultural biotechnology, which are important drivers of Puerto Rico's economy and which experienced notable impacts following Hurricane Maria. During this phase, the assessment team analyzed, revised, and prioritized the preliminary lists of industry assets and utility nodes, based on input from private and public sectors, as well as critical infrastructure owners and operators. The team employed economic analysis to evaluate the economic significance of industries and geographic clustering of facilities. Input-output economic models using municipio-level data delivered insight into priority industries and geographic areas that helped focus data-collection and analysis activities.

1.2.2.3 Phase 3: Data Collection

This third phase involved gathering qualitative and quantitative data to characterize the industries of focus and lifeline infrastructure systems identified during Phase 2. For this infrastructure interdependency assessment, the research team used a hybrid approach, including the following:

- Review of existing data that had been collected, compiled, and/or analyzed (e.g., databases, GIS layers, reports, best practices).
- Visits to selected critical manufacturing facilities and infrastructure assets. Each visit lasted approximately 1–3 hours. During this time, analysts met with infrastructure operators to learn about the facility's operations; potential impacts from disruptions to supporting lifeline infrastructure; and existing security and emergency procedures. The meetings often included a physical tour of the facility for a general understanding of facility operations and to observe the protective and resilience measures in place, as well as the utility connections.
- Dependency surveys to collect standardized information across facilities to assess the impacts of a disruption or loss of utility services on an asset's operations and an industry's essential functions.

- Meetings and facilitated discussions with subject matter experts (including federal partners in the JFO) and Puerto Rico stakeholders to understand perspectives on industry and utility operations. These discussions uncovered operational characteristics of relevant industries and utilities and their role in potential cascading and escalating failures.
- Structured interviews with industry and utility operators. These interviews occurred face to face and remotely to amplify data gathered through other avenues.

A key element of the data-collection phase was the development of a data architecture and data dictionary to achieve the following objectives:

- Understand the completeness of available data;
- Facilitate a common understanding of infrastructure dependency and interdependency characteristics;
- Support system-level modeling and analysis; and
- Identify opportunities for future engagement with public and private sector partners involved in interdependency analysis in support of infrastructure recovery in Puerto Rico.

1.2.2.4 Phase 4: Infrastructure Analysis

This phase was the core of the assessment approach, during which subject matter experts analyzed the data collected for two categories of infrastructure:

- **Infrastructure critical to economic stability and community resilience:** In Puerto Rico, these industries include pharmaceutical production, medical devices, agrochemical, agricultural biotechnologies, electronics, aerospace, business services, and food distribution.
- **Lifeline infrastructure providing essential resources and services to key industries.** The assessment specifically addresses energy, communications, water and wastewater systems, and transportation systems.

Interdependency Analysis

The interdependency analysis process involved top-down and bottom-up approaches to characterize infrastructure connectivity within and across sectors. Top-down dependencies analysis involves empirical-based, network-based, and system dynamic-based approaches to estimate the service capabilities of infrastructure systems (table 1-4). Empirical approaches are grounded in real-world observation of failure patterns. The network-based approach hinges on identifying critical utility nodes and their functions and then identifying potential resilience enhancements. This approach captures key characteristics (e.g., flows, operational mechanisms) of lifeline infrastructure sectors. The system dynamics-based approach complements the network-based approach by modeling the effect that the operating environment has on lifeline infrastructure system functions. It helps capture the effects of policy and technical factors that drive infrastructure system evolution.

Table 1-4: Components of Top-down Analysis

Component	Definition
Empirical-Based	Analyze interdependencies based on observation and experience by using historical data in combination with expert judgment.
Network-Based	Analyze infrastructure systems as networks where infrastructure assets are represented as nodes and the physical connections are represented as arcs. The two main network-based approaches are topology-based methods and flow-based methods.
System Dynamics-Based	Analyze the behavior of complex systems by modeling a system's dynamic and evolutionary behavior through stock and flow exchanges and causal loops.

Bottom-up analysis of infrastructure dependencies focuses on understanding the needs of industry and utility assets for specific infrastructure resources (i.e., electricity, fuels, water, wastewater, communications, critical supplies). The focus is on impacts of a disruption to these resources and services at a specific facility. Data collection focused on framing the variation in facility performance over time in light of these disruptions, including timelines, extent, and duration of the loss of services; measures in place (i.e., procedures, backup) to mitigate loss; and the extent of overall degradation on a facility's operations. Analysts collected this information at a subset of facilities in Puerto Rico based on time and accessibility; created a standardized structure through which to collect the information at other facilities in the future; and integrated this information into a broader data architecture to support analysis and visualization.

Top-down and bottom-up dependency analyses can be combined to define a high-level abstraction of infrastructure interdependencies that allows analysts to anticipate potential cascading and escalating failures within and across sectors. Each utility and industry system is visualized as a layer based on top-down dependency analysis. The asset-specific connections between layers are characterized through bottom-up dependency analysis (figure 1-6).

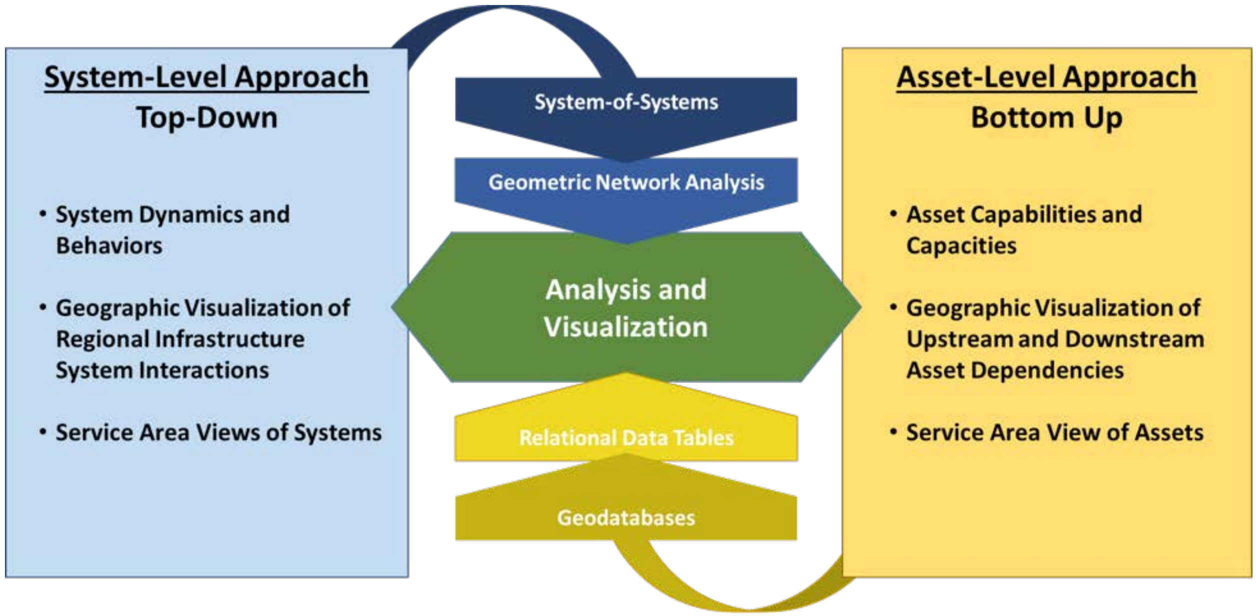

Figure 1-6: System of Systems Interdependency Abstraction Visual

For example, top-down dependency analyses of the electric grid shows how the disruption of given nodes or links (e.g., generator, line, or substation) or several nodes and links (e.g., n-2 contingency studies) would propagate across the electric grid and generate outage areas. Bottom-up analysis characterizes how operations at facilities within the power outage areas would be impacted. This use of "system of systems" interdependency analysis sheds light on downstream cascading and escalating failures. However, the approach also informs upstream analysis about how utility systems supply critical resources to a specific area of interest.

Case Studies

The assessment team conducted in-depth analyses of interdependencies with lifeline infrastructure systems across four industries of focus in Puerto Rico to assist in long-term recovery planning. These case studies provide tangible examples of how resilience and interdependencies analysis can inform the targeting and prioritization of recovery investments in critical infrastructure in Puerto Rico.

1.2.2.5 Phase 5: Development of Tools and Final Products

This assessment produced three main deliverables:

- **Summary report.** The report summarizes the analyses conducted, outlines the industries of focus in Puerto Rico, describes the lifeline infrastructure systems of concern and their system-level interactions, presents example case studies, and introduces potential next steps. The report is designed to capture the analyses performed to date.
- **Geocoded database.** Data problems are often intermingled with the challenges of meeting decision-maker needs for information. The data dictionary includes descriptions of data attributes, field names, descriptions of data elements and meta-data, and links these data fields to specific databases at a detailed level, providing a consolidated view of data availability for manufacturing facilities and infrastructure. Potential next steps could include identifying gaps in the data and developing a prioritized list of what data are still needed to advance dependency and interdependency models after identifying what data are currently available.
- **Prototype capability for web-based GIS analysis.** A beta version of a GIS capability will support future assessment and visualization of dependencies and interdependencies among lifeline infrastructure sectors and a selection of economically significant regions throughout the commonwealth of Puerto Rico.

1.3 UNDERSTANDING INDUSTRIES OF FOCUS

This analysis of the interdependencies of critical infrastructure in Puerto Rico centers on a subset of key industries that are major contributors to the commonwealth's economy in terms of jobs, wages, and direct and indirect economic output. This project initially focused on pharmaceuticals and medical devices in light of priorities that emerged during the initial response phase following Hurricane Maria. The industry scope broadened as the economic profile of Puerto Rico and the underlying infrastructure requirements came into clearer focus through site visits and stakeholder engagement on the island. More in-depth analysis of Puerto Rico's economy confirmed initial anecdotal observations about the criticality of these industries and provided a lens through which to prioritize current and future interdependency analysis of regional clusters of industry on the island.

1.3.1 Key Industries to the Economy of Puerto Rico

Direct economic output includes jobs and wages that are directly attributable to a specific industry. Figure 1-5 shows that over 42 percent of the direct economic output of Puerto Rico in 2016 was driven by the pharmaceuticals, medical devices, and agriculture and food industries.[15] The largest share of that economic output comes from pharmaceuticals actives at $50 billion annually or approximately one-third of Puerto Rico's total direct economic output. Medical devices ($9.2 billion) and food and agriculture ($7.7 billion) together represented an additional 11 percent of the total.

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15 Economic analysis of Puerto Rico at a commonwealth level was conducted using the Impact analysis for PLANning (IMPLAN) data and model. This input-output model was originally developed in the mid-1970s by the U.S. Department of Agriculture for community impact analysis and is now used broadly across government, the private sector, and academia for economic analysis. The Puerto Rico IMPLAN model differs from that for U.S. states in that trade flows into and out of Puerto Rico are modeled and not driven by primary data, which introduces some uncertainty. Building the IMPLAN model for the territory provides the employment, direct output, employee compensation, and other economic data elements for each of IMPLAN's 536 industry sectors. In addition, Census of Employment and Wages data support analysis at the municipio level, including the number of workers, facilities, and wages paid, using North American Industry Classification System (NAICS) codes. For purposes of this analysis, "Sectors" refers to one of the 536 IMPLAN sectors that are used for some of the further analysis that follows. Municipio-level data are driven by employment and wages data, also obtained from IMPLAN using NAICS codes.

Other notable industries include electronics (including semiconductors), business services/information technology, agrochemical production, biotechnology research/seed production, and aerospace, which account for $4.4 billion of direct output. Also of interest is wholesale trade ($4.8 billion), which is associated with moving goods out of Puerto Rico. The portion of wholesale trade in Puerto Rico that is attributable to pharmaceuticals/actives, medical devices, and food and agriculture is $2.5 billion.

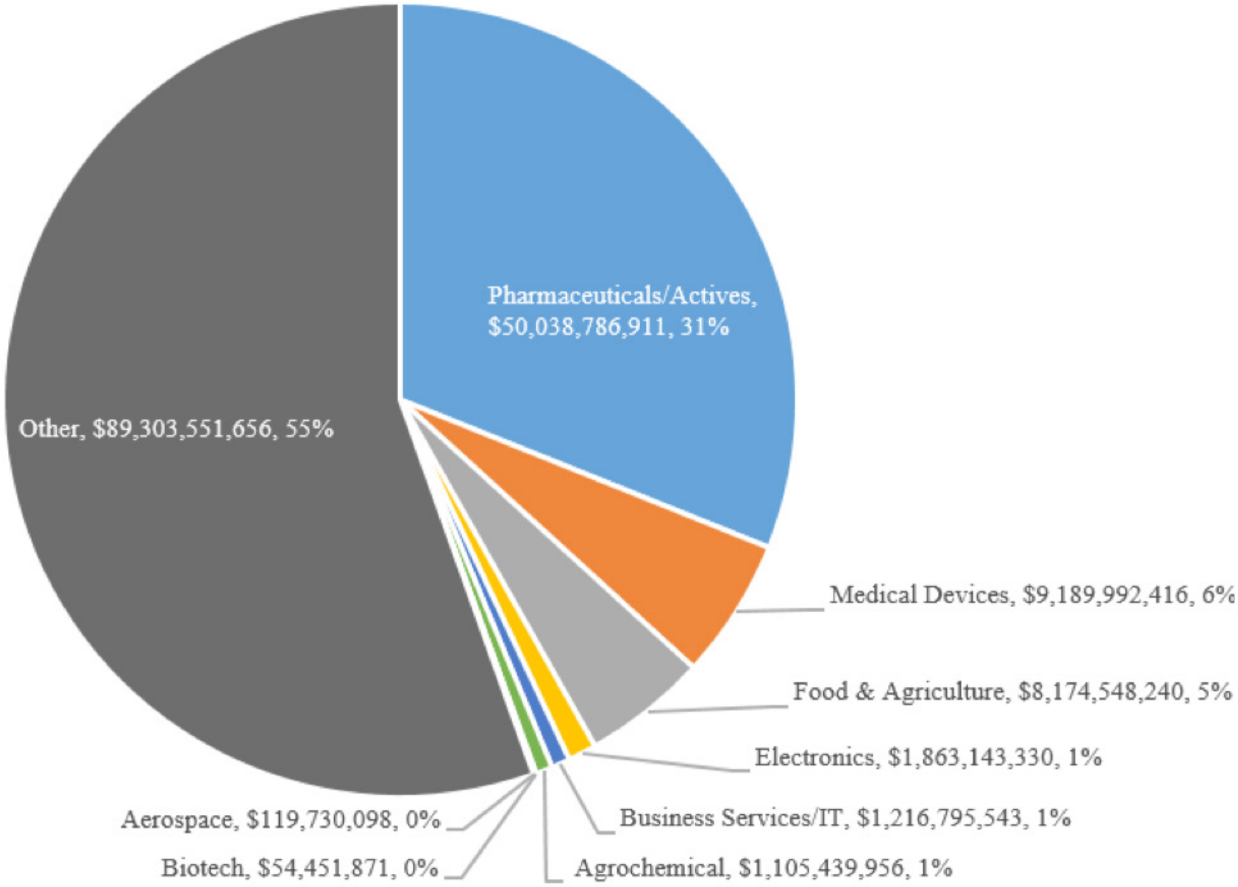

Figure 1-5: Direct economic output of selected industries in Puerto Rico (2016)

Table 1-5 shows both direct and total economic output specifically for medical products in Puerto Rico. Notably, in addition to nearly $60 billion in direct output associated with medical products manufacturing, another $16 billion is generated through in indirect and induced economic activity. Indirect economic activity includes business activities that occur in other industries as a result of the direct output (e.g., wholesale trade, suppliers); induced economic activity reflects household spending of income that is distributed across other local industries.

Table 1-5: Direct and Total Economic Output for Medical Products in Puerto Rico

Manufacturing Sector Description	Direct Output ($)	Total Output ($)
Medicinal and Botanical	1,198,646,973	1,628,146,479
Pharmaceutical Preparation	48,406,742,188	60,757,002,568
In-vitro Diagnostic Substance	213,534,470	270,862,588
Biological Product	219,863,281	272,214,147
Electromedical/Electrotherapeutic Apparatus	2,157,038,818	2,790,170,342
Surgical and Medical Instrument	2,285,594,238	3,246,852,127
Surgical Appliance and Supplies	3,700,115,967	5,093,296,621
Dental Equipment and Supplies	181,567,612	231,218,144
Ophthalmic Goods Manufacturing	865,675,781	1,231,842,200
Totals	**59,228,779,327**	**75,521,605,217**

1.3.2 Importance of Industries of Focus to Puerto Rico and the United States

Puerto Rico's economy depends heavily on the pharmaceuticals industry specifically and medical products in general; no U.S. state depends as much on a specific market segment. When the additional industries of focus are considered, they account for nearly all of the significant products shipped out of Puerto Rico. All industries in the commonwealth are important to the economic and social well-being of the public, but these industries of focus represent the prime sources of external revenue for the commonwealth. In general, these industries also generate a disproportionate amount of revenue and income that may, in turn, accelerate economic recovery.

The Puerto Rico medical products industry is economically important to the United States and also significant from a public health perspective. In pharmaceutical manufacturing, Puerto Rico trails only California in direct output domestically, and it exports nearly double the quantity of the largest foreign country, Ireland. Of the more than 1,000 drug products registered for manufacture in Puerto Rico, the U.S. Food and Drug Administration considers several hundred to be medically important. That list narrows to 30 drugs and 10 devices and biologics for which Puerto Rico is either the leading or sole manufacturing site.

Given the combination of specialized facilities and trained workforce, medical products companies have incentive to maintain operations in Puerto Rico rather than shift production elsewhere. Puerto Rico's skilled workforce also brings the advantage of operational cost efficiency for the firms; the average compensation across all employees in the pharmaceutical sector in Puerto Rico is $73,000 annually, compared with $155,000 annually for the rest of the United States.

1.3.3 Industry of Focus: Pharmaceuticals

The pharmaceutical manufacturing industry consists of facilities engaged in manufacturing biological and medical products; processing botanical drugs and herbs; isolating active pharmaceutical ingredients; and manufacturing pharmaceutical products intended for internal and external consumption in forms such as tablets, capsules, ointments, powders, injectables, and solutions.[16] The industry is primarily concerned with producing a continuous supply of active

16 U.S. Environmental Protection Agency, 2017, "Pharmaceutical and Medicine Manufacturing Sector (NAICS 3254)," https://www.epa.gov/regulatory-information-sector/pharmaceutical-and-medicine-manufacturing-sector-naics-3254, accessed May 17, 2018.

pharmacological ingredients that are within a specific quality range.[17] Input ingredients—including raw materials and intermediate products—are subjected to chemical transformations and combined to form treatments that prevent, diagnose, or treat diseases and disorders when metabolized.[18]

The United States is a global leader in medical research and pharmaceutical development. Industry estimates indicate that more than 800,000 people are employed in the pharmaceutical industry from research and development to product marketing to production.[19] The U.S. pharmaceutical industry accounted for an estimated $1.2 trillion in economic output in 2014, and the industry is expected to experience continued growth in the near future.[20] Pharmaceuticals are an important export industry in the United States. In 2015, U.S. pharmaceutical manufacturers exported $47 billion in products. Worldwide, the market for pharmaceutical products was more than $1 trillion in 2015.[21] The United States represents a large proportion of the global market for pharmaceuticals. Of the pharmaceuticals produced in Puerto Rico, 80 percent are consumed either on-island or in the United States mainland.[22]

The pharmaceutical industry has been an important economic driver in Puerto Rico for more than 40 years. Section 936 of the United States tax code, passed in 1976, incentivized U.S. manufacturers to establish operations in Puerto Rico. The pharmaceutical industry was among the sectors that took advantage of the tax credit exempting qualified income earned in Puerto Rico. American and foreign pharmaceutical companies established manufacturing operations on the island. Although the tax credit was phased out over a 10-year period beginning in 1996, the pharmaceutical industry remains an important contributor in Puerto Rico, employing tens of thousands of people.[23]

Pharmaceutical manufacturing facilities are located across the island. However, the largest concentration of the industry is located on the northern and eastern coasts. The most recent data available indicate that pharmaceutical manufacturing accounts for approximately $970 million in wages alone on the island.[24]

Pharmaceutical manufacturing accounts for 1.6 percent of employment in Puerto Rico but generates 3.7 percent of employee compensation and 30 percent of the island's overall direct output.

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17 Osakwe, Odilia, 2016, "Pharmaceutical Formulation and Manufacturing Development: Strategies and Issues," *Social Aspects of Drug Discovery, Development and Commercialization*, https://doi.org/10.1016/B978-0-12-802220-7.00008-9, accessed May 17, 2018.

18 Ibid.

19 Osakwe, Odilia, 2016, "Pharmaceutical Formulation and Manufacturing Development: Strategies and Issues," *Social Aspects of Drug Discovery, Development and Commercialization*, https://doi.org/10.1016/B978-0-12-802220-7.00008-9; SelectUSA.gov, undated, "Medical Technology Spotlight," https://www.selectusa.gov/medical-technology-industry-united-states; International Trade Administration, 2016, "2016 ITA Medical Devices Top Markets Report," https://www.trade.gov/topmarkets/pdf/Medical_Devices_Executive_Summary.pdf, all accessed May 17, 2018.

20 SelectUSA.gov, undated, "Medical Technology Spotlight," https://www.selectusa.gov/medical-technology-industry-united-states, accessed May 17, 2018.

21 International Trade Administration, 2016, "2016 ITA Medical Devices Top Markets Report," https://www.trade.gov/topmarkets/pdf/Medical_Devices_Executive_Summary.pdf, May 17, 2018; Economist Intelligence Unit, 2016, World Industry Outlook, Healthcare and Pharmaceutical.

22 U.S. Food and Drug Administration, 2017, *Testimony of Scott Gottlieb, M.D. Commissioner of Food and Drugs*, http://docs.house.gov/meetings/IF/IF02/20171024/106530/HHRG-115-IF02-Wstate-GottliebMDS-20171024.pdf, accessed May 17, 2018.

23 U.S. Census Bureau, 2012, "2012 Economic Census of Island Areas," https://www.census.gov/data/tables/2012/econ/census/island-areas.html; U.S. Census Bureau, 2007, "2007 Economic Census of Island Areas," https://www.census.gov/data/tables/2007/econ/census/island-areas.html, both accessed May 17, 2018.

24 MIG, Inc., 2017. IMPLAN, undated, Home page, http://www.implan.com, accessed May 17, 2018.

1.3.4 Industry of Focus: Medical Devices

The medical device manufacturing industry consists of facilities engaged in the manufacture of equipment, materials, and substances that doctors, dentists, nurses, and technicians use in the treatment, diagnosis, and monitoring of patients under their care. Products generated by this industry may be intended for internal implantation (e.g., pacemakers, artificial joints, plasters and cements), internal use (e.g., dental and surgical instruments and tools), external use (e.g., diagnostic imaging equipment, ultrasonic scanning devices), or support to medical procedures or general patient care (e.g., needles, syringes, surgical gloves, intravenous bags).[25]

The medical device industry is a diverse mix of large and small companies. In the United States, between 15 and 20 percent of the firms engaged in medical device manufacturing have fewer than 100 employees. Nearly 95 percent of firms have asset valuations of less than $10 million. A small number of large, multinational firms account for most employment and revenues in the industry.[26] The global market for medical devices is around $340 billion, with approximately $44 billion of exports shipped by U.S. manufacturers.[27] The United States also represents a significant purchaser in the medical device industry, accounting for about 40 percent of the global market.[28] The industry is expected to grow in the coming years, with the International Trade Administration suggesting growth of more than 28 percent between 2016 and 2020.[29]

The 2012 economic census indicates that the medical device manufacturing industry in the United States employs more than 350,000 workers.[30] Of the ten largest medical device companies, eight are based in the United States.[31] Around 40 domestic and international companies manufacture medical devices in Puerto Rico.[32] The companies, located across the island, contribute nearly $440 million to the wage base of Puerto Rico's economy.[33] Major medical device manufacturers with production locations in Puerto Rico include Abbott, Baxter, Boston Scientific, Medtronic, Roche, and Stryker.[34]

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25 SelectUSA.gov, undated, "Medical Technology Spotlight," https://www.selectusa.gov/medical-technology-industry-united-states, accessed May 17, 2018.

26 The Medicare Payment Advisory Commission, 2017, "An Overview of the Medical Device Industry," http://www.medpac.gov/docs/default-source/reports/jun17_ch7.pdf?sfvrsn=0, accessed May 17, 2018.

27 International Trade Administration, 2016, "2016 ITA Medical Devices Top Markets Report," https://www.trade.gov/topmarkets/pdf/Medical_Devices_Executive_Summary.pdf; SelectUSA.gov, undated, "Medical Technology Spotlight," https://www.selectusa.gov/medical-technology-industry-united-states, both accessed May 17, 2018.

28 SelectUSA.gov, undated, "Medical Technology Spotlight," https://www.selectusa.gov/medical-technology-industry-united-states; International Trade Administration, 2016, "2016 ITA Medical Devices Top Markets Report," https://www.trade.gov/topmarkets/pdf/Medical_Devices_Executive_Summary.pdf, both accessed May 17, 2018.

29 International Trade Administration, 2016, "2016 ITA Medical Devices Top Markets Report," https://www.trade.gov/topmarkets/pdf/Medical_Devices_Executive_Summary.pdf, accessed May 17, 2018.

30 SelectUSA.gov, undated, "Medical Technology Spotlight," https://www.selectusa.gov/medical-technology-industry-united-states, accessed May 17, 2018.

31 Medical Product Outsourcing, 2013, "The top 30 global medical device companies," https://www.mpo-mag.com/issues/2013-07/view_features/the-top-30-global-medical-device-companies-564773, accessed May 17, 2018. In The Medicare Payment Advisory Commission. (2017). "An Overview of the Medical Device Industry." http://www.medpac.gov/docs/default-source/reports/jun17_ch7.pdf?sfvrsn=0.

32 U.S. Food and Drug Administration, 2017, *Testimony of Scott Gottlieb, M.D. Commissioner of Food and Drugs*, http://docs.house.gov/meetings/IF/IF02/20171024/106530/HHRG-115-IF02-Wstate-GottliebMDS-20171024.pdf, accessed May 17, 2018.

33 IMG, Inc., 2017; IMPLAN, undated, Home page, http://www.implan.com, accessed May 17, 2018.

34 PRIDCO, undated, "Medical Devices: A Mecca for medical device manufacturing," http://www.pridco.com/industries/Pages/Medical-Devices.aspx, accessed May 17, 2018

1.3.5 Industry of Focus: Food Distribution

The food distribution system in the United States is a network that includes food production, food wholesalers, and retail outlets. Products that food wholesalers distribute include frozen and packaged foods; prepared foods; dairy items; baked goods; and poultry, fish, and meat.[35] Food wholesalers link producers (either on farms or food processors) and food retailers/food service distributors. The largest proportion of wholesale sales is to retailers.[36] Food wholesalers fall into one of three categories based on their level of specialization:

- Broadline wholesalers that stock a wide variety of products;
- Specialty foodservice distributors that stock a narrow selection of products for which they have a specialized knowledge with respect to handling requirements or product sourcing; and
- System foodservice distributors that support the operation of chain restaurants.[37]

Within the continental United States, large retailers have integrated wholesale operations; large wholesalers service local chains and other wholesale operations. Food and other groceries are efficiently moved by road or rail from production and processing points to retail outlets.

More than 85 percent of food consumed in Puerto Rico arrives by vessel into the Port of San Juan from the continental United States; the food distribution system is, in turn, concentrated in the municipios surrounding the port. A small number of food items are produced in Puerto Rico, including milk, cheese, some meats, and baked goods. Even in industries where domestic capability exists, other supply chain dependencies impact local production including packaging and transportation. When disruptions occur in domestic supply, existing local supply chain connections cannot fill the void immediately.

1.3.6 Industry of Focus: Agricultural Chemicals and Biotechnology

The agricultural chemicals industry includes facilities that manufacture fertilizers, pesticides and precursor chemicals intended for application on farms and commercial properties and for residential use. Input ingredients may be either raw materials or intermediate products, which are subjected to chemical transformations or combinations to form patented products. Agricultural chemicals allow growers to increase the yields by growing more crops per acre and preventing crop damage from diseases and pests.[38]

The global market for agricultural chemicals is nearly $125 billion.[39] The agricultural chemical industry is highly concentrated among large international conglomerates, many of which also engineer new varieties of crops through traditional breeding and genetic engineering. The new crop varieties contain traits that protect the commercially valuable plants from pesticides and herbicides that manage weeds, diseases, and pests. Between fertilizers and pesticides, the eight largest manufacturers produce between 70 percent and 75 percent of total revenues for their respective segments.[40]

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35 D&B Hoovers, undated, "Food Wholesalers Report Summary," http://www.hoovers.com/industry-facts.food-wholesalers.1361.html, accessed May 17, 2018.

36 U.S. Department of Agriculture, 2017, "Wholesaling," https://www.ers.usda.gov/topics/food-markets-prices/retailing-wholesaling/wholesaling/, accessed May 17, 2018.

37 Ibid.

38 U.S. Environmental Protection Agency, 2000, *Profile of the Agricultural Chemical, Pesticide, and Fertilizer Industry*, September, https://nepis.epa.gov/Exe/ZyPDF.cgi/50000EGG.PDF?Dockey=50000EGG.PDF, accessed May 17, 2018.

39 Research and Markets, 2016, "Analyzing the Global Agricultural Chemicals Industry 2016," https://www.researchandmarkets.com/publication/mtxxtg6/analyzing_the_global_agricultural_chemicals_i, accessed May 17, 2018.

40 D&B Hoovers, undated, "Agricultural Chemial Manufacturing Overview," http://www.hoovers.com/industry-facts.agricultural-chemical-manufacturing.1086.html, accessed May 17, 2018.

Facilities engaged in agricultural biotechnology conduct research, development, and testing of new plant varieties. Agricultural biotechnology is the combination of traditional breeding techniques and genetic engineering that seeks to improve plants or animals by altering genetics.[41] Advances in biotechnology may alter the ripening cycle to increase the shelf life of perishable goods, make crops more resistant to insects and more resilient to climatic conditions, or allow farmers to use chemical herbicides to kill weeds but leave the crops healthy.[42] Many of the agricultural products that the United States exports to trading partners are derived from advances in biotechnology.[43] An important component of those exports is seed.

The seed market is a global industry that international chemical conglomerates dominate. The five largest seed firms generated a total of around $40 billion in sales from their seed businesses alone in 2016 and 2017.[44] The global export market alone for sowing seeds exceeded $8 billion (value of shipments in U.S. dollars) in 2016. The United States accounted for 14 percent of that, or approximately $1.2 billion, making it the second-largest exporter in the world.[45]

Agricultural biotechnology is a growth industry in Puerto Rico, particularly on the south side of the island. The industry employs more than 5,000 workers and injects more than $125 million into Puerto Rico's economy annually.[46] For over 30 years, seed businesses have operated in Puerto Rico, attracted by a warm climate that can sustain four growing seasons. Puerto Rico's fields hosted the research and development for up to 85 percent of the commercial corn, soybean, and other hybrid seeds that U.S. farmers use today.[47]

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41 U.S. Department of Agriculture, undated, "Biotechnology Frequently Asked Questions," https://www.usda.gov/topics/biotechnology/biotechnology-frequently-asked-questions-faqs, accessed May 17, 2018.

42 Wieczorek, Ania, and Mark Wright, 2012, "History of Agricultural Biotechnology: How Crop Development has Evolved," *Nature Education Knowledge*, 3(10): 9, https://www.nature.com/scitable/knowledge/library/history-of-agricultural-biotechnology-how-crop-development-25885295, accessed May 17, 2018.

43 U.S. Department of Agriculture, undated, "Biotechnology," https://www.usda.gov/topics/biotechnology, accessed May 17, 2018.

44 Bayer, 2017, *Annual Report*, https://www.investor.bayer.de/en/downloads/2013-2017/2017/; DowDuPont, 2018, *2017 Annual Report*, http://s21.q4cdn.com/813101928/files/doc_downloads/DowDuPont-2017-Annual-Report.PDF; Syngenta, 2018, "2017 Full Year Results," https://www.syngenta.com/media/media-releases/yr-2018/15-02-2018; KWS, 2018, *Annual Report 2017/2017*, http://www.kws.com/global/show_document.asp?id=aaaaaaaaaaxycvw; Vilmorin & Cie, 2018, *Annual Report 2016-2017*, https://www.vilmorincie.com/wp-content/uploads/2018/01/VILMORIN_DDR2016-2017_UK_COMPLET_03.pdf, all accessed May 17, 2018.

45 Observatory of Economic Complexity, undated, "Which countries export sowing seeds? (2016)," https://atlas.media.mit.edu/en/visualize/tree_map/hs92/export/show/all/1209/2016/, accessed May 17, 2018.

46 Puerto Rico Agricultural Biotechnology Industry Association, undated, "Agricultural Biotechnology in Puerto Rico," https://www.prabia.org/agbio-puerto-rico, accessed May 17, 2018.

47 Mayer, Amy, 2017, "Puerto Rico's Hurricane Recovery Hinders Farm Businesses' Seed Research," *National Public Radio*, November 29, https://www.npr.org/sections/thesalt/2017/11/29/567254037/puerto-ricos-hurricane-recovery-complicates-ag-businesses-seed-research, accessed May 17, 2018.

Infrastructure System Characterization

2 INFRASTRUCTURE SYSTEM CHARACTERIZATION

2.1 SYSTEM-LEVEL ANALYSIS

2.1.1 Top-Down Approach

Interdependencies among lifeline infrastructure systems continue to grow in number and complexity, resulting in systems that are increasingly vulnerable to cascading and escalating effects across infrastructure sectors. Infrastructure owners and operators, as well as customer bases for their services and resources, increasingly seek an enhanced understanding of interdependencies among infrastructure systems—including both the vulnerabilities and opportunities that these relationships produce—to anticipate and respond to the potential effects from a change in system dynamics. These issues are equally pertinent to post-incident recovery plans and programs, where public and private sector partners make investment decisions on rebuilding infrastructure to be more resilient to a range of threats and hazards.

Top-down approaches to infrastructure analysis center on assessing and characterizing infrastructure systems; conducting modeling and failure analyses at the system level; and ultimately integrating these efforts into system-of-systems analyses that hone in on critical nodes across systems that can lead to cascading and escalating effects (figure 2-1).

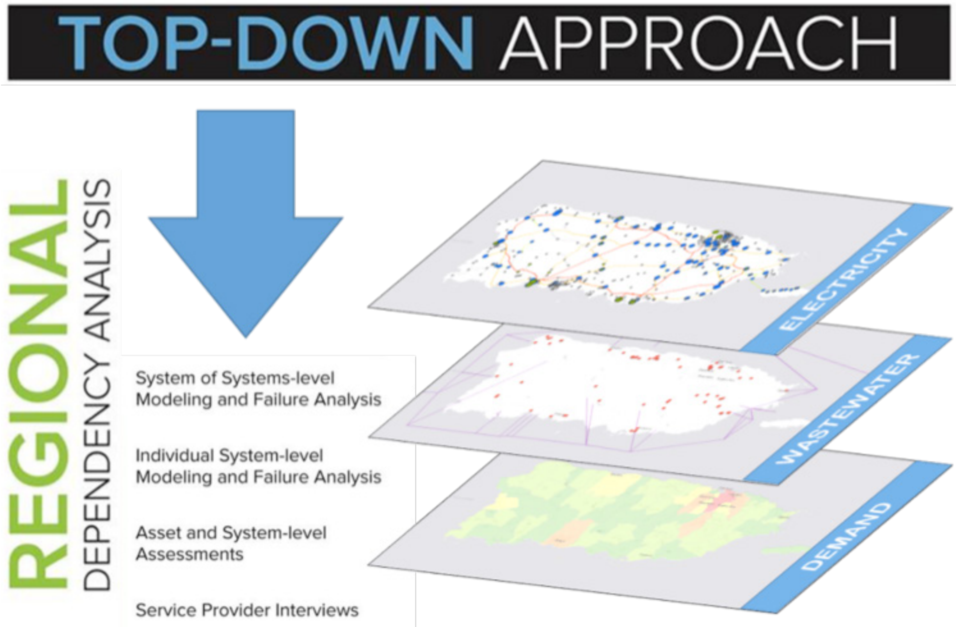

Figure 2-1: Focusing on Top-Down Interdependencies[48]

[48] Adapted from Petit, Frederic, Duane Verner, and Leslie-Anne Levy, 2017, *Regional Resiliency Assessment Program Dependency Analysis Framework*, Argonne National Laboratory, Global Security Sciences Division, ANL/GSS-17/05, Argonne, Ill, USA.

2.1.1.1 Characterizing Infrastructure Systems

One foundational component of top-down, system-level analysis is the process of characterizing infrastructure sectors of interest. This process includes defining how the system functions in general; how it functions in a particular geographical and operational context; the interdependencies between that sector and other critical infrastructure systems; and the potential consequences that could result from cascading failures. Characterizations include a mix of operational information (i.e., to understand functions and capacities of system components) and geographic data (i.e., GIS information that visualizes system within a given geographic footprint). These initial system characterizations are the basic building blocks for more advanced analysis that uses these inputs in models and simulations.

In the case of Puerto Rico, the goals of infrastructure interdependency analysis included the following: (1) characterizing the vital hubs and chains of activity for key industrial sectors and their dependencies on lifeline infrastructure; and (2) mapping and analyzing the dependencies and interdependencies between these users and the infrastructure, as well as between infrastructure sectors themselves. Therefore, a key initial step was to identify which infrastructure sectors and subsectors to characterize, with an eye toward integrating that information with asset-level data collected through a bottom-up process running in parallel for key industries. Eight critical infrastructure sectors and subsectors became focal points for system-level analysis:

- Electricity (Energy Sector),
- Petroleum and other fuels (Energy Sector),
- Communications,
- Water systems (Water and Wastewater Sector),
- Wastewater systems (Water and Wastewater Sector),
- Maritime transportation (Transportations Systems Sector),
- Aviation transportation (Transportation Systems Sector), and
- Road transportation (Transportation Systems).

2.1.1.2 Modeling and Simulation

Several modeling and simulation approaches, generally developed for risk assessment and system engineering, also apply to critical infrastructure interdependencies analysis. Three categories are particularly relevant: empirical-based, network-based, and system dynamics-based. Table 2-1 presents a general description of these different approaches.

Table 2-1: Description of Top-down Interdependencies Analysis Methodologies

Approach	Description
Empirical-Based	Analyze interdependencies based on observation and experience by using historical data in combination with expert judgment.
Network-Based	Analyze infrastructure systems as networks where infrastructure assets are represented as nodes and the physical connections are represented as arcs. The two main network-based approaches are topology-based methods and flow-based methods.
System Dynamics-Based	Analyze the behavior of complex systems by modeling a system's dynamic and evolutionary behavior through stock and flow exchanges and causal loops.

To date, DHS-IP's interdependency analysis in Puerto Rico has not included these more advanced top-down activities that can help planners identify failure points within and among systems. However, geocoded databases were developed to support the future integration of data required to apply such models. Together, these approaches could help public and private sector partners in the following areas:

- Identify the different functions within the lifeline system,
- Identify the physical assets that enable the system to perform its required functions,
- Identify how the failure of physical assets would propagate within the system, and
- Identify the protective and mitigation measures in place at the system level.

2.1.2 Applying a Top-Down Approach in Puerto Rico

This project included system characterizations for the eight lifeline systems of concern (i.e., electricity, petroleum and other fuels, communications, water systems, wastewater systems, maritime transportation, road transportation, and aviation transportation). The system characterizations summarize how infrastructure systems operate, with a focus on system aspects that impact resilience. Each section illustrates how specific sectors and subsectors function in general and in Puerto Rico, as well as what interdependencies exist among critical infrastructure systems, and the potential consequences that could result from cascading failures.

In the course of developing the sector characterizations, several important themes emerged about key system-level relationships. In aggregate, the interdependencies among certain infrastructure sectors result in closely intertwined system dynamics that may spread and intensify across sectors. Three important examples of these interdependency themes are the nexus between maritime transportation, fuels, and electricity; the nexus between electricity and communications; and the nexus between energy and water. These issues are evident in both the top-down system characterizations as well as the bottom-up asset level analysis and related case studies discussed later in this report. More broadly, they represent important cross-sector considerations that can inform decision making around investments to rebuild infrastructure in Puerto Rico and enhance resilience.

2.1.2.1 Maritime Transportation-Fuels-Electricity Nexus

The Electricity, Fuels (Petroleum, Natural Gas, and Coal), and Maritime Transportation Subsectors are highly interdependent in Puerto Rico, representing a critical cross-sector nexus. Nearly all electricity generated in Puerto Rico comes from fossil fuel sources (i.e., 96 percent of all projected electricity generation in 2018). All of this fuel is imported to Puerto Rico through maritime ports, which themselves require electricity for intermodal operations.[49]

With the exception of the small PREPA gas turbine plant Vega Baja, all fossil fuel-fired power plants are located within 10 miles of a maritime port. However, the fuel used by a particular power plant may not come from the closest port. The majority of fuel arriving in Puerto Rico comes through two ports: the Port of San Juan and the Port of Ponce.[50,51] Nearly all natural gas comes into Puerto Rico through a private liquefied natural gas (LNG) facility in Peñuelas (i.e., EcoEléctrica LNG Facility). Fuel imported in San Juan and Ponce must be transported via roadway transportation to power plants, often requiring fuel transport across the island. Investments in existing port infrastructure would enable fuel to be imported at ports located near power plants using the fuel, reducing the demand on roadway transportation infrastructure in Puerto Rico.

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49 PREPA, 2017, *Puerto Rico Electric Power Authority Fiscal Plan*, http://www.aafaf.pr.gov/assets/fiscal-plan---pr-electric-power-authority.pdf, accessed June 4, 2018.

50 Petroleum products data from: https://www.eia.gov/petroleum/imports/companylevel/archive/2016/data/impa16d.xlsx

51 Coal data from: https://www.eia.gov/coal/data/browser/#/topic/39?agg=2,1,0&rank=ok&map=COAL.EXPORT_QTY.TOT-TOT-TOT.A&freq=A&start=2000&end=2016&ctype=map&ltype=pin&rtype=s&maptype=0&rse=0&pin=&mntp=g

2.1.2.2 Electricity-Communications Nexus

The Electricity Subsector and the Communications Sector are highly interconnected.[52] The Communications Sector provides key monitoring and control services to the Electricity Subsector, while the Electricity Subsector provides power that is necessary for Communications Sector operations. In addition, wired communications and electric power infrastructure also often share rights-of-way; this is particularly true in Puerto Rico where communication fiber lines are generally hung on existing electric transmission and distribution infrastructure.

Nearly all communications assets require electric power for operation and will suffer significant degradation of operations without power. Backup power (via either battery or generation) and associated backup fuel for generators are critical to prevent complete shutdown of communications assets in the event of a blackout or brownout. An extended loss of power event will deplete backup fuel reserves and batteries, causing significant degradation of communications services.

Similarly, the Electricity Subsector requires telecommunication service for daily operations and for industrial control systems (ICS) and SCADA systems that monitor and control electric power infrastructure. Electric power assets are highly automated and thus depend upon communication services for operations. The integration of communications infrastructure into the Electricity Subsector has increased over the past two decades, driven by technological advancements (i.e., improvements in sensor, network and software technologies); increasing needs for wide-area situational awareness of grid conditions due to more diverse and complex grid operations (i.e., increasing distributed generation, smart metering, variable renewable generation, and demand management); and economic motivations (i.e., gains in operational efficiencies).[53] Greater reliance on communications also increases the vulnerability of electricity infrastructure to cyber dependencies.[54]

2.1.2.3 Energy-Water Nexus

The Energy Sector and the Water and Wastewater Systems Sector have significant interdependencies: water is used in all phases of energy production and electricity generation,[55] while electricity and other fuels are used to extract, convey and deliver water and to treat wastewater prior to their return to the environment.[56] A significant amount of energy, mainly electricity, is also required for water treatment and distribution, and for wastewater collection and treatment. Electricity is particularly important for operating mechanical and electrical equipment, control systems, lighting, and for security and safety purposes. The water system uses electricity to move raw water from water intakes to water treatment plants; monitor and control treatment process; and move treated water through the distribution system. In general, water distribution systems are operated by gravity. However, electricity is still needed to pump water into elevated reservoirs and maintain an appropriate pressure in the system. Similarly, wastewater systems are also important consumers of electricity, using it to power pumps that move wastewater to wastewater treatment plants; monitor and control treatment processes; move and treat sludge byproducts; and move treated water out to the system discharge.

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52 While this section discusses the explicit connection between the Communications Sector and Electricity Subsector, the Information Technology Sector is another component of this nexus. The Information Technology Sector consists of IT hardware, software, systems and service that work in conjunction with the communications infrastructure.

53 Pacific Northwest National Laboratory, 2015, *The Emerging Interdependence of the Electric Power Grid & Information and Communication Technology*, August, https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24643.pdf, accessed June 4, 2018.

54 DHS, 2015, *Energy Sector-specific Plan*, https://www.dhs.gov/sites/default/files/publications/nipp-ssp-energy-2015-508.pdf, accessed June 4, 2018.

55 DOE (U.S. Department of Energy), 2014, *The Water-Energy Nexus: Challenges and Opportunities – Overview and Summary*, https://www.energy.gov/sites/prod/files/2014/07/f17/Water%20Energy%20Nexus%20Executive%20Summary%20July%202014.pdf, accessed June 4, 2018.

56 Ibid.

Disruption of electric power to water and wastewater systems would have immediate impacts if sufficient onsite generating capacity were not available. Furthermore, water collection, treatment, and distribution systems cannot operate on backup generators for a prolonged period of time. Water quality monitoring and select processes at treatment plants may continue if testing materials and trained personnel are available. The loss of electricity is less detrimental for gravity flow systems. However, maintaining adequate pressure and flow in the system would be problematic if lift pumps were not available. Backup generators can operate lifting equipment, but their use depends heavily on the availability of petroleum (mostly diesel) to fuel the pumps.

Similarly, energy facilities across all the subsectors use water for a variety purposes: drinking water for personnel; water for sanitary purposes; processing activities such as dissolution of product ingredients and dilution of concentrates; process support activities including temperature control and seal fluid in pumps and compressors; firefighting and deluge systems; and general services such as maintenance and plant wash-up.

In addition to physical interconnections between energy and water resources, some distribution systems are geographically collocated and share rights-of-way corridors. However, water and energy systems are generally developed and operated in silos, creating a fragmented landscape of political, regulatory, economic, environmental, and social factors.[57] In particular, the policy landscape in Puerto Rico is highly fragmented, making it difficult to effectively balance energy and water goals.[58]

57 Ibid.

58 DOE, 2017, *Environment Baseline Vol. 4: Energy-Water Nexus*, January, https://www.energy.gov/sites/prod/files/2017/01/f34/Environment%20Baseline%20Vol.%204--Energy-Water%20Nexus.pdf, accessed June 4, 2018.

2.2 ELECTRICITY SUBSECTOR CHARACTERIZATION

2.2.1 Scope

This characterization summarizes how the infrastructure system that constitutes the Electricity Subsector operates, with a focus on system aspects that impact resilience. This section provides a baseline understanding of how the electricity system functions in general, how it functions in Puerto Rico, interdependencies between the Electricity Subsector and other critical infrastructure systems, and the potential consequences that could result from cascading failures.

2.2.2 Sector Background: General

The Electricity Subsector is one of nine subsectors constituting the Energy Sector (figure 2-2).

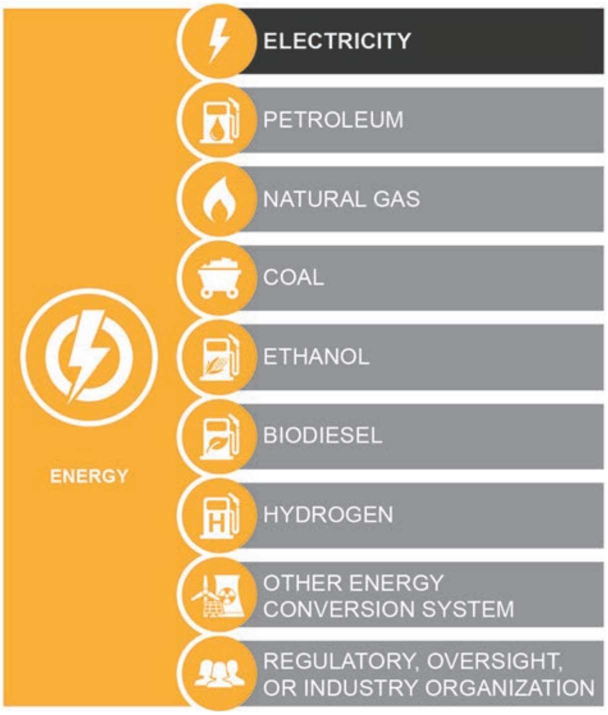

Figure 2-2: DHS Critical Infrastructure Taxonomy—Energy Sector[59]

The electricity system is a vast, complex network that includes hundreds, if not thousands, of entities, including private, public, and government organizations. Private entities can be as small as a company operating a single, small power plant or as large as a corporation controlling the power system covering multiple states. In addition, regulatory authorities, from municipalities, states and territories, and the Federal Government oversee the operation of the power system and the price of electricity delivered to customers.

Electricity is transmitted across high voltage lines to substations and delivered at lower voltages to end users through the distribution system. The physical process is controlled locally through centralized facilities and economically through a system of national/regional interconnections. The U.S. electricity system includes generation, transmission, and distribution assets (table 2-2). Figure 2-3 presents a diagram overview of the electricity supply chain.

Table 2-2: Electricity Subsector Assets

Generation	Transmission	Distribution
□ Fossil fuel power plants	□ Substations	□ Substations
□ Nuclear power plant	□ Lines	□ Lines
□ Hydroelectric dams	□ Control centers	□ Control centers
□ Renewable energy		

59 DHS, 2011, *Infrastructure Data Taxonomy, Version 4*, National Protection and Programs Directorate, Office of Infrastructure Protection, Infrastructure Information Collection Division, June.

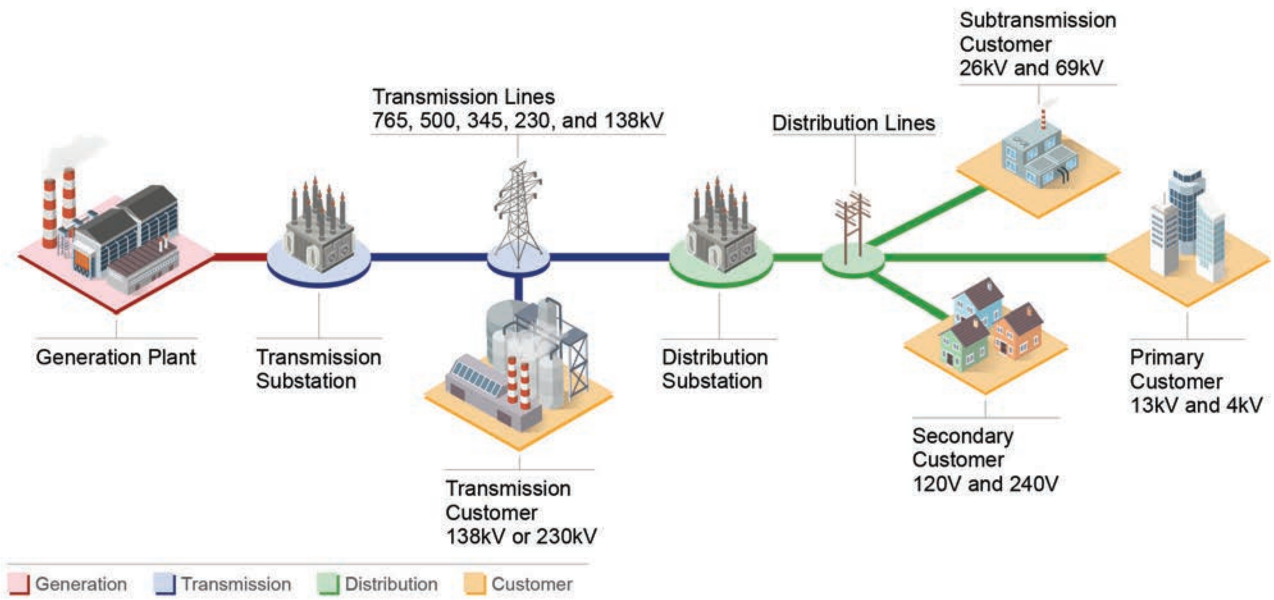

Figure 2-3: Electricity Generation, Transmission, and Distribution Process[60]

Key elements of the Electricity Subsector include the following:

- **Power generation:** Generating plants produce electricity from petroleum, coal, natural gas, nuclear, and renewable sources and deliver it to the transmission system. In December 2016, the U.S. Energy Information Agency (EIA) reported that 8,084 plants produced 4.1 trillion kilowatt-hours (kWh) of electricity.[61] Most of U.S. electricity was generated using fossil fuels: 34 percent using natural gas and 30 percent using coal. Nuclear power represented 20 percent of the electricity generated, and renewable energy sources provided 15 percent of U.S. electricity.[62]
- **Transmission lines:** Transmission systems are high-voltage highways that connect numerous geographically dispersed generating facilities with geographically dispersed load centers served by non-connected distribution systems. Transmission lines move electricity from generation sites to customers, and they connect systems. Voltages in the transmission system are high (e.g., 115, 138, 161, 230, 345, 500, or 765 kilovolts [kV]), which makes it possible to carry electricity efficiently over long distances and to deliver it to substations near customers.
- **Distribution lines:** Distribution systems serve local communities of end users in defined geographic areas. Distribution lines usually carry 69 kV and below; however, lines carrying voltages between 34.5 and 69 kV may be considered sub-transmission lines.[63]

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60 DOE, 2015, *United States Electricity Industry Primer*, July, https://www.energy.gov/sites/prod/files/2015/12/f28/united-states-electricity-industry-primer.pdf, accessed May 14, 2018.

61 EIA (U.S. Energy Information Administration), undated, "How Many Power Plants are there in the United States?" https://www.eia.gov/tools/faqs/faq.php?id=65&t=2, accessed May 14, 2018.

62 EIA, 2018, "Electricity in the United States is Produced with Diverse Energy Sources and Technologies," April 20, https://www.eia.gov/energyexplained/index.php?page=electricity_in_the_united_states, accessed May 14, 2018.

63 U.S. Department of Labor, undated, "Illustrated Glossary: Transmission Lines," https://www.osha.gov/SLTC/etools/electric_power/illustrated_glossary/transmission_lines.html, accessed May 14, 2018.

- **Transmission and distribution substations:** Substations are located at the ends of transmission and distribution lines. Substations play a critical role in the electric power system, connecting the generation, transmission, and distribution segments of the system by stepping voltages up or down. A transmission substation located near a power plant uses large transformers to increase the voltage for more efficient movement along the transmission line. At the other end of a transmission line, a substation uses transformers to step transmission voltages back down so the electricity can be distributed to customers at a usable voltage. Voltage level tends to define whether a substation is considered a transmission substation or a distribution substation.
- **Control centers:** Control centers have sophisticated monitoring and control systems and are staffed continuously by operators. These operators are responsible for several key functions, including balancing power generation and demand, monitoring flows over transmission lines to avoid overloading, planning and configuring systems to operate reliably, maintaining system voltage levels and stability, preparing for emergencies, and placing equipment in and out of service for maintenance and during emergencies.[64]
- **Regulators:** The North American Electric Reliability Council (NERC) and its Regional Reliability Councils have developed system operating and planning standards to ensure the reliability of the electricity system in the international connected grid spanning the continental United States, Canada, and the northern portion of Baja California, Mexico. NERC is the electric reliability organization for North America, subject to oversight by the Federal Energy Regulatory Commission (FERC) and governmental authorities in Canada. NERC's jurisdiction includes users, owners, and operators of the bulk power system, which serves more than 334 million people. FERC is an independent agency that regulates the interstate and intrastate transmission of electricity, natural gas, and oil.

2.2.3 Sector Background: Puerto Rico

2.2.3.1 Physical Market in Puerto Rico

Founded in 1941, PREPA is a government agency that is the sole provider of electricity and owns the distribution and transmission systems for the main island, Vieques, and Culebra, as well as most generating stations.[65,66]

As of August 2013, PREPA reported an installed generating capacity of 6,023 megawatts (MW) (5,839 MW dependable capacity) with a peak demand of 3,685 MW.[67] Similar to the continental United States, most of the electricity in Puerto Rico is generated using fossil fuels (i.e., petroleum, natural gas, and coal). However, while the majority of generation in the United States comes from coal (30 percent) and natural gas (34 percent), the majority of generating systems in Puerto Rico use petroleum (45 percent, compared to less than 1 percent nationally).[68,69]

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64 FCC (Federal Communications Commission), undated, "American Recovery and Reinvestment Act of 2009," https://www.fcc.gov/general/american-recovery-and-reinvestment-act-2009, accessed May 14, 2018.

65 EIA, 2017, "Profile Analysis," September 21, https://www.eia.gov/state/analysis.php?sid=RQ, accessed May 14, 2018.

66 PREPA, undated, "From Executive Director Office," https://www.aeepr.com/INVESTORS/Default.aspx, accessed May 14, 2018.

67 PREPA, undated, "Operational Profile," https://www.aeepr.com/INVESTORS/OperationalProfile.aspx, accessed May 14, 2018.

68 EIA, undated, "Total Energy," https://www.eia.gov/totalenergy/data/browser/?tbl=T07.02A#/?f=A&start=1949&%20end=2016&charted=1-2-3-5-8-14, accessed May 14, 2018.

69 PREPA, 2017, *Puerto Rico Electric Power Authority Fiscal Plan*, April 28, http://www.aafaf.pr.gov/assets/fiscal-plan---pr-electric-power-authority.pdf, accessed May 14, 2018.

The percentage of electricity generated using natural gas in Puerto Rico is similar to the percentage generated using natural gas overall in the United States. Coal and renewable generation capabilities are less prevalent in Puerto Rico than nationally, and Puerto Rico has no nuclear generation capabilities. Figure 2-4 presents the projected sources of electricity generation in Puerto Rico for 2018.

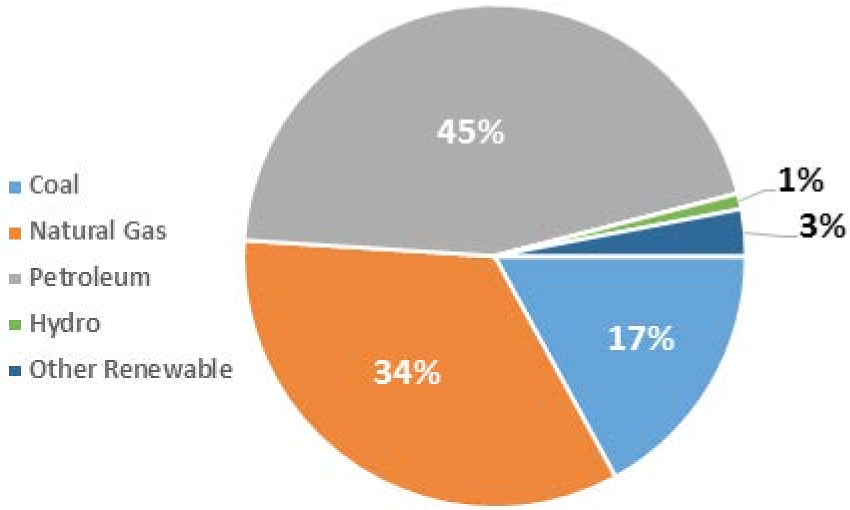

Figure 2-4: Puerto Rico's 2018 Fuel Production Portfolio[70]

Although Puerto Rico has employed hydroelectric power generation for more than 100 years, use of other renewable generation sources has been minimal on the island. Renewable energy capabilities have been increasing in recent years with the construction of several solar and wind farms. Two wind farms supplied nearly half of Puerto Rico's renewable generation in 2016; in fact, the 95-MW Santa Isabel facility is the largest wind farm in the Caribbean.[71] Puerto Rico also has the largest solar farm in the Caribbean, the 58-MW Oriana Solar Farm.[72] As of June 2017, Puerto Rico had 127 MW of utility-scale solar photovoltaic generating capacity and 88 MW of distributed (customer-sited, small-scale) capacity.[73] In the first 6 months of 2017, more renewable electricity came from solar energy than any other source.[74] Biomass generation now contributes more than 2 percent of Puerto Rico's renewable electricity.[75] The percentage of power generated from renewable sources in Puerto Rico remains well below the corresponding percentage for the United States overall, where renewable sources provide 15 percent of the Nation's electricity.[76] PREPA's long-term investment program requires upgrades for plant efficiencies and pivoting the generation mix from primarily petroleum to cheaper natural gas and renewables by 2026 to reduce generation expenses (figure 2-5).[77]

70 Ibid.

71 EIA, undated, "U.S. Overview," https://www.eia.gov/state/analysis.php?sid=RQ#127, accessed May 14, 2018.

72 Sonnedix, 2016, "The Largest Solar Power Plant in the Caribbean Begins Producing Energy," September 14, http://sonnedix.com/news/the-largest-solar-power-plant-in-the-caribbean-begins-producing-energy/, accessed May 14, 2018.

73 EIA, 2017, "Puerto Rico Territory Energy Profile," September 21, https://www.eia.gov/state/print.php?sid=RQ, accessed May 14, 2018.

74 Ibid.

75 Ibid.

76 EIA, undated, "Total Energy," https://www.eia.gov/totalenergy/data/browser/?tbl=T07.02A#/?f=A&start=1949&end=2016&charted=1-2-3-5-8-14, accessed May 14, 2018.

77 PREPA, 2017, *Puerto Rico Electric Power Authority Fiscal Plan*, April 28, http://www.aafaf.pr.gov/assets/fiscal-plan---pr-electric-power-authority.pdf, accessed May 14, 2018.

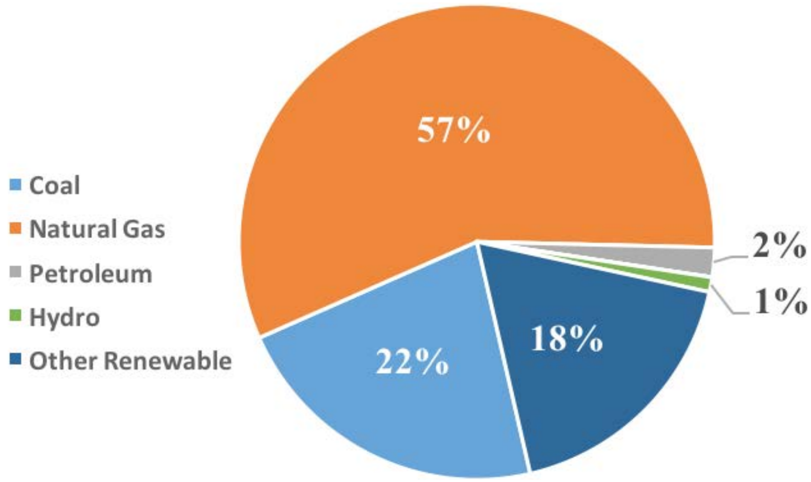

Figure 2-5: Anticipated Electricity Generation Portfolio in 2026[78]

This anticipated generation portfolio in 2026 will be similar to average U.S. generation capability. A more balanced generation portfolio decreases the island's vulnerability to the disruption of a given fuel supply. While the increased role of renewable generation reduces Puerto Rico's dependency on imported fuel, it presents its own disruption vulnerability because of the stochastic nature of wind and solar irradiance availability. In fact, the proposed future generation mix may be less resilient than the current generation mix in certain aspects. The anticipated 2026 generation mix relies more heavily on a single fuel than the projected 2018 generation mix (57 percent from natural gas in 2026 compared to 45 percent from petroleum in 2018). This means that disruptions of a single fuel could be more detrimental in the future generation mix than in the current mix. If the majority of the new natural-gas-fired units are dual fuel, whether by retrofitting existing petroleum units to operate on natural gas or by replacing existing petroleum generators with new dual-fuel units, disruption of the natural gas supply will have less impact.

Beyond the potential impacts to system resilience, switching from petroleum to natural gas would also be beneficial for thermal generation by decreasing electricity production costs and retail prices.[79] However, most of electricity generation will still use fossil fuels that are not produced on the island and will require maritime transportation. Consequently, all thermal generation plants are located along the coast (figure 2-6).

78 Ibid.

79 Ibid.

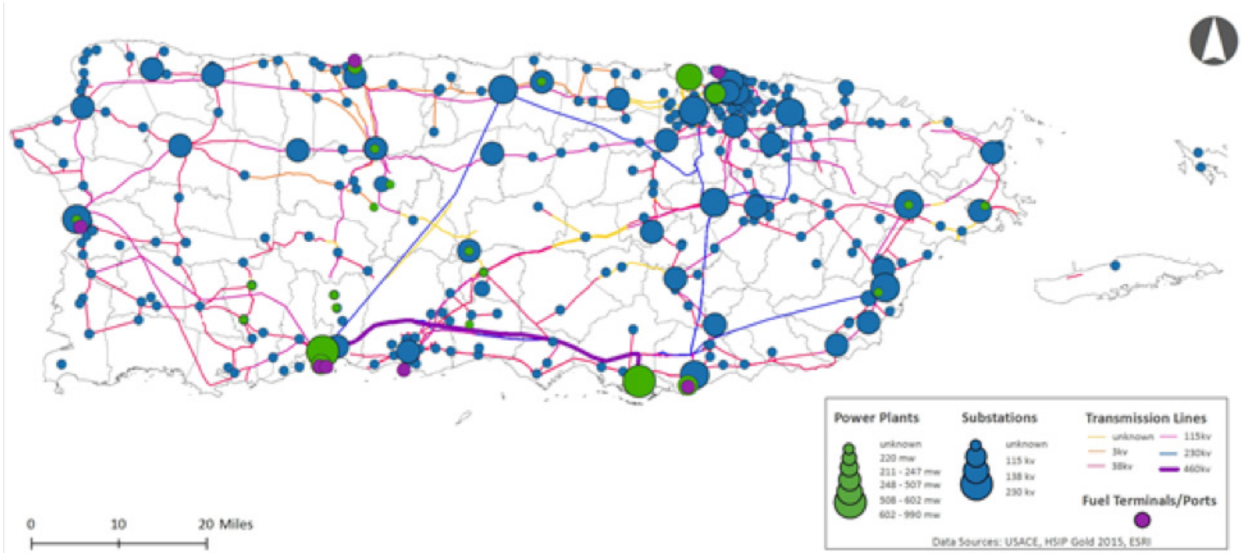

Figure 2-6: Power Generating Facilities in Puerto Rico[80]

Most energy that PREPA produces is generated in four main power plants: Costa Sur, Aguirre, San Juan, and Palo Seco.[81] Table 2-3 presents an overview of electricity generation capacity in Puerto Rico.

Table 2-3: Characteristics of Primary Electricity Subsector System Infrastructure Generation Plants[82]

Asset Name	Location	Owner	Type and Fuel	Capacity (MW)
San Juan Generation Plant	San Juan	PREPA	Thermal – Oil #6	400
Costa Sur Generation Plant	Guayanilla	PREPA	Thermal – Natural Gas/Oil #6[83]	900
Palo Seco Generation Plant	Cataño	PREPA	Thermal – Oil #6	602
Aguirre Generation Plant	Salinas	PREPA	Thermal – Oil #6	900
Aguirre Combined Cycle Generation Plant	Salinas	PREPA	Thermal – Oil #2	592
Cambalache Generation Plant	Arecibo	PREPA	Thermal – Oil #2	247
San Juan Combine Generation Plant	San Juan	PREPA	Thermal – Oil #2	440
Mayagüez Generation Plant	Mayaguez	PREPA	Thermal – Oil #2	220
EcoEléctrica Generation Plant[84]	Peñuelas	EcoEléctrica L.P.	Private Cogenerator Thermal – Natural Gas	507
AES Cogeneration Generation Plant	Guayama	AES Corporation	Thermal – Coal[85]	454[86]
AES Illumina	Guayama	AES Corporation	Renewable – Solar	20[87]
Salinas Solar Farm	Salinas	Sonnedix Group	Renewable – Solar	15.5[88]
Aquion Solar Farm	Aquion	Sonnedix Group	Renewable – Solar	0.25[89]
Oriana Solar Farm	Santa Isabel	Sonnedix Group	Renewable – Solar	57.7[90]
Fajardo Solar Farm	Under Construction	Sonnedix Group	Renewable – Solar	26[91]

80 Platts, 2017, "DOE Pushes to Repair Puerto Rico Power System," October 2, https://www.platts.com/latest-news/electric-power/houston/doe-pushes-to-repair-puerto-rico-power-system-21122369, accessed May 14, 2018.

81 Autoridad de Energia Eléctrica, 2016, "Sistem Eléctrico," https://www.aeepr.com/Aeees/sistema_electrico.asp, (in Spanish), accessed May 14, 2018.

Table 2-3: (cont.)

Asset Name	Location	Owner	Type and Fuel	Capacity (MW)
Yabucoa Solar Farm	Under Construction	Sonnedix Group	Renewable – Solar	26[92]
Santa Isabel Wind Farm	Santa Isabel	Pattern Energy	Renewable – Wind	95[93]
San Fermin solar Farm	Loiza	TSK	Renewable – Solar	27[94]
Punta Lima Solar Farm	Naguabo	TBK	Renewable – Solar	Unknown
Landfill Gas Technologies of Fajardo	Fajardo	Landfill Gas Technologies of Fajardo, LLC	Renewable – Landfill Gas	4[95]
Landfill Gas Technologies of Fajardo (Toa Baja)	Toa Baja	Landfill Gas Technologies of Fajardo, LLC	Renewable – Landfill Gas	4[96]
Dos Bocas Hydroelectric Plant	Dos Bocas	PREPA	Renewable – Hydroelectric	Unknown
Yauco Hydroelectric Plant	Yauco	PREPA	Renewable – Hydroelectric	Unknown
Coanillas Hydroelectric Plant	Coanillas	PREPA	Renewable – Hydroelectric	Unknown
Patillas Hydroelectric Plant	Patillas	PREPA	Renewable – Hydroelectric	Unknown

82 PREPA, undated, "Operational Profile," https://www.aeepr.com/INVESTORS/OperationalProfile.aspx, accessed May 14, 2018; only select renewable generation plants are shown.

83 The Costa Sur plant has two 410-MW dual-fuel units and two 85-MW units that use Oil #6. See URS Corporation, 2013, *Fortieth Annual Report on the Electric Property of the Puerto Rico Electric Power Authority, San Juan, Puerto Rico,* June, https://www.aeepr.com/INVESTORS/DOCS/Financial%20Information/Annual%20Reports/Consulting%20Engrs%20Annual%20Report%20FY2013.pdf, accessed May 14, 2018.

84 The waste heat is used in a desalination plant that produces 2 million gallons of water per day, 50 percent of which is sold to the Puerto Rico Aqueduct and Sewer Authority and to PREPA for use in the Costa Sur plant; see URS Corporation, 2013, *Fortieth Annual Report on the Electric Property of the Puerto Rico Electric Power Authority, San Juan, Puerto Rico*, June, https://www.aeepr.com/INVESTORS/DOCS/Financial%20Information/Annual%20Reports/Consulting%20Engrs%20Annual%20Report%20FY2013.pdf and EcoElectrica, 2015 "Sobre Nostotros," http://ecoelectrica.com/sobre-nosotros/ (in Spanish), both accessed May 14, 2018.

85 Generators use Oil #2 as a startup fuel; see Government of Puerto Rico Office of the Governor Environmental Quality Board, undated, "Air Quality Area," http://www.agencias.pr.gov/agencias/jca/Documents/Permisos%20y%20Formularios/Calidad%20de%20Aire/Permisos%20de%20Operaci%C3%B3n%20T%C3%ADtulo%20V%20Finales/AES%20FINAL%20Permit.pdf, accessed May 14, 2018.

86 AES, 2016, *The AES Corporation Fact Sheet*, February 24, http://s2.q4cdn.com/825052743/files/doc_downloads/Comapny_Inf/02-24-16-Q4-2015-Fact-Sheet_FINAL.pdf, accessed May 14, 2018.

87 Ibid.

88 Sonnedix, undated, "Puerto Rico," http://sonnedix.com/country/puerto-rico/, accessed May 14, 2018.

89 Ibid.

90 Ibid.

91 Ibid.

92 Ibid.

93 Siemens Industry, 2015, *Siemens PTI Report Number: R054-15; Integrated Resource Plan Volume I: Supply Portfolios and Futures Analysis; Draft for the Review of the Puerto Rico Energy Commission*, August 17, https://www2.aeepr.com/Documentos/Ley57/PREPA%20IRP%20Volume%20I%20%E2%80%93%20Draft%20for%20PREC%20review.pdf, accessed May 14, 2018.

94 TSK, undated, "27 MW Photovoltaic Plant," http://en.grupotsk.com/proyectos/puerto-rico, accessed May 14, 2018.

95 Autoridad de Energia Eléctrica, 2015, *Other Information Required in the Regulation on Integrated Resource Plan for the Puerto Rico Electric Power Authority,* https://www.aeepr.com/Docs/Ley57/Other%20Information%20Required%20for%20the%20Regulation%20of%20the%20IRP%20for%20PREPA%20July%206,%202015.pdf, accessed May 14, 2018.

96 Ibid.

Transmission System – The transmission system consists of 2,478 miles of 230-kV transmission lines, 115-kV transmission lines, and 38-kV sub-transmission lines connecting 48 transmission substations.[97]

Distribution System – The distribution system is mostly aerial, with a total of 31,446 miles of aerial lines and 1,723 miles of underground lines. The distribution systems connect 293 substations with 27 technical offices.[98]

Regulatory Regime – Puerto Rico's grid is isolated and not interconnected with other North American bulk power systems. Consequently, NERC does not oversee the reliability of the Puerto Rico electric system. However, electricity generation requires fuel supplies from the continental United States, and FERC oversees receipt, storage, and processing of fuels for PREPA's power generation. In particular, FERC oversees the liquefied natural gas import terminal and regasification facilities to fuel electricity generation plants. Created in 2014, the Puerto Rico Energy Commission (PREC) is the independent body responsible for regulating, monitoring, and enforcing Puerto Rico's energy policy.[99]

2.2.3.2 Commercial Activities in Puerto Rico

PREPA serves more customers than any other public electric utility in the United States. The commercial sector consumes nearly half of PREPA's retail electricity; the residential sector consumes slightly more than one third. The industrial sector, including agriculture, accounts for around 13 percent of consumption, with the balance consumed for public uses like street lighting (figure 2-7).

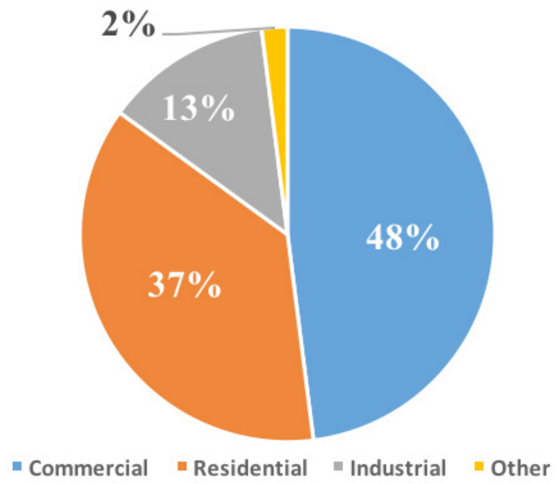

Figure 2-7: Electricity Consumption by Sector[100]

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97 Autoridad de Energia Eléctrica, 2016, "Sistem Eléctrico," https://www.aeepr.com/Aeees/sistema_electrico.asp, (in Spanish), accessed May 14, 2018.

98 Ibid.

99 PREC, undated, "About the Puerto Rico Energy Commission," http://energia.pr.gov/en/about-the-commission/, accessed May 14, 2018.

100 PREPA, undated, "Company Profile," https://www.aeepr.com/INVESTORS/CompanyProfile.aspx, accessed May 14, 2018.

Figure 2-8: Total Municipal Consumption in Millions of Kilowatt Hours (2003–2015)[101]

Maximum electricity consumption is concentrated in six areas characterized by major cities and economic hubs (figure 2-8).

- In the northwest, the **Aguadilla-Isabela-San Sebastián** metropolitan area is the second-largest metropolitan area by population in Puerto Rico. This metropolitan area also hosts a major aerospace and technological hub.
- In the north, **Arecibo and Manatí** municipalities are part of the San Juan, Caguas, and Guaynabo Metropolitan Area. Arecibo is the largest municipality in Puerto Rico by area and hosts the Arecibo Observatory. Several pharmaceutical and chemical industries are located in this region.
- In the northeast, the **San Juan Metropolitan Area** constitutes the major economic hub of the island. San Juan is the capital and most populous municipality in Puerto Rico. Furthermore, San Juan hosts the biggest seaport and is an important manufacturing, financial, cultural, and tourism center. Figure 2-9 illustrates the density of fuel transfer, power generation, and transmission infrastructure located in the San Juan Metropolitan Area.
- In the southeast, **Humacao** is an important tourist hub that also houses a satellite campus of the University of Puerto Rico.
- In the south, **Ponce** is the second-largest municipality in Puerto Rico in terms of both population and land area. A mix of critical manufacturing, agriculture, and tourism characterizes Ponce's economy.
- In the southwest, **Mayagüez and San Germán** are major cities of the Mayagüez–San Germán–Cabo Rojo Combined Statistical Area. Mayagüez is the eighth-largest municipality of Puerto Rico and hosts universities and aerospace companies. San Germán is the second-oldest city in Puerto Rico, after San Juan. Its economy is built on agriculture, while also hosting some pharmaceutical, manufacturing, and engineering companies.

[101] PREC, 2015, "Total Municipal Consumption in Millions of Kilowatt-hours," November 4, http://energia.pr.gov/en/datos/total-municipal-consumption-in-millions-of-kilowatt-hours/, accessed May 14, 2018.

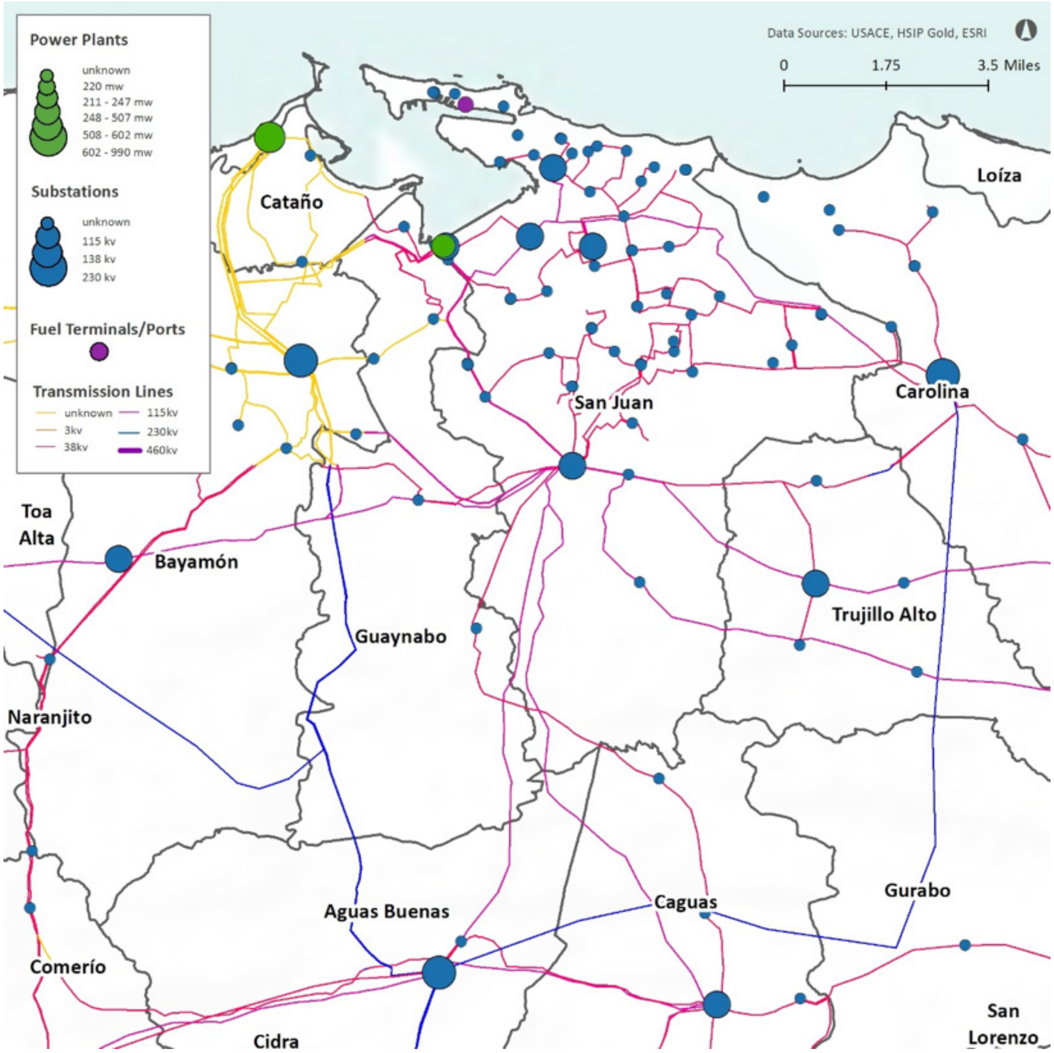


Figure 2-9: Power Generation and Transmission in the San Juan Metropolitan Area[102]

Per capita, Puerto Rico's electricity consumption is a little more than 40 percent of the U.S. average. Puerto Rico's industrial rates are approximately $0.18/kWh—almost 2.5 times the average retail price in U.S. states—but electricity rates remain lower than rates for other island utilities.[103,104] Table 2-4 compares electricity retail prices in Puerto Rico and U.S. average retail prices as of August 2017.

102 Ibid.

103 EIA, 2018, "Profile Data," April 19, https://www.eia.gov/state/data.php?sid=RQ, accessed May 14, 2018.

104 PREPA, 2017, Puerto Rico Electric Power Authority Fiscal Plan, April 28, http://www.aafaf.pr.gov/assets/fiscal-plan---pr-electric-power-authority.pdf, accessed May 14, 2018.

Table 2-4: Comparison of Electricity Retail Prices between Puerto Rico and the United States[105]

Customer Type	Puerto Rico (cents/kWh)	United States (cents/kWh)
Residential	20.47	13.19
Commercial	22.39	11.04
Industrial	18.64	7.25

2.2.4 System Interdependencies

All classes (i.e., physical, cyber, geographic, and logical) of interdependencies affect the operations of the Electricity Subsector. The characteristics of these interdependencies vary according to the level of assessment.

Physical Interdependencies

An infrastructure is physically dependent if there is a functional and structural linkage between the input(s) and output(s) of two assets: a commodity produced or modified by one infrastructure (an output) is required by another infrastructure for its operation (an input). Figure 2-10 shows the Electricity Subsector's physical interdependencies at the system level.

105 Ibid.

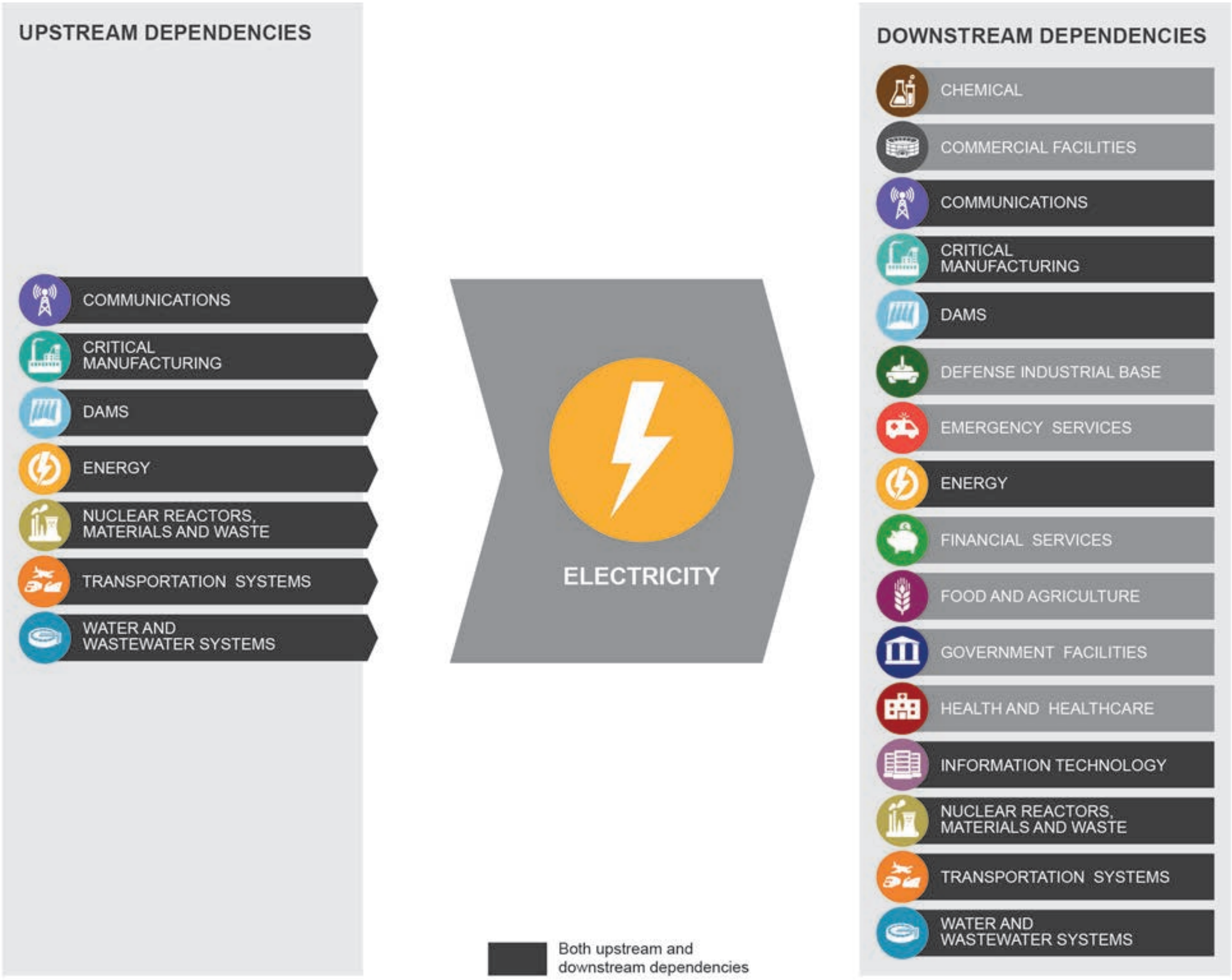


Figure 2-10: Electricity Subsector System-Level Interdependencies[106]

In Figure 2-10, the light grey shading indicates critical infrastructure sectors that depend on electricity; the dark grey shading indicates critical infrastructure sectors that are interdependent with the Electricity Subsector. Most of these sectors are the lifeline sectors. Table 2-5 presents an overview of the Electricity Subsector upstream dependencies.

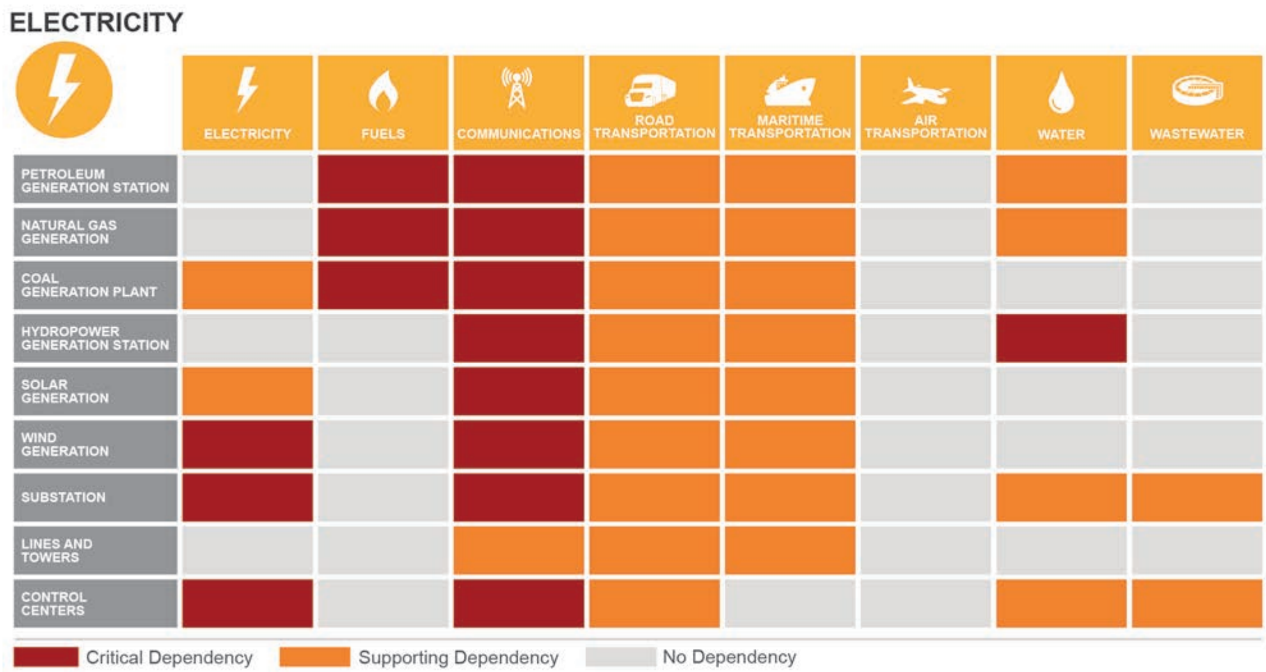
[106] Source: Argonne National Laboratory – Note that this Figure shows only dependencies and interdependencies between sectors for normal daily operations.

Table 2-5: Electricity Subsector System-Level Upstream Dependencies

Sector	Asset	Service/Resources Provided
Communications	Wired, wireless, satellite, and Internet	Telecommunication for daily operations; ICS and SCADA systems
Critical Manufacturing	Electrical equipment manufacturing	Transmission towers, generators, turbines, alternators, transformers
Dams	Water retention and conveyance structures	Production of hydroelectric power distributed by the Energy Sector
IT	Hardware, software, and electronics industries	Security hardware, routing, and switching equipment; electronic devices; data storage system; computer; printer; IT management service; operating system; control system; business software; Internet services; ICS and SCADA systems
Nuclear Reactors, Materials, and Waste	Nuclear facility	Generation of electric power distributed by the Energy Sector
Transportation Systems	Maritime, road, and mass transit assets	Fuel supply, transportation of personnel, road access for maintenance of equipment and fuel supply
Water and Wastewater Systems	Surface water and treated water distribution system	Temperature control (e.g., cooling of equipment), fire suppression, potable water, wastewater removal service, raw water supply for hydroelectric generation

The Electricity Subsector also depends heavily on other energy subsectors (i.e., natural gas, coal, and petroleum) supplying fossil fuels for power generation. These upstream dependencies can vary when considered at the asset level (table 2-6).

Table 2-6: Electricity Subsector Asset-Level Upstream Dependencies Matrix[107]



[107] Source: Argonne National Laboratory.

Red cells indicate the most critical[108] dependencies that would impact operations at the Electricity Subsector asset if the resources supplied by another sector or subsector were disrupted. Electricity Subsector assets are generally automated and therefore depend on communications and IT. The other critical upstream dependencies primarily relate to fuel supplies used for power generation. Orange cells represent less-critical upstream dependencies. They mostly encompass transportation dependencies that enable the movement of personnel, the delivery of fuels and equipment, and water and wastewater removal services for sanitary purposes. Electricity generation may require electricity to perform a "black start" of its equipment or to manage power fluctuations.

The Electricity Subsector has downstream dependencies with all 16 critical infrastructure sectors. All sectors rely on electricity, making its reliability a fundamental need and economy-wide requirement. Electricity is particularly important for heating, control systems, lighting, mechanical and electrical equipment, and security and safety. Large regional blackouts (i.e., electricity service is completely interrupted) can occur when multiple transmission lines or substations are disrupted, causing other system components to become desynchronized and fail to act as an integrated power system. Localized blackouts, rotating blackouts (i.e., subareas take turns being with/without power to preserve the maximum temporary allowable regional demand), brownouts (i.e., lights in an area temporarily burn dim), and disruptions to other critical infrastructure may occur when local transmission or distribution facilities are disrupted. In these more common occurrences, the power system outside of the impacted region remains intact and operates properly. The resulting impact of a disruption on the local or regional population largely determines the outage severity and provides an indication of the extent of restoration efforts needed to resume normal system operations.

Cyber Interdependencies

An infrastructure has a cyber dependency if its operation depends on information transmitted via electronic or informational links. Increased use of ICS and SCADA systems increase the cyber interdependencies of the Electricity Subsector. The control of most generation, transmission, and distribution systems is automated, although manual operation, in at least some limited capability, is possible at most facilities as long as staff are available to address the need. Staff will generally be stationed at most Electricity Subsector infrastructure assets except substations (unless collocated with another electricity asset such as a power plant or control center) and potentially wind and solar generation farms. Cyber dependencies pose a risk to automatic operating mechanisms such as SCADA systems used for operations at transmission and distribution system substations. Cyber dependencies increase the likelihood that multiple substations could be incapacitated from a single disruption, causing a greater impact on the customer base and potentially leading to a power outage. At a time when automation is on the rise because of existing or proposed smart grid initiatives, cyber vulnerability concerns are also increasing. Due to the nature of ICSs, many can be run without a network dependency, which typically provides the greatest security. On the other hand, the advantages of smart grid applications stem from their broader geographic representation and carry with them high network dependencies.

Geographic Interdependencies

Infrastructure is geographically dependent if an event in the local environment can create changes in those assets' state of operations. A geographic dependency occurs when infrastructure assets are in close spatial proximity. The Electricity Subsector presents several geographic interdependencies, mostly with other lifeline critical infrastructure sectors. Generally, utilities (e.g., natural gas, water, wastewater, and communications) are collocated and share the same rights of way. The strongest geographic interdependencies exist with the Communications Sector, because the communications and electricity distribution systems usually share the poles to support their overhead lines.

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[108] Based on results of an Argonne National Laboratory survey of subject matter experts

Logical Interdependencies

Logical infrastructure dependencies are attributable to human decisions and actions. Logical dependencies relate more to business and strategic decisions that affect an asset's operations. A good example of the logical interdependencies affecting the Electricity Subsector is the price fluctuation of fossil fuels that affects the development and management of generation capabilities.

2.2.4.1 Concerns, Needs, and Challenges

PREPA operates an isolated system, in challenging terrain, and is subject to a variety of natural events. In its 2017 fiscal plan, PREPA identified several key challenges that must be addressed to increase the reliability of the electricity grid in Puerto Rico:[109]

- High dependence on fuel oil and inability to diversify fuel mix,
- Safety system and record below industry standards,
- Chronic underinvestment and inconsistent management,
- Lack of institutionalized processes and procedures,
- Outdated systems and IT,
- Prolonged and ongoing recession has led to a significant drop in energy sales, and
- Delayed maintenance of electricity infrastructure.

PREPA has started to address these issues. Puerto Rico depends heavily on imported fossil fuels, leaving it vulnerable to global price fluctuations that directly affect the cost of electricity. To reduce fuel costs, the objective is to increase the share of renewable energy to reach 20 percent of the generation portfolio by 2035.[110] Furthermore, PREPA has planned to add natural gas capability at its largest generating stations, but these conversions depend on the construction of LNG import terminals and natural gas distribution infrastructure.[111] PREPA is considering different fuel alternatives and supply options to reduce generating costs.[112] Decisions on PREPA's future directions are awaiting PREPA's bankruptcy reorganization in the face of the ongoing recession and completion of an Integrated Resource Plan with the PREC.[113] PREPA planning recognizes that an atmospheric disturbance could affect the ocean transport of fuel and that PREPA should have enough fuel to supply an average of 20 generation days in its electrical power plants. It also notes that after the disturbance, the port area should facilitate the critical movement of fuels as PREPA directs.[114] In 2014, PREPA renegotiated some contracts to require energy storage equal to 30 percent of projected capacity to increase grid stability.[115]

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109 PREPA, 2017, *Puerto Rico Electric Power Authority Fiscal Plan*, April 28, http://www.aafaf.pr.gov/assets/fiscal-plan---pr-electric-power-authority.pdf, accessed May 14, 2018.

110 Energy Transition Initiative, 2015, *Energy Snapshot Puerto Rico,* March, https://www.nrel.gov/docs/fy15osti/62708.pdf, accessed May 14, 2018.

111 EIA, 2017, "Profile Analysis," September 21, https://www.eia.gov/state/analysis.php?sid=RQ, accessed May 14, 2018.

112 Ibid.

113 Ibid.

114 DHS, 2014, *Puerto Rico Resiliency Assessment.*

115 EIA, undated, "U.S. Overview," https://www.eia.gov/state/analysis.php?sid=RQ#127, accessed May 14, 2018.

PREPA has also identified immediate actions for addressing the safety issues:[116]

- Enforce safety rules/discipline,
- Develop bridge between management and union leadership,
- Deploy risk mitigation teams, and
- Establish operational risk management systems.

Considerations for Interdependent Lifeline Infrastructure in Puerto Rico

The Electricity Subsector presents several critical physical, cyber, and geographic interdependencies with the Communications and IT Sectors. However, these systems are outdated, and they introduce additional vulnerabilities. The fact that the grid was degraded, unsafe, and mostly unreliable even before Hurricane Maria led to a lack of confidence by owners and operators of dependent infrastructures. In many locations, the use of diesel generators mitigates electricity outages. In an isolated environment such as Puerto Rico, the use of backup generators may be challenging for an outage lasting for an extended period. Generator use would create an additional dependency on fuel supply, which already is the major dependency for electricity generation on the island.

Considerations for Dependent Industries and Community Functions in Puerto Rico

Private industry stakeholders reported long-standing issues with the service they receive from the electric grid. In addition to recurring power losses, stakeholders reported voltage instability issues that frequently affect internal operations. Pharmaceutical manufacturing in particular, which involves the use of sensitive instruments during fermentation and production processes, is susceptible to batch loss or contamination if these facilities have fluctuations in voltage; this instability can result in the loss of millions of dollars in product and delays in the delivery of critical pharmaceuticals by primary producers for the U.S. market.[117]

To address these issues, several large industrial stakeholders confirmed investments in prime generators and onsite cogeneration capabilities. These internal assets are dedicated to the manufacturing and internal IT systems within the facilities. Private industry stakeholders that share industrial campuses with other manufacturers are also exploring the implementation of microgrids, leveraging the Puerto Rico Industrial Development Company’s incentives for these developments.[118]

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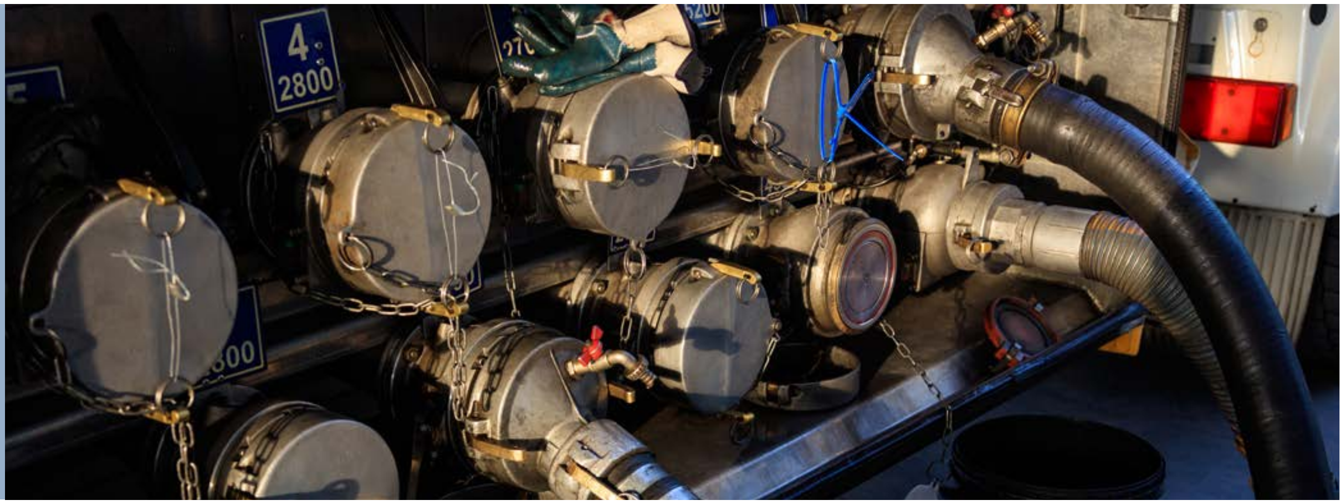
116 PREPA, 2017, *Puerto Rico Electric Power Authority Fiscal Plan*, April 28, http://www.aafaf.pr.gov/assets/fiscal-plan---pr-electric-power-authority.pdf, accessed May 14, 2018.

117 Observations derived from in-person stakeholder meetings in January and February 2018.

118 Ibid.



2.3 FUELS SUBSECTOR CHARACTERIZATION

2.3.1 Scope

This characterization summarizes how the infrastructure systems that constitute the Petroleum, Natural Gas, and Coal Subsectors (part of the Energy Sector) operate, with a focus on aspects of the system that impact resilience. This section provides a baseline understanding of how these fuel systems function in general, how they function in Puerto Rico, the interdependencies between the Petroleum, Natural Gas, and Coal Subsectors and other critical infrastructure systems, and the potential consequences that could result from cascading failures. This section complements the electricity system characterization (Section 2.2) and the maritime transportation system characterization (Section 2.7). Section 2.4 contains a brief discussion of the strong interdependencies between fuels and the Electricity and Maritime Subsectors.

2.3.2 Sector Background: General

The Petroleum, Natural Gas, and Coal Subsectors are fuel-related subsectors within the Energy Sector, as highlighted in figure 2-11. In the United States, the majority of primary energy consumption—80 percent in 2017 (figure 2-12)—is from fossil fuels (i.e., natural gas, petroleum, and coal).[119] The main energy subsectors operating in Puerto Rico are electric power, natural gas, petroleum, and coal.

[119] EIA (U.S. Energy Information Agency), 2018, *Monthly Energy Review*, April 28, 2018, https://www.eia.gov/totalenergy/data/monthly/, accessed May 15, 2018.

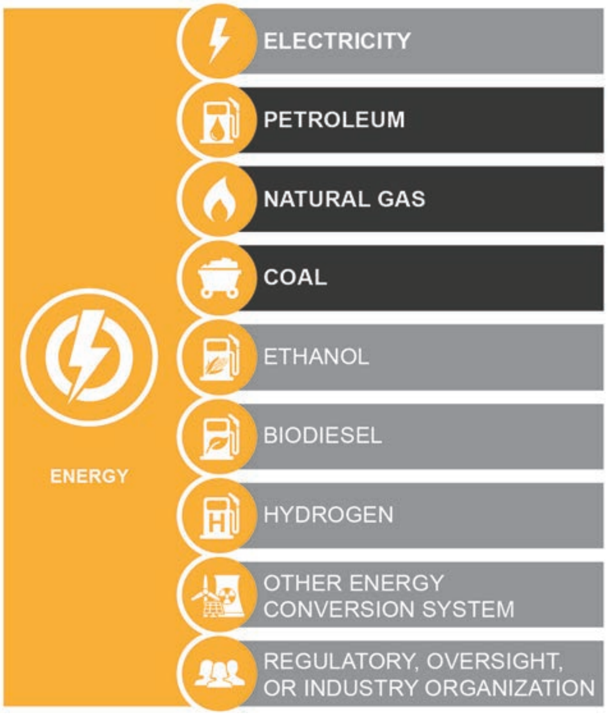


Figure 2-11: DHS Critical Infrastructure Taxonomy–Energy Sector[120]

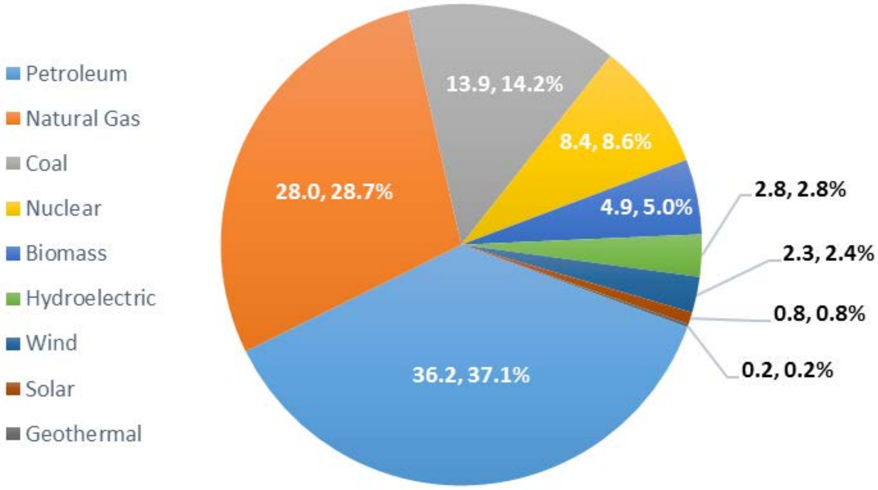


Figure 2-12: U.S. Primary Energy Consumption by Source in Quadrillion British Thermal Units (BTUs) (Quads) (2017)[121]

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120 DHS, 2011, *Infrastructure Data Taxonomy, Version 4*, National Protection and Programs Directorate, Office of Infrastructure Protection, Infrastructure Information Collection Division, June.

121 EIA, 2018, *Monthly Energy Review*, April 28, 2018, https://www.eia.gov/totalenergy/data/monthly/, accessed May 15, 2018.

2.3.2.1 Petroleum Subsector

The Petroleum Subsector is divided into crude oil and refined petroleum products. Refined petroleum products, which include diesel fuel, gasoline, jet fuel, and lubricants, are used in wide variety of applications such as chemical production, electricity production, heating, manufacturing, and transportation. The Petroleum Subsector includes the production, transportation, and storage of crude oil; processing of crude oil into petroleum products; transmission, distribution, and storage of petroleum products; and sophisticated control systems to coordinate storage and transportation, as illustrated in figure 2-13. The Petroleum Subsector is connected with the Natural Gas Subsector because oil and natural gas production wells often yield both crude oil and natural gas. Furthermore, plant condensate produced during natural gas processing is further processed at petroleum refineries, and natural gas liquids produced during natural gas processing are refined petroleum products.[122]

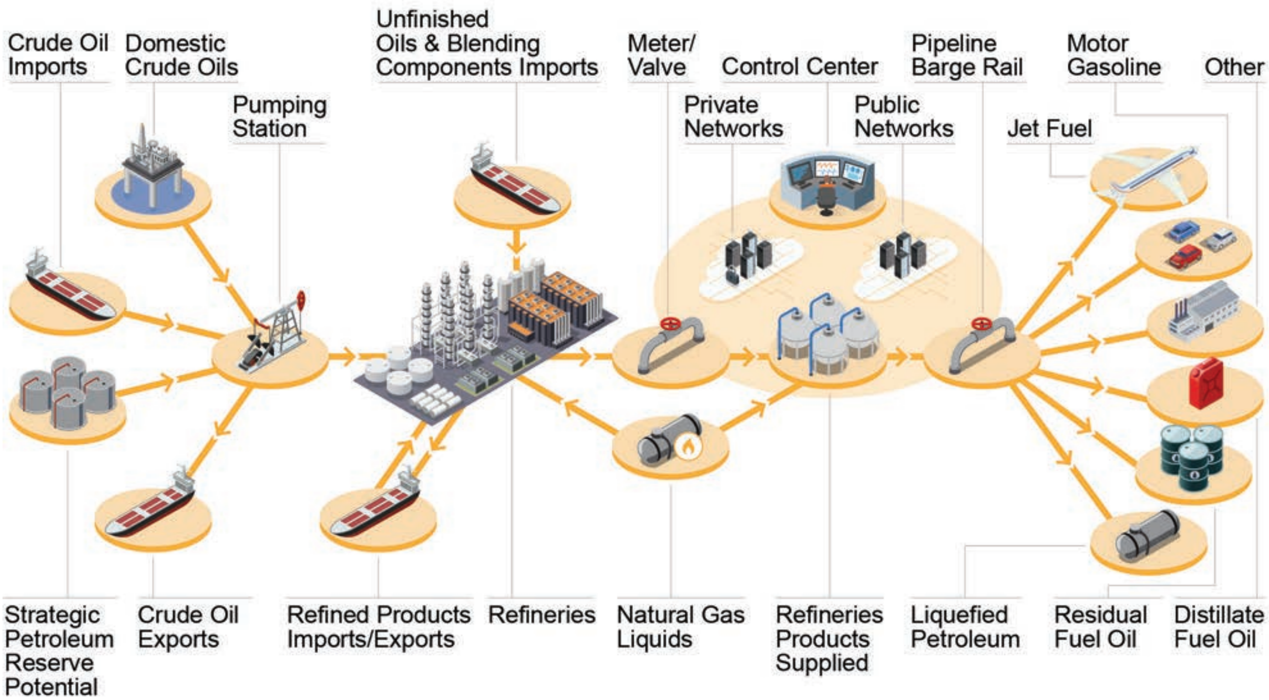

Figure 2-13: Petroleum Subsector Flow Process[123]

Petroleum accounted for 37 percent of the primary energy consumed in the United States in 2017; transportation accounted for 71 percent of all petroleum consumed in the United States in 2017.[124] From 2005–2015, petroleum net imports accounted for a decreasing portion of U.S. total petroleum consumption, declining from 60 percent in 2005 to 24 percent in 2015 as petroleum imports decreased by 31 percent and petroleum exports increased by 306 percent over this period.[125] After a slight increase in the share of petroleum imports in total petroleum consumption, net petroleum imports accounted for 19 percent of the petroleum consumed in the United States in 2017. Figure 2-14 illustrates the breakdown of petroleum consumption in the United States in 2017.

[122] EIA, 2017, "Where do Hydrocarbon Gas Liquids Come From?" December 13, https://www.eia.gov/energyexplained/index.php?page=hgls_where, accessed May 15, 2018.

[123] DHS, 2010, *Energy Sector-Specific Plan, An Annex to the National Infrastructure Protection Plan*, https://www.dhs.gov/sites/default/files/publications/nipp-ssp-energy-2010-508.pdf, accessed May 15, 2018.

[124] EIA, 2018, "Total Energy, Monthly Energy Review," April 26, https://www.eia.gov/totalenergy/data/monthly/, accessed May 15, 2018.

[125] Ibid.

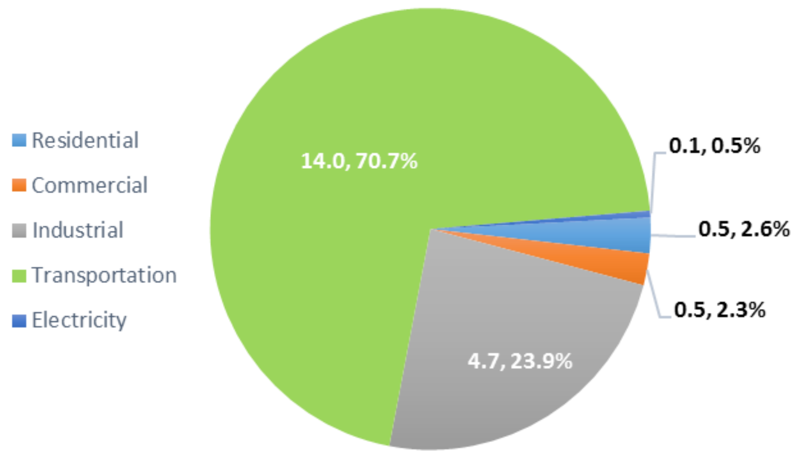

Figure 2-14: U.S. Petroleum Consumption Breakdown in Millions of Barrels per Day (2017)[126]

Petroleum products are transported primarily by pipeline, tanker, or barge, but rail tank cars or trucks are also used. Pumps along pipeline transmission routes keep crude and petroleum products moving at desired speeds and pressures. Petroleum products are stored both above and below ground at tank farms and storage fields to minimize the impacts of unwanted fluctuations in pipeline throughput and product delivery.

Control systems continuously monitor, transmit, and process pipeline data (e.g., flow rate, pressure, and speed). SCADA systems monitor and control pumping stations and track terminal inventories.

2.3.2.2 Natural Gas Subsector

The Natural Gas Subsector includes assets and facilities involved in the production, processing, storage, transport, distribution, marketing, and regulation of natural gas, as illustrated in figure 2-15. Natural gas is transported from oil and natural gas production sites and processed to remove hydrocarbons, fluids, and other gases to produce dry natural gas, which is distributed to end users or to storage facilities. Natural gas can be produced from oil and gas wells and coal beds.[127]

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126 DHS, 2010, *Energy Sector-Specific Plan, An Annex to the National Infrastructure Protection Plan*, https://www.dhs.gov/sites/default/files/publications/nipp-ssp-energy-2010-508.pdf, accessed May 15, 2018.

127 EIA, 2017, “Where Our Natural Gas Comes From,” October 25, https://www.eia.gov/energyexplained/index.php?page=natural_gas_where, accessed May 15, 2018.

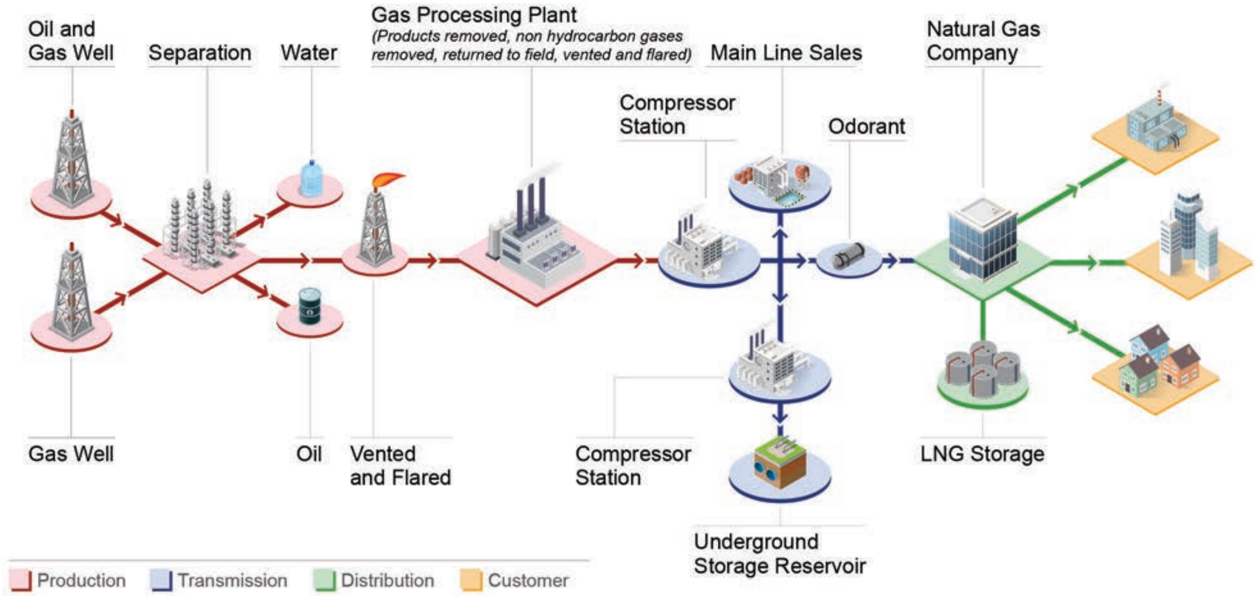

Figure 2-15: Natural Gas Subsector Flow Process[128]

Natural gas accounted for 29 percent of the primary energy consumed in the United States in 2017. Natural gas consumption in the United States is highly seasonal, with the higher demand in winter for heating and lower demand in summer. This seasonality is partially offset by the increased electricity demand in summer, which increases the natural gas consumption for electricity production.[129] Figure 2-16 provides the breakdown of the natural gas consumption in the United States in 2017.

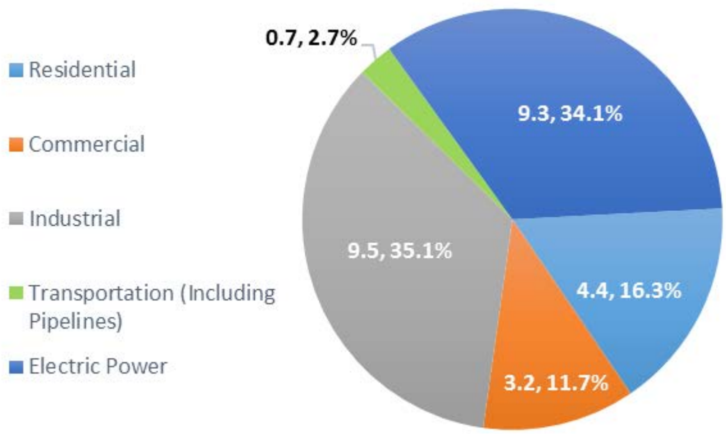

Figure 2-16: U.S. Natural Gas Consumption Breakdown in Trillion Cubic Feet (2017)[130]

128 EIA, 2018, "Delivery and Storage of Natural Gas," March 28, https://www.eia.gov/energyexplained/index.cfm?page=natural_gas_delivery, accessed May 15, 2018.

129 EIA, 2018, "Total Energy, Monthly Energy Review," April 26, https://www.eia.gov/totalenergy/data/monthly/, accessed May 15, 2018.

130 Ibid.

Pure natural gas requires processing to separate hydrocarbons, fluids, and non-hydrocarbon gases to produce "dry" natural gas that is transported by pipeline. Most processing plants are located near production facilities. The extracted natural gas is transported to a processing plant through a network of gathering pipelines. In the continental United States, the interstate pipeline network transports natural gas from processing plants in producing regions to market areas with high natural gas requirements, particularly large urban areas. Compression stations along the pipeline transmission route keep the gas moving at the desired volume and pressures. Local distribution companies typically transport natural gas from interstate pipeline delivery points to end users through millions of miles of distribution pipe. Delivery points to local distribution companies are often termed "city gates" and are important market centers for natural gas pricing. Gas is typically stored underground and under pressure as an efficient way to balance the seasonal variations in market demand with relatively constant production levels.

Liquefied natural gas (LNG) is produced by cooling natural gas to −260 degrees Fahrenheit. In its liquid state, natural gas occupies 618 times less volume than the same mass of gaseous methane at standard conditions, which allows it to be transported using specially designed ships or tankers.[131]

The Natural Gas Subsector uses complex SCADA systems and distributed control systems to monitor product flow data, such as volume, pressure, and temperature, and control the flow of natural gas. Centralized gas control stations collect, assimilate, and manage data received from compressor stations along the pipeline, and integrate gas flow and measurement data with other administrative systems such as billing and accounting.

2.3.2.3 Coal Subsector

The Coal Subsector consists of facilities and assets involved in the production, processing, storage, transport, distribution, marketing, and regulation of coal. Coal may be produced through underground mining or surface mining. Mined coal may be transported to a preparation plant that cleans it by removing impurities such as sulfur, rocks, ash, dirt, and other unwanted materials. Trains, barges, and ships transport coal, with trains accounting for over 70 percent of coal deliveries.[132,133]

The United States produced 774 million short tons of coal in 2017.[134] The majority of coal production is located in three U.S. regions: the Appalachian coal region (25 percent of national production in 2016); the Interior coal region, including Midwestern and Gulf Coast states (20 percent of national production in 2016); and the Western coal region (55 percent of national production in 2016). Wyoming produces significantly more coal than any other state, accounting for 41 percent of all coal production in the United States in 2016.[135] As of late 2016, the United States had 898 active coal mines.[136]

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131 EIA, 2017, "Liquefied Natural Gas," April 25, https://www.eia.gov/energyexplained/index.php?page=natural_gas_lng, accessed May 15, 2018.

132 EIA, 2017, "Coal Mining and Transportation," August 31, https://www.eia.gov/energyexplained/index.php?page=coal_mining, accessed May 15, 2018.

133 Coal can also be transported by slurry pipeline which involves crushing the coal and mixing it with water. However, this method is not currently used in the United States. Ibid.

134 EIA, 2018, "Total Energy, Month Energy Review," April 26, https://www.eia.gov/totalenergy/data/monthly/, accessed May 15, 2018.

135 EIA, 2017, "Where our Coal Comes From," December 18, https://www.eia.gov/energyexplained/index.php?page=coal_where, accessed May 15, 2018.

136 EIA, undated, "Coal Data Browser," https://www.eia.gov/coal/data/browser/, accessed May 15, 2018.

Coal provided 14 percent of the primary energy consumed in the United States in 2017, and its use has been has been rapidly decreasing since 2007, with a 36 percent decrease in coal consumption over this period.[137] The United States is a net exporter of coal, with net exports of 89 million short tons in 2016.[138] At the end of January 2018, the United States had 151 million short tons of coal in stocks, with the Electricity Subsector holding 82 percent of the coal stocks.[139] The Electricity Subsector accounts for almost all coal consumption; nearly 93 percent in 2017. Figure 2-17 provides the breakdown of coal consumption in the United States.

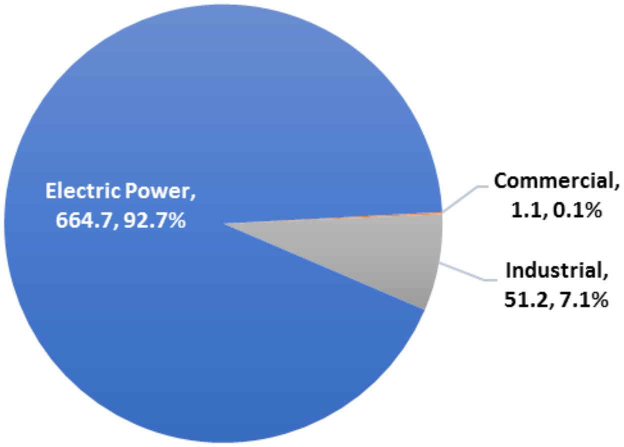

Figure 2-17: U.S. Coal Consumption Breakdown in Million Short Tons (2017)

2.3.3 Sector Background: Puerto Rico

2.3.3.1 Physical Market in Puerto Rico

The fuel consumption in Puerto Rico differs significantly from that in the rest of the United States, particularly the fuel mix used for generating electricity. Puerto Rico generates the majority of electricity using petroleum (45 percent), which accounts for only 0.5 percent of electric generation in United States (figure 2-18). This is primarily a result of legacy equipment and a lack of investment in the electric power system.[140] Given the lower cost to produce electricity using natural gas compared with petroleum, replacing old petroleum generation units with new, gas-fired, combined-cycle units or modifying the existing petroleum generation units to run on natural gas will reduce the cost of electricity production in Puerto Rico.

137 EIA, 2018, "Total Energy, Month Energy Review," April 26, https://www.eia.gov/totalenergy/data/monthly/, accessed May 15, 2018.

138 Ibid.

139 Ibid.

140 PREPA, 2017, *Puerto Rico Electric Power Authority Fiscal Plan*, April 28, http://www.aafaf.pr.gov/assets/fiscal-plan---pr-electric-power-authority.pdf, accessed May 15, 2018.

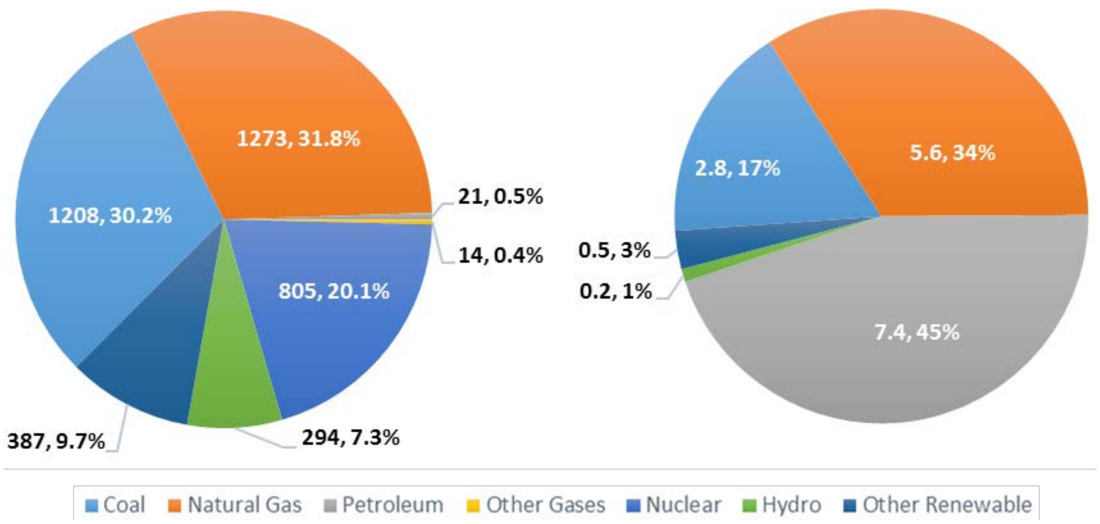

Figure 2-18: Electric Power Generation by Source (in BkWh) in the United States[141] (left, 2017) and Puerto Rico[142] (right, projected 2018)

The petroleum infrastructure in Puerto Rico consists primarily of petroleum terminals and ports. Refined petroleum products arrive in Puerto Rico at sea ports and are transported by truck to fuel terminals, power plants, and other end users. Puerto Rico previously imported crude oil and refined the crude oil at a few refineries; however, the last refinery on the island was shut down in 2009. The natural gas infrastructure in Puerto Rico consists primarily of a single LNG terminal located in Peñuelas, owned by EcoEléctrica L.P, that supplies the EcoEléctrica 507-MW power plant and two 410-MW dual-fuel units in the PREPA Costa Sur power plant via a pipeline.[143] The EcoEléctrica LNG terminal is capable of receiving LNG tankers up to 140,000 cubic meters in size and has 160,000 cubic meters (1 million barrels[144]) of onsite LNG storage.[145] FERC approved EcoEléctrica's application in August 2017 to expand operations at the LNG terminal. The expansion will increase the facility's send-out capacity to 279 million cubic feet per day, allowing the EcoEléctrica terminal to increase its annual LNG tanker shipments from 24 to 40.[146] PREPA has proposed creating a floating LNG import terminal in Aguirre to supply the PREPA Aguirre power plant and has also investigated the potential for building an LNG facility on the northern coast near San Juan.[147] Puerto Rico imports coal to the Port

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141 EIA, 2018, "Total Energy, Month Energy Review," April 26, https://www.eia.gov/totalenergy/data/monthly/, accessed May 15, 2018.

142 PREPA, 2017, Puerto Rico Electric Power Authority Fiscal Plan, April 28, http://www.aafaf.pr.gov/assets/fiscal-plan---pr-electric-power-authority.pdf, accessed May 15, 2018.

143 URS, 2013, *Fortieth Annual Report on the Electric Property of the Puerto Rico Electric Power Authority,* June, https://www.aeepr.com/INVESTORS/DOCS/Financial%20Information/Annual%20Reports/Consulting%20Engrs%20Annual%20Report%20FY2013.pdf, accessed May 15, 2018.

144 Passut, Charlie, 2017, "FERC Approves Expansion of LNG Import Terminal in Puerto Rico," *Natural Gas Intel*, August 29, http://www.naturalgasintel.com/articles/111554-ferc-approves-expansion-of-lng-import-terminal-in-puerto-rico, accessed May 15, 2018.

145 Gas Natural Fenosa, undated (in Spanish), http://www.gasnaturalfenosa.com/en/activities/global+presence/america/1285338593289/puerto+rico.html, accessed May 15, 2018.

146 Passut, Charlie, 2017, "FERC Approves Expansion of LNG Import Terminal in Puerto Rico," *Natural Gas Intel*, August 29, http://www.naturalgasintel.com/articles/111554-ferc-approves-expansion-of-lng-import-terminal-in-puerto-rico, accessed May 15, 2018.

147 Siemens Industry, 2015, *Integrated Resource Plan Volume I: Suppy Portfolios and Futures Analysis*, August 17, https://www2.aeepr.com/Documentos/Ley57/PREPA%20IRP%20Volume%20I%20%E2%80%93%20Draft%20for%20PREC%20review.PDF, accessed May 15, 2018.

of San Juan and the Port of Ponce from Columbia, and the coal is distributed by truck to end users.[148,149,150] Figure 2-19 and table 2-7 provide an overview of the primary petroleum, natural gas, and coal infrastructure assets in Puerto Rico.

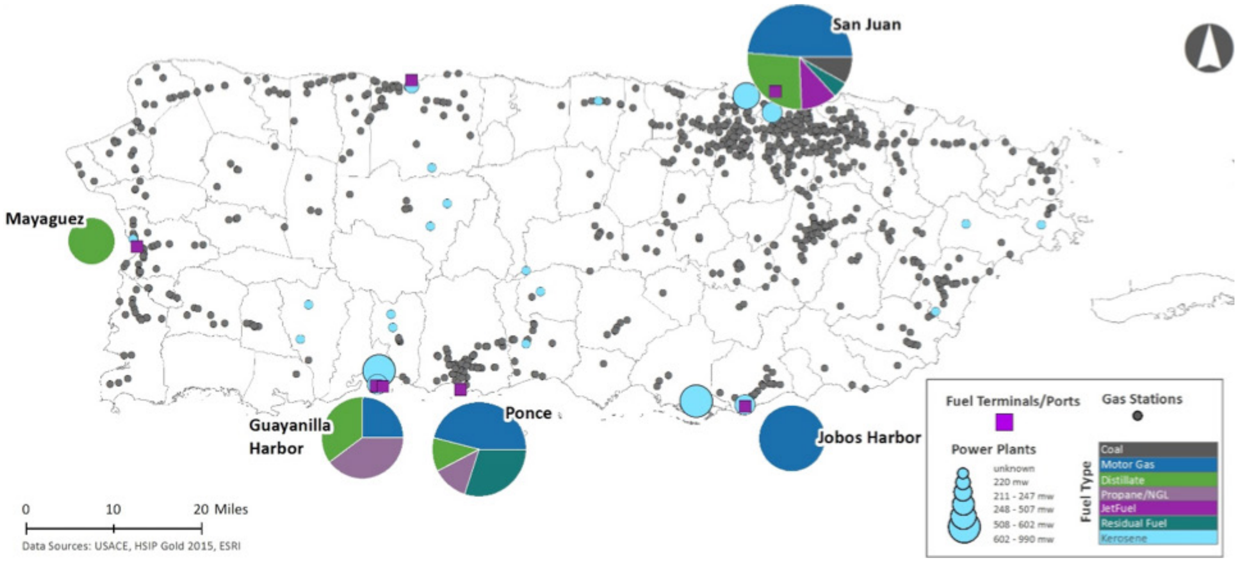

Figure 2-19: Petroleum, Natural Gas, and Coal Subsector Infrastructure in Puerto Rico

148 EIA, undated, "U.S. Overview," https://www.eia.gov/state/analysis.php?sid=RQ#34, accessed May 15, 2018.

149 Seair, undated, "Home page," https://www.seair.co.in/us-import/product-coal/port-san-juan-puerto-rico.aspx, accessed May 15, 2018.

150 Seair, undated, "Home page," https://www.seair.co.in/us-import/product-coal/port-ponce-puerto-rico.aspx, accessed May 15, 2018.

Table 2-7: Petroleum, Natural Gas, and Coal Subsector Infrastructure Asset Characteristics[151,152,153,154]

Asset Name	Asset Category	Owner/Operator	Location	Fuels Handled
Peerless Terminal	Petroleum Terminal	Peerless Oil & Chemicals Inc.	Peñuelas	Distillate fuel and refined petroleum products
Buckeye Terminal	Petroleum Terminal	Buckeye Caribbean Terminals LLC	Yabucoa	Refined petroleum
Port of Arecibo	Petroleum Port	Puerto Rico Ports Authority	Arecibo	Refined petroleum
Port of Mayagüez	Petroleum Port	Puerto Rico Ports Authority	Mayagüez	Distillate fuel
Port of Ponce (Port of the Americas)	Petroleum Port, Coal Port	Port of Ponce Authority	Ponce	Motor gasoline, motor gasoline blending components, distillate fuel, propane, residual fuel, and coal
Port of San Juan	Petroleum Port, Coal Port	Puerto Rico Ports Authority	San Juan	Motor gasoline, distillate fuel, jet fuel, kerosene, butane, propane, residual fuel, and coal
Port of Guayanilla	Petroleum Port	Puerto Rico Ports Authority	Guayanilla	Motor gasoline blending components, distillate fuel, and propane
Port of Jobos Bay	Petroleum Port	Puerto Rico Ports Authority	Guayama/ Salinas	Motor gasoline
Port of Fajardo	Petroleum Port	Puerto Rico Ports Authority	Fajardo	Distillate fuel
EcoEléctrica LNG Facility	LNG Facility	EcoEléctrica L.P.	Peñuelas	LNG

2.3.3.2 Commercial Activities in Puerto Rico

The majority of the commercial use of natural gas, petroleum, and coal in Puerto Rico occurs in the Electricity Subsector and Transportation Systems Sector. Other consumers include manufacturing companies, who may use both metallurgical and steam coal. In discussions during site visits, several manufacturing representatives mentioned that the electric power system in Puerto Rico has poor reliability. Voltage instability was identified as particularly problematic for the manufacturing sector; sudden voltage changes can cause complete failure of batches in production, causing multi-million dollar losses. The reliability issues have led several manufacturing companies to invest in

151 Petroleum terminals from: Homeland Infrastructure Foundation-Level Data, 2017, "Petroleum Terminals," https://hifld-geoplatform.opendata.arcgis.com/datasets/petroleum-terminals, accessed May 15, 2018.

152 Petroleum ports from: Homeland Infrastructure Foundation-Level Data, 2017, "Petroleum Ports," August 24, https://hifld-geoplatform.opendata.arcgis.com/datasets/petroleum-ports; EIA, 2016, "impa16d," Excel file, https://www.eia.gov/petroleum/imports/companylevel/archive/2016/data/impa16d.xlsx; and www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf; all accessed May 15, 2018.

153 LNG facility from Siemens Industry, 2015, Integrated Resource Plan Volume I: Suppy Portfolios and Futures Analysis, August 17, https://www2.aeepr.com/Documentos/Ley57/PREPA%20IRP%20Volume%20I%20%E2%80%93%20Draft%20for%20PREC%20review.PDF, accessed May 15, 2018

154 Fuels handled data from: Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico Islandwide 2040 Long Range Transportation Plan*, December, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf; EIA, 2016, "impa16d," Excel file, https://www.eia.gov/petroleum/imports/companylevel/archive/2016/data/impa16d.xlsx; and https://www.eia.gov/coal/data/browser/#/topic/39?agg=2,1,0&rank=ok&map=COAL.EXPORT_QTY.TOT-TOT-TOT.A&freq=A&start=2000&end=2016&ctype=map&ltype=pin&rtype=s&maptype=0&rse=0&pin=&mntp=g; all accessed May 15, 2018.

primary (rather than backup) electricity generators, which they use during critical points in the manufacturing process. This has caused a moderate non-utility fuel demand for electricity production.[155]

Data on fuel demand or fuel consumption in Puerto Rico are difficult to obtain, and those that are published appear to be inconsistent or incomplete, with omissions or errors in the dataset. Table 2-8 outlines fuel consumption values from EIA Puerto Rico State Profile Data[156] and the EIA International Energy Statistics dataset.[157]

Table 2-8: Puerto Rico Energy Consumption by Fuel Type[158,159,160]

Energy Source	EIA State Profile Data	EIA International Energy Statistics	Period
Total Energy (trillion BTUs)	383	317	2014
Total Petroleum Products (thousand barrels/day)	155	106	2015
Motor Gasoline (thousand barrels/day)	59	43	2013
Distillate Fuel (thousand barrels/day)	23	17	2013
Liquefied Petroleum Gases (thousand barrels/day)	3.7	2.7	2013
Jet Fuel (thousand barrels/day)	2.7	2	2013
Kerosene (thousand barrels/day)	0	0	2013
Residual Fuel (thousand barrels/day)	52	38	2013
Other Petroleum Products (thousand barrels/day)	4	2.7	2013
Natural Gas (billion cubic ft)	55	55	2014
Coal (thousand short tons)	1,963	1567	2014

Table 2-9 lists imports by individual port for petroleum and coal products, based on EIA data. While specific fuel demand is not widely available, PREPA has published some information for its electric generation assets, as well as fuel storage capabilities at individual plants. Table 2-10 provides information on major utility fossil fuel electric generation plants, as well as fuel consumption and onsite fuel storage capacity when available.

155 In-person discussions/interviews conducted between November 2017 and March 2018.

156 EIA, 2018, "Alabama Profile Data," April 19, https://www.eia.gov/state/data.php?sid=RQ#Reserves, accessed May 15, 2018.

157 EIA, undated, "International Energy Statistics," https://www.eia.gov/beta/international/data/browser/index.cfm, accessed May 15, 2018.

158 EIA, 2018, "Alabama Profile Data," April 19, https://www.eia.gov/state/data.php?sid=RQ#Reserves, accessed May 15, 2018.

159 EIA, undated, "International Energy Statistics," https://www.eia.gov/beta/international/data/browser/index.cfm, accessed May 15, 2018.

160 Central Intelligence Agency, undated, "Central America and Caribbean: Puerto Rico," https://www.cia.gov/library/publications/the-world-factbook/geos/rq.html, accessed May 15, 2018.

Table 2-9: Petroleum and Coal Imports by Port in Thousand Barrels (2016)[161,162]

Product Name	Fuel Type	Port of Guayanilla	Port of Jobos Bay	Port of Mayagüez	Port of Ponce	Port of San Juan
All Other Motor Gas Blending Components (MBGC)	Motor Gasoline	188	0	0	499	0
MGBC, Gasoline Treated as Blendstock	Motor Gasoline	0	0	0	657	0
Motor Gas, Conventional, Other	Motor Gasoline	0	138	0	4,335	10,352
Distillate, 15 parts per million (ppm) Sulfur and Under	Distillate	268	0	105	1,388	4,712
Distillate, Greater than 15 ppm to 500 ppm Sulfur	Distillate	0	0	0	0	939
Distillate, Greater than 500 ppm Sulfur	Distillate	0	0	0	0	95
Jet Fuel, Kerosene-Type	Jet Fuel	0	0	0	0	2,349
Kerosene	Kerosene	0	0	0	0	7
Normal Butane/Natural Gas Liquid (Ngl)	Normal Butane/Ngl	0	0	0	0	13
Propane/Ngl	Propane/Ngl	302	0	0	1,472	29
Residual Fuel, 0.31-1.00% Sulfur	Residual Fuel	0	0	0	3,578	758
Residual Fuel, Over 1.00% Sulfur	Residual Fuel	0	0	0	0	298
Coal, Steam Coal (thousand short tons)	Coal	0	0	0	0	1,729
Coal, Metallurgical (thousand short tons)	Coal	0	0	0	0	34

161 EIA, 2016, “impa16d,” Excel file, https://www.eia.gov/petroleum/imports/companylevel/archive/2016/data/impa16d.xlsx, accessed May 15, 2018.

162 EIA, undated, "Coal Data, Browser," https://www.eia.gov/coal/data/browser/#/topic/39?agg=2,1,0&rank=ok&map=COAL.EXPORT_QTY.TOT-TOT-TOT.A&freq=A&start=2000&end=2016&ctype=map&ltype=pin&rtype=s&maptype=0&rse=0&pin=&mntp=g, accessed May 15, 2018.

Table 2-10: Fuel Subsector Resource Demands from Electric Subsector by Municipio[163,164]

Municipio	Facility	Owner	Generator Type and Capacity	Fuel	Resource Demand	Onsite Storage
Salinas	Aguirre Generation Plant	PREPA	(2) 450 MW Steam Turbines	Residual Fuel Oil (Oil #6)	21,700 barrels per day (BPD) total	(3) 260,000 barrel capacity
			(2) 296 MW Combined Cycle Turbines	Distillate Fuel Oil (Diesel, Oil #2)		
Guayanilla	Costa Sur Generation Plant	PREPA	(2) 85 MW Steam Turbine	Residual Fuel Oil (Oil #6)		800,000 barrel capacity
			(2) 410 MW Steam Turbines	Residual Fuel Oil (Oil #6) and/or Natural Gas		
Cataño	Palo Seco Generation Plant	PREPA	(2) 85 MW and (2) 216 MW Steam Turbines	Residual Fuel Oil (Oil #6)	22,400 BPD (including the San Juan Steam Plant)	450,000 barrel capacity
San Juan	San Juan Generation Plant	PREPA	(4) 100 MW Steam Turbines	Residual Fuel Oil (Oil #6)	22,400 BPD (including the Palo Seco Steam Plant)	138,000 barrel capacity
			(2) 220 MW Combined Cycle Turbines	Distillate Fuel Oil (Diesel, Oil #2)		
Arecibo	Cambalache Generation Plant	PREPA	(3) 82.5 MW Gas Turbines	Distillate Fuel Oil (Diesel, Oil #2)		
Mayagüez	Mayagüez Generation Plant	PREPA	(4) 55 MW Gas Turbines	Distillate Fuel Oil (Diesel, Oil #2)		
Peñuelas	EcoEléctrica Cogeneration Plant	EcoEléctrica L.P.	(2) 167 MW Combustion and (1) 173 MW Steam Turbines	Natural Gas		
Guayama	AES Cogeneration Plant	AES Corporation	(2) 227 MW Steam Turbines	Coal		

163 Siemens Industry, 2015, *Integrated Resource Plan Volume I: Suppy Portfolios and Futures Analysis*, August 17, https://www2.aeepr.com/Documentos/Ley57/PREPA%20IRP%20Volume%20I%20%E2%80%93%20Draft%20for%20PREC%20review.PDF, accessed May 15, 2018.

164 URS, 2013, *Fortieth Annual Report on the Electric Property of the Puerto Rico Electric Power Authority*, June, https://www.aeepr.com/INVESTORS/DOCS/Financial%20Information/Annual%20Reports/Consulting%20Engrs%20Annual%20Report%20FY2013.pdf, accessed May 15, 2018.

2.3.4 System Interdependencies

The petroleum and natural gas fuel systems tend to have similar upstream and downstream dependencies. Figures 2-20 and 2-21 provide upstream and downstream dependencies of the Petroleum and Natural Gas Subsectors, respectively, with all other 15 critical infrastructure sectors.[165] The Coal Subsector presents some differences, as shown in figure 2-22.[166] Upstream dependencies are relatively similar except for the dependency on the Chemical Sector, which provides explosives used for coal mining. The Coal Subsector also has significantly fewer downstream dependencies than the Petroleum and Natural Gas Subsectors. In these figures, the light grey shading indicates critical infrastructure sectors that depend on either petroleum or natural gas (figures 2-21 and 2-22) or critical infrastructure sectors upon which the Coal Subsector depends; the dark grey shading indicates critical infrastructure sectors that are interdependent with the Petroleum, Natural Gas, or Coal Subsectors.

Figure 2-20: Petroleum Subsector System-Level Interdependencies

165 Source: Argonne National Laboratory – Note that this Figure shows only dependencies and interdependencies between sectors for normal daily operations.

166 Ibid.

Figure 2-21: Natural Gas Subsector System-Level Interdependencies

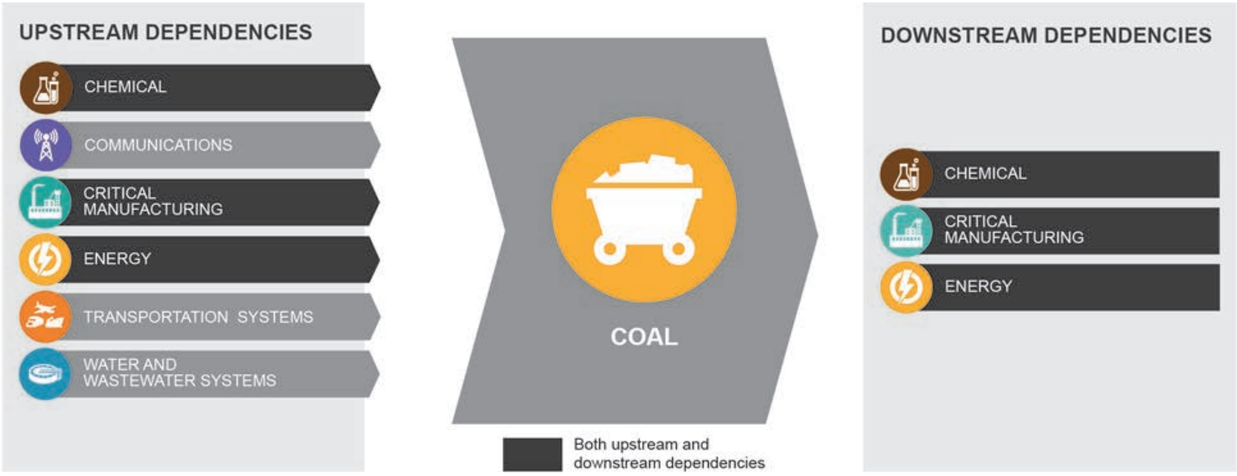

Figure 2-22: Coal Subsector System-Level Interdependencies

Interdependencies exist between the Petroleum and Natural Gas Subsectors and the Communications, Critical Manufacturing, IT, Transportation Systems, and Water and Wastewater Systems Sectors. The Coal Subsector depends on the Communications, IT, Transportation Systems, and Water and Wastewater Sectors. The Chemical and Critical Manufacturing Sectors have interdependencies with the Coal Subsector.

Interdependencies also exist within the Energy Sector. Petroleum, natural gas, and coal are used for generating electric power, while electric power is used for core operations in each fuels subsector (e.g., for pumping stations, storage, control systems). Tables 2-11, 2-12, and 2-13 describe upstream dependencies for the fuels subsectors, while Table 2-14 outlines downstream dependencies of the Coal Subsector.

Table 2-11: Petroleum Subsector System-Level Upstream Dependencies

Sector	Asset	Service/Resources Provided
Communications	Wired, wireless, satellite, and Internet	ICS and SCADA systems used to monitor and control the movement of crude and refined petroleum products; telecommunications (voice, video, data) for business operations
Critical Manufacturing	Petroleum equipment manufacturing	Storage tanks; control machinery; pumps; valves; loading and unloading material handling equipment; vapor recovery units;
IT	Hardware, software, and electronics industries	Security hardware, routing and switching equipment; electronic device; data storage system; computer; printer; IT management service; operating system; control system; business software; Internet services; ICS and SCADA systems
Transportation	Roadway assets, railway assets, maritime assets, aviation assets, pipelines	Transportation of personnel; road access for maintenance of equipment; pipeline, roadway, railway, and maritime assets for petroleum transport and delivery
Water and Wastewater	Raw water supply, treated water distribution system, wastewater collection system	Drilling; temperature control (e.g., cooling of equipment); boiler feed; processing; fire suppression; potable water; sanitation

Table 2-12: Natural Gas Subsector System-Level Upstream Dependencies

Sector	Asset	Service/Resources Provided
Communications	Wired, wireless, satellite, and Internet	ICS and SCADA systems used to monitor and control the movement of natural gas; telecommunications (voice, video, data) for business operations
Critical Manufacturing	Natural gas equipment manufacturing	Storage tanks; control machinery; pumps; valves; loading and unloading material handling equipment; vapor recovery units
IT	Hardware, software, and electronics industries	Security hardware, routing and switching equipment; electronic device; data storage system; computer; printer; IT management service; operating system; control system; business software; Internet services; ICS and SCADA systems
Transportation	Roadway assets, railway assets, maritime assets, aviation assets, pipelines	Transportation of personnel; road access for maintenance of equipment; pipeline, roadway, railway, and maritime assets for natural gas transport and delivery
Water and Wastewater	Raw water supply, treated water distribution system, wastewater collection system	Drilling; temperature control (e.g., cooling of equipment); boiler feed; processing; fire suppression; potable water; sanitation

Table 2-13: Natural Gas Subsector System-Level Downstream Dependencies

Sector	Asset	Service/Resources Provided
Chemical	Explosive manufacturing	Explosives for coal mining
Communications	Wired, wireless, satellite, and Internet	Telecommunications for business operations
Critical Manufacturing	Coal equipment manufacturing	Mining and extraction equipment; loading and unloading material handling equipment; conveyer equipment
IT	Hardware, software, and electronics industries	Security hardware, routing and switching equipment; electronic device; data storage system; computer; printer; IT management service; operating system; control system; business software; Internet services
Transportation	Roadway assets, railway assets, maritime assets	Transportation of personnel; road access for maintenance of equipment; roadway, railway, and maritime assets for coal transport and delivery
Water and Wastewater	Raw water supply, treated water distribution system, wastewater collection system	Temperature control (e.g., cooling of equipment); fire suppression; potable water; wastewater removal service; coal washing processes

Table 2-14: Coal Subsector System-Level Downstream Dependencies

Sector	Asset	Function Supported
Chemical	Multiple	Raw material used for activated carbon production, carbon fiber, and silicon metal
Critical Manufacturing	Primary metal manufacturing	Metallurgical coal critical for metal production; raw material used for carbon fiber manufacturing; cement manufacturing

The Petroleum and Natural Gas Subsectors have downstream dependencies with the other 15 critical infrastructure sectors. The Petroleum Subsector provides oils, grease, and lubricants used in machinery in most sectors and serves as the primary fuel for vehicle fleets and for the majority of backup power generation. Petroleum can also be used for heating and cooking purposes. The Road Transportation Subsector is a downstream dependency of the Petroleum Subsector because petroleum products are used in asphalt production. The Chemical Sector is another downstream dependency of the Petroleum Subsector; many refined petroleum products as used in producing various chemicals. The Natural Gas Subsector provides natural gas that the other 15 critical infrastructure sectors use for heating, steam generation, and cooking.

The petroleum, natural gas, and coal infrastructure existing in Puerto Rico is limited primarily to shipping and storage facilities. Table 2-15 maps upstream dependencies of specific fuel subsector assets in Puerto Rico to lifeline critical infrastructure subsectors and the Critical Manufacturing Sector.

Table 2-15: Fuel Asset-Level Upstream Dependencies Matrix

	Electricity Subsector	Natural Gas Subsector	Petroleum Subsector	Coal Subsector	Water Subsector	Wastewater Subsector	Communications Sector	IT Sector	Critical Manufacturing	Maritime Subsector	Aviation Subsector	Road Subsector
Petroleum Port	●				●	●	●	●	●	●		
Petroleum Terminal	●				●	●	●	●	●			●
Gas Stations	●				●	●	●	●	●			●
LNG Facility	●				●	●	●		●	●		
Coal Port	●	●			●	●	●	●	●	●		

All three fuel subsector assets rely on the Water and Wastewater and Communications Sectors for daily operations. In addition, interdependencies exist between the three fuel subsectors and the Electricity Subsector because electric power is necessary for daily operations of fuel subsector assets, and petroleum, natural gas, and coal are all used in Puerto Rico for electricity generation. Furthermore, assets of these three fuel subsectors rely on the Critical Manufacturing Sector for manufacturing of large machinery and equipment.

2.3.4.1 Concerns, Needs, and Challenges

Puerto Rico has no petroleum, natural gas, or coal production or refining operations. Thus, all these fuels must be imported to the island, introducing a significant dependency on the Maritime Transportation Subsector. Furthermore, nearly all fuel comes in through the Port of San Juan and the Port of Ponce, which makes the fuel supply particularly vulnerable; the loss of either port would likely cause large disruptions in fuel supplies.

Considerations for Interdependent Lifeline Infrastructure in Puerto Rico

The petroleum, natural gas, and coal subsectors are all critical to the Electricity Subsector in Puerto Rico. These subsectors account for nearly 96 percent of all commercial power generating capacity on the island. The Petroleum Subsector in particular is critical to the Electricity Subsector, fueling 45 percent of the island's power-generating capacity. While short-term (i.e., a few days) disruptions may have limited impacts due to fuel storage at fuel terminals and power plants, longer-term disruptions in the petroleum, natural gas, or coal subsectors would cause significant reductions in electric power service.

Considerations for Dependent Industries and Community Functions in Puerto Rico

The Critical Manufacturing Sector depends on the Coal Subsector for metallurgical production. Unique to Puerto Rico, low grid reliability has led many critical manufacturers to purchase, operate, and maintain independent primary electricity generation technology to ensure operation independent of grid performance. These manufacturers depend on the fuels that their primary generators use. This fuel demand has increased the overall fuel demand for electricity generation in Puerto Rico beyond that of electric power utilities.

2.4 COMMUNICATIONS SECTOR CHARACTERIZATION

2.4.1 Scope

This characterization summarizes how the infrastructure system that constitutes the Communications Sector operates, with a focus on system aspects that impact resilience. This section provides a baseline understanding of how the communications system functions in general, how it functions in Puerto Rico, interdependencies between the Communications Sector and other critical infrastructure systems, and the potential consequences that could result from cascading failures.

Hurricanes Irma and Maria caused catastrophic damage to much of the communication infrastructure servicing Puerto Rico and resulted in widespread disruptions to voice and data communications. The devastation was so severe that officials often had difficulty determining any single cause for the outages. Impacts from the storms included destruction of 95 percent of cellular communications sites, loss of 80 percent of aerial optical fiber installations (as a result of downed utility poles), and disruptions to the electric grid caused by offline communication systems.[167]

2.4.2 Sector Background: General

The Communications Sector consists of nine subsectors, as shown in figure 2-23.

[167] Federal Emergency Management Agency (FEMA), 2017, *DR-4339-PR Consolidated Communications Restoration Plan.*

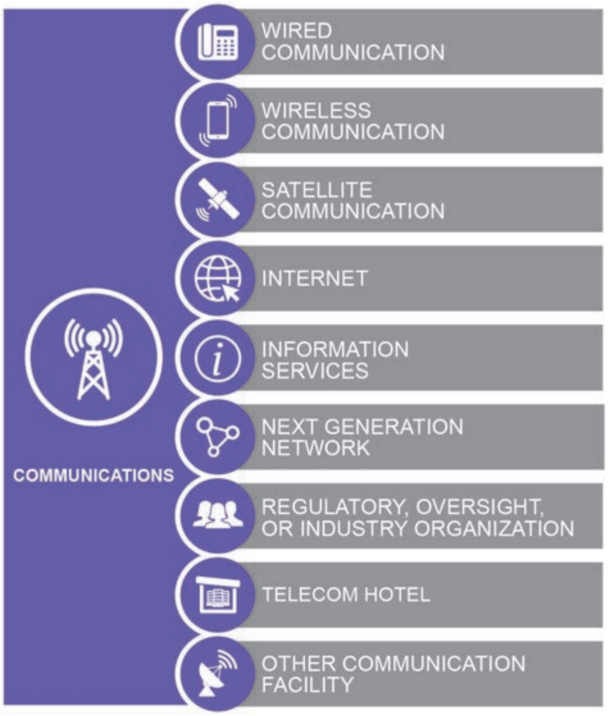

Figure 2-23: DHS Critical Infrastructure Taxonomy—Communications Sector[168]

The Communications Sector has evolved rapidly in the past decade to include mobile broadband, cloud computing, the Internet of Things, and software-defined networks. Voice and data networks have continued to converge, and mobile devices (e.g., smartphones and tablet computers) have been widely adopted, creating enormous demand for mobile broadband communications. Communication networks involve both physical infrastructure (e.g., buildings, switches, towers, antennas) and cyber infrastructure (e.g., routing and switching software, operational support systems, and user applications). The Communications Sector includes five access segments (broadcast, cable, satellite, wireless, and wireline) through which users access voice, video, and data services on the core network.[169]

Communication methods generally fall into two categories: broadcast and point-to-point. Modern communication systems/networks often combine broadcast and point-to-point technologies depending on network segment (e.g., core, metro, or access) and service type (e.g., digital subscriber line [DSL], Cable, T3, satellite).

Broadcast communication networks are networks that transmit one or many simplex information-bearing signals from a central/single location to multiple, often unaffiliated, receiving stations (e.g., cars, homes).[170] Examples include AM/FM radio; satellite, over-the-air, and cable television; and global positioning systems.

168 DHS, 2011, *Infrastructure Data Taxonomy, Version 4*, National Protection and Programs Directorate, Office of Infrastructure Protection, Infrastructure Information Collection Division, June.

169 DHS, 2015, *Communications Sector Specific Plan,* https://www.dhs.gov/sites/default/files/publications/nipp-ssp-communications-2015-508.pdf, accessed May 12, 2018.

170 Simplex communication is a communication channel that sends information in one direction only.

Point-to-point networks are designed to transmit and potentially receive signals from affiliated distant stations. Point-to-point networks can operate in simplex and duplex modes.[171] Examples include voice telephony, backhaul microwave communication systems,[172] and SCADA systems.

Figure 2-24 illustrates a simple network consisting of customer premise equipment (CPE) or end-user (UE) devices, network interface/switching nodes, and transmission links.[173] CPE/UE devices include service provider- and customer-furnished equipment that enables on-premise and mobile communications (e.g., phones, WiFi access points, modems and routers). The network interface/switching nodes represent facilities such as central offices (COs),[174] cable head-end facilities,[175] and network exchanges that enable communication between and across different networks. Finally, the links among them represent different ways that communication signals are transmitted from CPE/UE devices to switching nodes, from switching nodes to other switching nodes, and ultimately back to the receiving CPE/UE device. Radio, fiber, coaxial cable, and wired pair are the most common methods of establishing links.

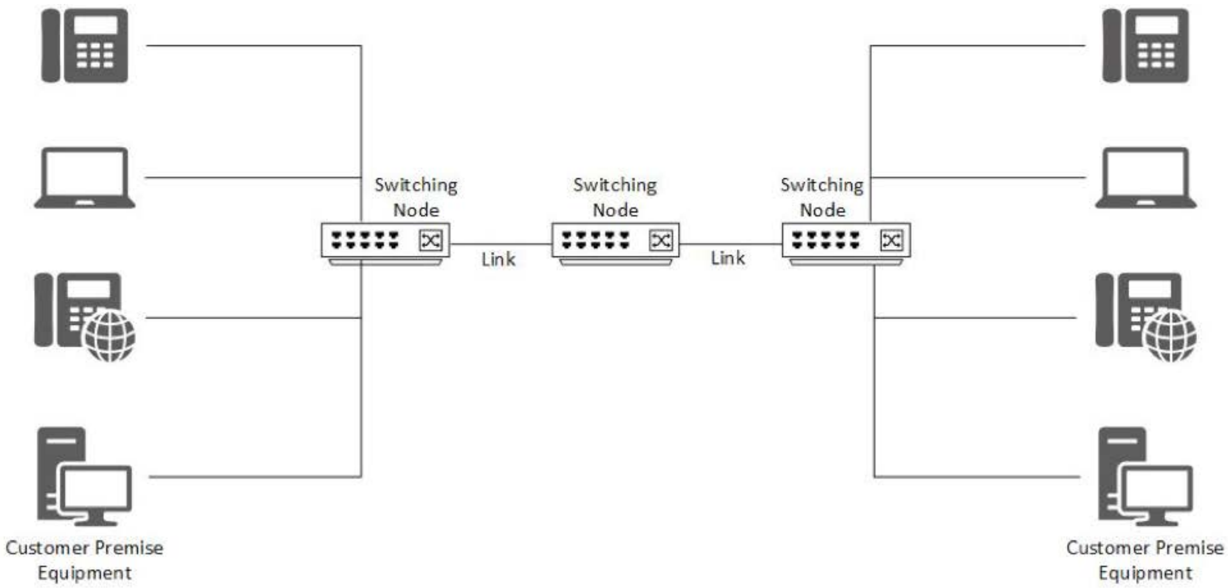

Figure 2-24: General Communications Network

171 Duplex communication is a communication channel that sends information in both directions (half and full duplex).

172 Backhaul communication is a communication channel between remote/access networks and master/core network sites, carrying multiple individual channel.

173 Derived from *Fundamentals of Telecommunications*, 2nd Edition, Wiley-IEEE Press, 2005.

174 COs are switching/exchange facilities, most often associated with the public switched telephone network.

175 Headend facilities are master facilities for receiving and multiplexing television signals; they are associated with cable television providers and now serve as points of presence (POPs) for Internet service.

2.4.2.1 Transmission Link Types

Fiber Optic Cable

Fiber optic cable consists of one or more optic fibers that are used to transmit data. Fiber optic cable transmits data as pulses of light moving through tiny tubes of glass. The transmission capacity of optical fiber cable is as much as 26,000 times higher than that of wired pair cable.[176] Outside plant fiber optic cabling can be installed in aerial, underground, and submarine configurations.

- Aerial deployments typically use existing utility poles and are less expensive than underground deployments. However, they are considerably more vulnerable to damage from wind, temperature, and ice.[177]
- In underground deployment, cables are generally considered more resistant to hazards, but installation and repair costs may be greater.
- Submarine cable deployment adds complexity and cost due to the long cable distances, harsh operating environment, and general inaccessibility. Submarine cable deployments include cable, repeaters and power feed equipment, cable landing points, and cable termination stations.[178]

When installing optical fiber cable, carriers and municipalities typically install excess capacity to allow for future growth. Carriers often exchange this spare capacity with other carriers or lease it to regional Internet service providers or businesses to help offset installation and maintenance costs. According to current estimates, 80 percent of the world's long distance voice and data communications are carried over optical fiber.[179] As discussed subsequently in section 2.4.2.2, each of the transmission link types discussed below depend on the core network for functionality.

Coaxial Cable (Coax)

Coaxial cable is widely deployed to transmit data, video, and voice communication. Coaxial cable generally provides higher data rates than wired pair and is considered more durable. Coaxial is still widely used for last-mile, on-premises, and custom communication deployments. Most coaxial networks require the installation of powered amplifiers to overcome signal attenuation when long runs are necessary. Transmission congestion is considered a major drawback of carrier-level coaxial networks because it has significant impacts on data rates during periods of high demand. As with optical fiber, coaxial cable can be installed in aerial and underground configurations with the same benefits and tradeoffs.

Wired Pair (Copper/Twisted Pair)

Wired pair cabling is the most widely deployed cable type, historically providing plain old telephone service (POTS) and—more recently—data and video communication to most homes and businesses. The primary drawback of wired pair communication is available bandwidth that limits data rates. As a result, wired pair is often used for last-mile, on-premises, and custom communication deployments.

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176 FS.com, 2013, "Fiber Optic Cable vs Twisted Pair Cable vs Coaxial Cable," March 25, https://community.fs.com/blog/the-difference-between-fiber-optic-cable-twisted-pair-and-cable.html, accessed May 14, 2018.

177 Byrne, Joe, 2018, "Key Factors when Choosing between Buried and Aerial Fiber Deployments," *PPC*, http://www.ppc-online.com/blog/key-factors-when-choosing-between-buried-and-aerial-fiber-deployments, accessed May 14, 2018.

178 Morris, Michael, 2009, "The Incredible International Submarine Cable Systems," *Network World*, April 19, https://www.networkworld.com/article/2235353/cisco-subnet/the-incredible-international-submarine-cable-systems.html, accessed May 14, 2018.

179 Alwayn, Vivek, 2004, "Fiber-Optic Technologies," *Cisco*, April 23, http://www.ciscopress.com/articles/article.asp?p=170740, accessed May 14, 2018.

Wireless (Radio)

Wireless communication occurs through the transmission and reception of radio signals. Wi-Fi, cellular, satellite, and microwave systems are all forms of radio-based communication. From a wireless link perspective, each of these segments relies on a radio set (e.g., a radio and antennae) to transmit and receive information containing radio frequencies. Figure 2-25 shows the general components needed to broadcast or establish a two-way radio link and the radio spectrum by frequency segment and common application.

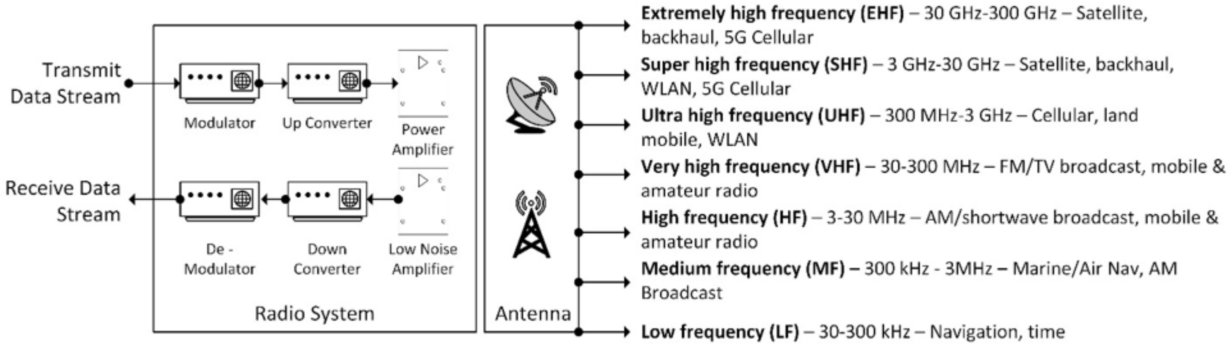

Figure 2-25: Common Radio Components and Applications

2.4.2.2 Communication Networks

Industry, commercial, government, and residential users rely on a range of technologies to meet their communications requirements. Figure 2-26 is a high-level depiction of how individual service provider networks are typically interconnected to facilitate voice, video, and data communications. These networks are often characterized by their function which include core, metropolitan (metro), or access networks, and often leverage both wired line and wireless technologies to enable communication between end-users. The core network segment provides the high-bandwidth, long-haul links that interconnect regional metro networks with one another and are often associated with the largest global telecommunication providers. The core segment infrastructure supports the full range of telecommunication voice, video, and data services through the deployment of high-capacity fiber optical cable. Core networks are typically interconnected at facilities known as exchanges or co-locations that allow the exchange of information between provider networks.

The metro network segment generally provides direct links (access) to utility, commercial, governmental customers and middle-mile services to small business and residential consumers. The segment is often referred to as the local loop. In general, most telephone and Internet service providers in urban areas (i.e., medium to large cities) install or lease fiber optical cable space to establish high-bandwidth networks. Smaller providers typically connect to larger service providers through peering agreements that provide switch/routing services. Fewer small cities and rural areas have fiber-based metro networks; in many cases, they use microwave and in some cases satellite links to backhaul aggregated local traffic to switching/routing facilities connected to the core network. This practice is also common in cellular service and private networks that service rural and remote areas.

The access network segment is currently the most diverse segment and is the direct interface with the end-user networks and CPE/UE. The access networks include wireless radio based technologies (e.g., cellular, WiFi, WiMAX, satellite), and wired networks (e.g., wired pair, cable, fiber optics). Access networks are highly dependent on the core and metro segments to switch and route traffic into and outside of the local area. For the wired access segment, the trend is to install fiber deeper into the network, often referred as Fiber to the x (FTTx); however, cable and to a lesser extent wired-pair still are widely used for the subscriber access loop. The wireless access segment uses radios to establish the access link that enables mobile communication, but the network access points—including cellular towers and WiFi hot spots—depend heavily on wired links to facilitate network connectivity. This segment also has the greatest number of service providers, which gives the impression of diversity. However, many of these last-mile providers depend directly on the larger regional providers for switching and routing services or are merely resellers that contract directly with the large local providers. Satellite-based service providers in general are not dependent on local resources, unless the distant end-user device is within the local service area. Satellite-based access is typically more expensive, bandwidth-constrained, and prone to impacts from weather events.

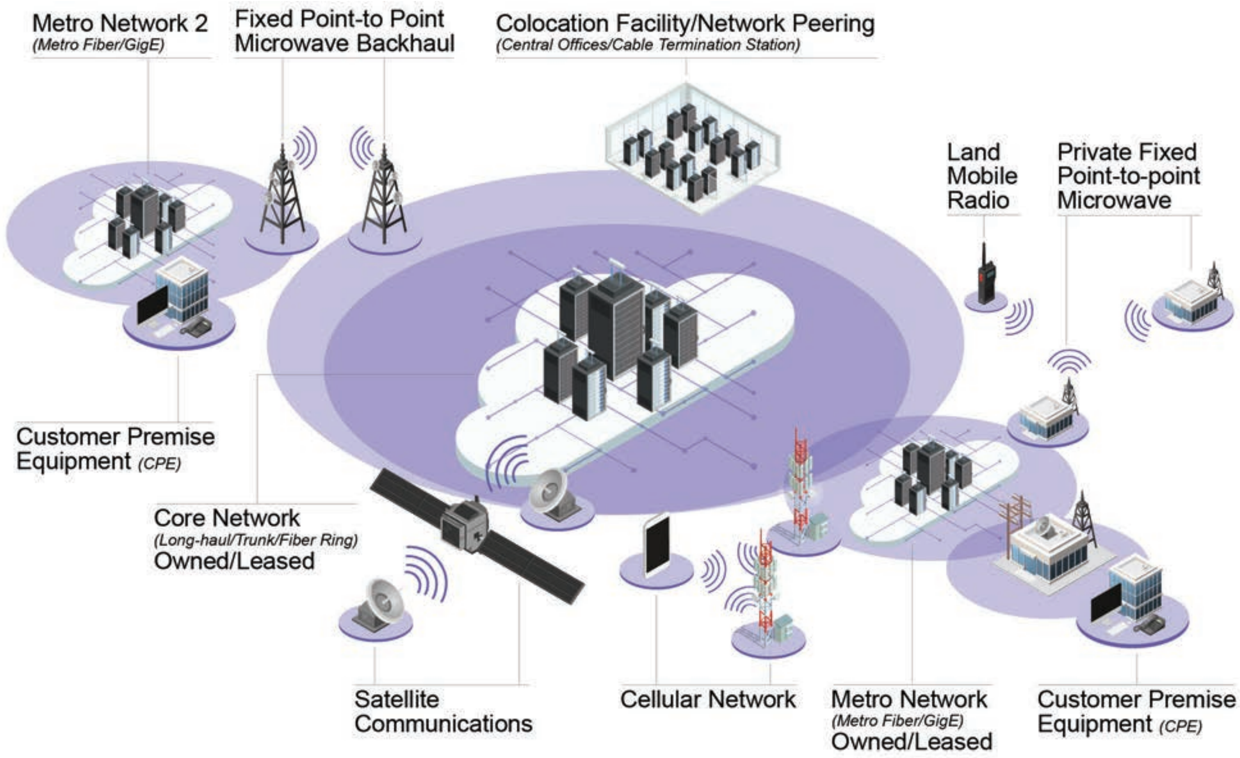

Figure 2-26: Communications Networks

Core Networks

One of the first major communication networks constructed was the public switched telephone network (PSTN), designed to provide circuit-switched voice communications. Circuit-switched networks require that the transmission path be established prior to the exchange of communications. This path remains constant throughout the conversation. The PSTN is widely associated with POTS and copper wired pairs. However, modern service providers primarily use fiber optic cables for backhaul trunk communications between COs and exchanges and limit copper pairs for last-mile communications between the CO and CPE.

The second major wired communication network grew out of the cable television coaxial cable network. Originally, the cable system was designed as a broadcast network to provide television service across the service area; however, demand for broadband Internet access drove technology advances that allowed cable providers to become Internet service providers delivering data, television, and phone services. Today, most cable providers operate what is known as a hybrid fiber-coaxial network that uses fiber optic cables to connect head-end and content delivery nodes together; they use coaxial cable segments to connect CPE to local optical nodes or directly to head-end facilities.

2.4.3 Sector Background: Puerto Rico

The Commonwealth of Puerto Rico relies on communication services that commercial, private, and public systems provide.

2.4.3.1 Commercial Communications

Multiple service providers support commercial communications in Puerto Rico. They vary in size, coverage, functions, and services offered. The sector experienced significant changes in providers through privatization and mergers over the last decade. Puerto Rico has also been a rapid adopter of wireless technologies, with only 20 percent of the population maintaining traditional landline services from Claro, the island's incumbent local exchange telephone carrier.[180] AT&T, T-Mobile, and Sprint also provide cellular telephone service in Puerto Rico. Figure 2-27 shows major components of commercial communications in Puerto Rico, including the submarine cable system, island-wide optical fiber backbones, exchange and switching facilities, metro optical fiber rings, microwave (middle mile) backhauls, and local wired and wireless services.

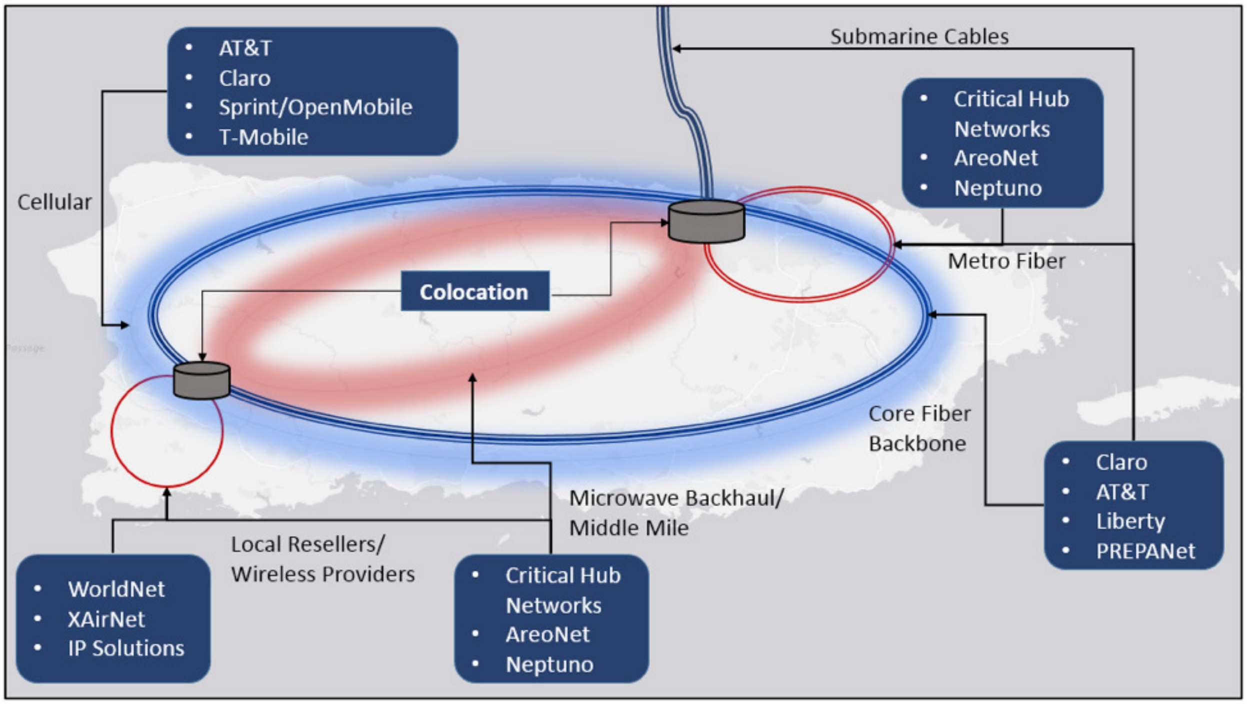

Figure 2-27: Key Components of Commercial Communication Systems in Puerto Rico

Submarine Cable System

Access to submarine optical cables is essential to most commercial communication providers in Puerto Rico, because satellite and microwave systems do not provide adequate bandwidth to maintain the quality of service that modern applications require. Satellite technologies also play an important role for critical communication channels, such as network and system management for the larger telecommunication providers. For example, AT&T was able to provide

[180] FEMA, 2017, DR-4339-PR *Consolidated Communications Restoration Plan.*

emergency restoration of voice and Short Message Service (SMS)[181] systems to some islanded cellular sites via mobile satellite radio terminals.[182]

Commercial service providers connect to submarine cables at colocation facilities known as cable landing stations. Data from TeleGeography indicate that Puerto Rico has four submarine cable landing stations, three of which service the island's telecom providers (figure 2-28) and one that the U.S. Government operates.[183] All four stations are located in the San Juan area and terminate in 13 submarine cable systems.

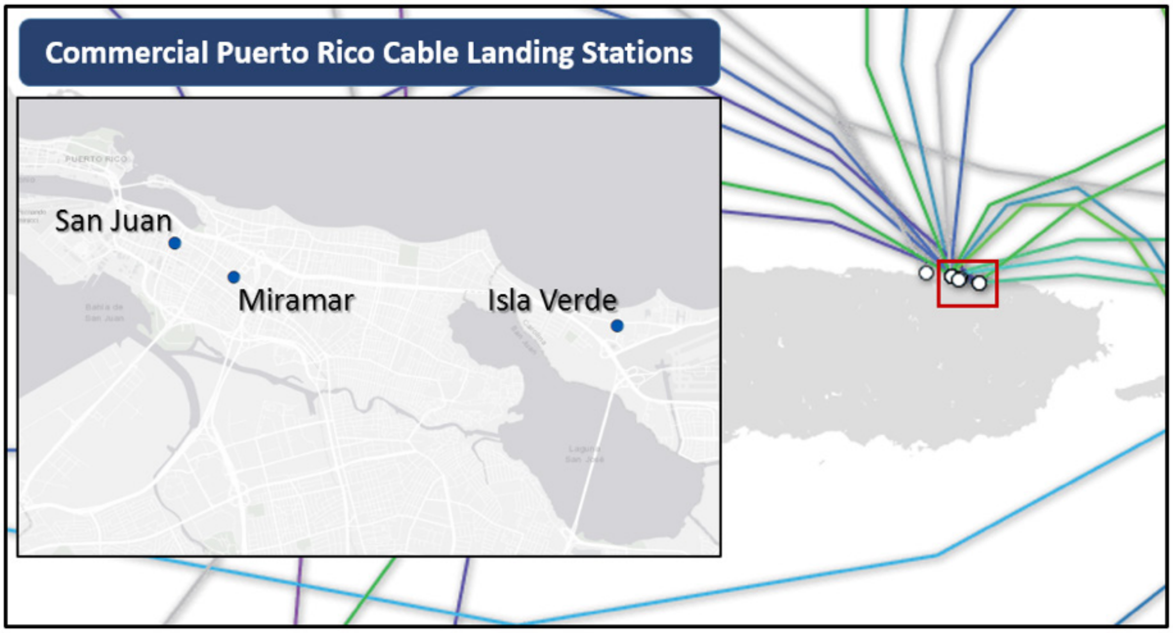

Figure 2-28: Commercial Cable Landing Stations[184]

Core and Metro Fiber Backbones

Fiber optic networks form the backbone of Puerto Rico's communication networks, interconnecting a service provider's cellular, switching, COs, and head-end facilities. One of the following providers own the majority of the fiber that traverses the island: Claro, AT&T, Liberty, or PREPANet. These providers deploy the majority of fiber optic installations in an aerial configuration along utility poles.[185] However, some providers reportedly have considerably more buried cable than others. Currently, it is not clear how much cable any one provider owns (versus leases) through indefeasible right-of-use contracts. Figure 2-29 depicts the 38-kV electricity distribution lines that are assumed to be a defensible proxy for pre-hurricane, island-wide, aerial fiber installations[186] and the Connect Puerto Rico's proposed island-wide fiber buried conduit routes.[187]

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181 SMS is a text messaging service that can include up to 160 characters.

182 AT&T News Team, 2018, "Hurricane Maria: Response & Live Updates," *AT&T*, February 2, http://about.att.com/inside_connections_blog/hurricane_maria, accessed May 14, 2018.

183 Submarine Cable Map, 2018, "Submarine Cable Map," https://www.submarinecablemap.com/, accessed May 14, 2018.

184 Ibid.

185 FEMA, 2017, DR-4339-PR *Consolidated Communications Restoration Plan.*

186 Aerial fiber installations very frequently used PREPA's electric distribution power line poles.

187 PR.gov, undated, "Sistemas de Información Geográfica (GIS)," http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed May 14, 2018.

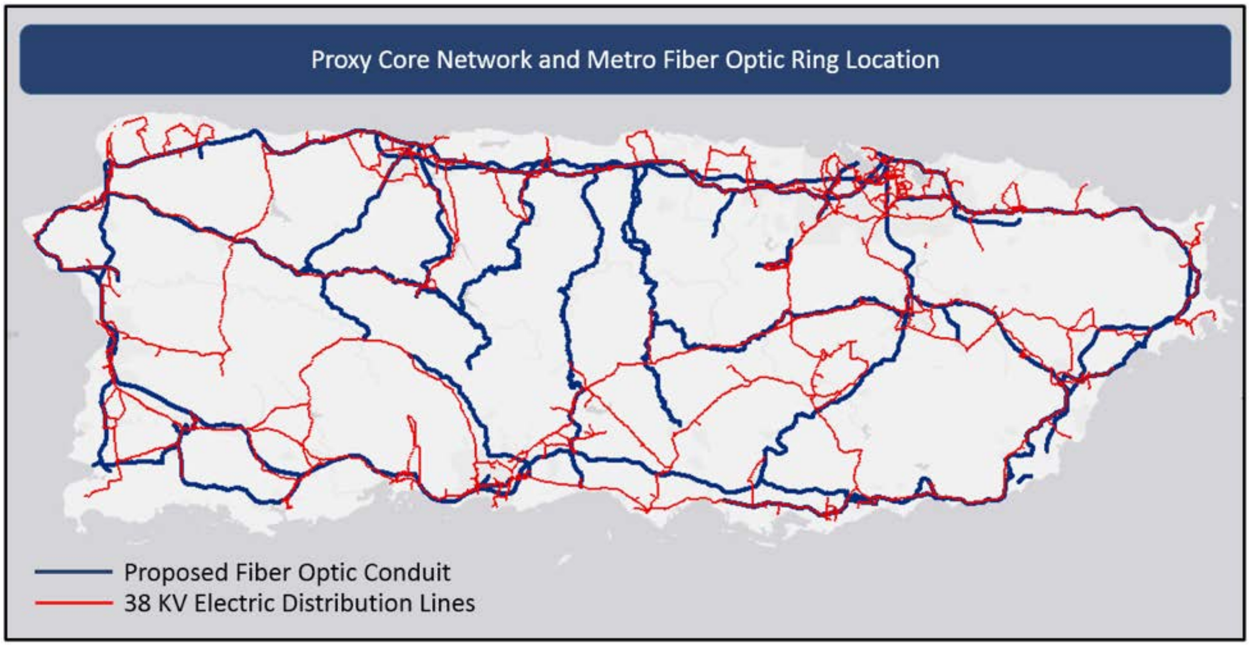

Figure 2-29: Aerial Fiber Proxy and Proposed Fiber Ring

Exchanges, Switching Facilities (Colocation/Peering), and Access Points

Exchanges and switching facilities are the interconnection points of administratively separate Internet/telecom networks. These facilities exist to exchange traffic between carrier networks and are often referred to as Internet exchanges and telecom hotels. The functions they perform now frequently occur in data centers and COs. Access points are the locations where CPE/UE devices access a service provider's network.

2.4.3.2 Commercial Providers

Claro – America Movil Group (Puerto Rico Telephone Company) – ILEC

Claro is the incumbent local exchange carrier (ILEC) in Puerto Rico. Claro offers video, voice, and broadband Internet access throughout the island. As the ILEC, Claro owns and operates local telephone switching centers and provides telephone exchanges with access and services, including interconnection, colocation, and resale services to competitive local exchange carriers (CLEC), such as AT&T and Liberty. In addition, Claro is the second-largest cellular communication provider in Puerto Rico.[188]

Claro's infrastructure includes access tandem offices, end/servicing offices, cellular tower and other fixed wireless radios, core and metro fiber optic cable, and last-mile wired-pair subscriber loop infrastructure. Claro is the sole POTS provider, but recent estimates suggest that only 20 percent of the population subscribes to this service. Figure 2-30

188 Report Linker, 2017, "Puerto Rico – Telcoms, Mobile and Broadband – Statistics and Analyses," December, https://www.reportlinker.com/p05178644/Puerto-Rico-Telecoms-Mobile-and-Broadband-Statistics-and-Analyses.html, accessed May 14, 2018.

depicts known Claro infrastructure identified through the Federal Communication Commission (FCC),[189] the commonwealth of Puerto Rico,[190] and open-source information.

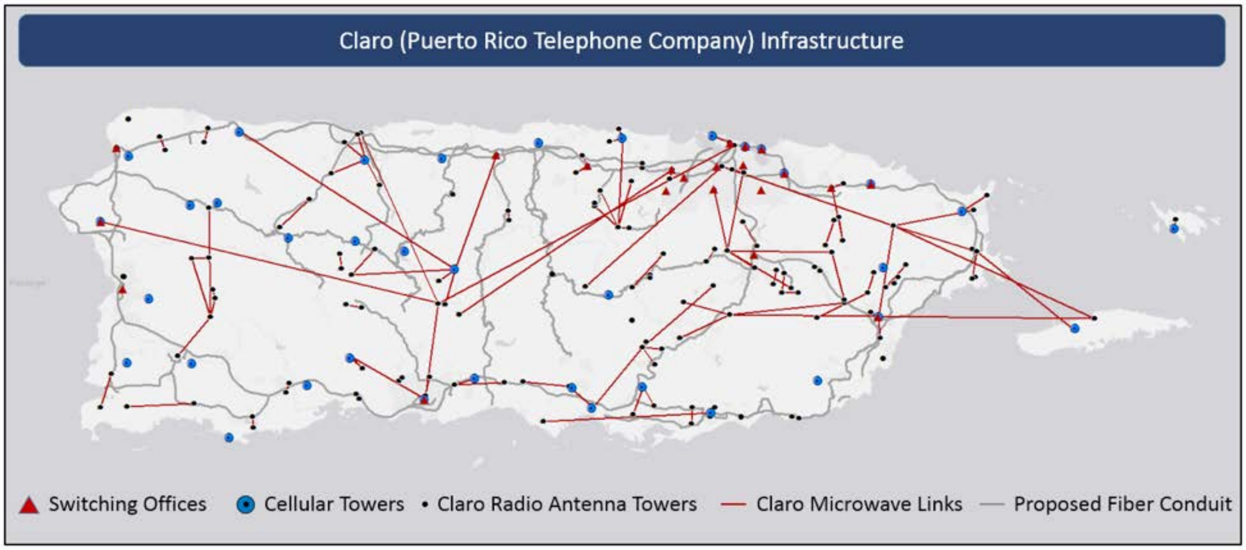

Figure 2-30: Known Claro Facilities

AT&T Mobility - CLEC

AT&T/DirectTV owns and operates a wireless and fiber optic network throughout much of Puerto Rico and offers video via direct broadcast satellite. AT&T Mobility operates the largest cellular network in Puerto Rico and is a CLEC. As a CLEC, AT&T operates its own network and switching facilities to support core operations. Most of AT&T's intra-island core network was installed in an aerial configuration on utility poles that fell during the storm and triggered major disruptions in voice and data services. In addition, AT&T has point-to-point microwave links installed for backhaul and business consumer needs.

Liberty Cablevision of Puerto Rico (Liberty) - CLEC

Liberty operates a hybrid fiber-coaxial broadband network throughout Puerto Rico, providing cable services, high-speed Internet access, voice-over-Internet protocol (VoIP)-based voice services, and a variety of point-to-point and enterprise network services. In addition to enterprise, governmental, carrier, and large-business customers, Liberty serves approximately 260,000 cable subscribers, 335,000 broadband subscribers, and 212,000 voice subscribers. The loss of the aerial fiber network also affected Liberty, causing major disruption in voice and data services.

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189 FCC (Federal Communications Commission), undated, "Search FCC Databases," https://www.fcc.gov/licensing-databases/general/search-fcc-databases, accessed May 14, 2018.

190 PR.gov, undated, "Sistemas de Información Geográfica (GIS)," http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed May 14, 2018.

PREPA Networks (PREPANet)

PREPANet is a wholly owned subsidiary of PREPA, the commonwealth-owned power company in Puerto Rico. PREPANet offers high-capacity enterprise network services to large commercial, governmental, and carrier customers. In addition, PREPANet manages all pole attachment agreements for PREPA. PREPANet mostly operates as a middle-mile provider, supplying backhaul fiber and fixed wireless infrastructure to last-mile providers. In addition to providing backhaul services, it also provides colocation services at its HUB878 facility. This facility terminates four undersea cables that service other major telecom providers.

Critical Hub Networks

Critical Hub Networks operates the Puerto Rico Bridge Initiative (PRBI) Internet exchange point (IXP). PRBI IXP was the first facility to provide colocation services to the island, alleviating the need to transmit data to Miami. In addition, the Miramar facility terminates two undersea cables, one with connectivity to Miami. Critical Hub Networks is also in the process of deploying a middle-mile microwave network throughout the island. Figure 2-31 shows the pre-hurricane microwave network.

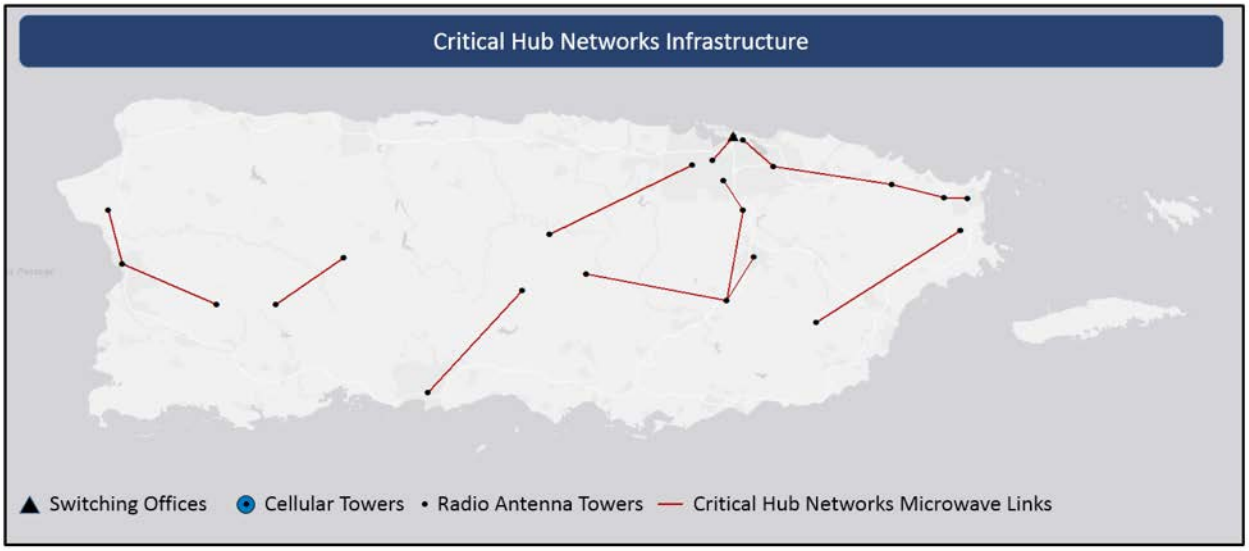

Figure 2-31: Pre-Hurricane Microwave Network for Critical Hub Network

Other Notable Commercial Communication Providers

AeroNet is a last-mile provider that focuses on CPE, wireless access points, microwave backhaul, and fiber links to the core fiber network. AeroNet appears to depend on AT&T for tier 1 routing.[191]

Neptuno is a last-mile provider that focuses on CPE, wireless access points, microwave backhaul, and fiber links to the core fiber network.

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191 AeroNet, undated, “Home page,” http://aeronetpr.com/, accessed May 14, 2018.

2.4.3.3 Public Safety Communications

Puerto Rico State Police Department

The Puerto Rico State Police Department operates a 700/800-megahertz (MHz) radio system that supports first responders on the island. The Puerto Rico State Police, Puerto Rico Emergency Management Agency, Puerto Rico Fire Department, the mass transit system, and the judicial system all use this radio system. According to documents filed with the National Telecommunications and Information Administration, this system would also support traffic signal management and traffic flow into and out of an incident area.[192]

Emergency Medical Services (EMS)/Interoperability Radio Network (P-25)

The EMS and Interoperability Radio Network share the same tower infrastructure. The Puerto Rico Emergency Management Agency maintains ownership and responsibility for the 800-MHz system, the ten 700-MHz Project 25-Compliant radios, and the nine very-high-frequency repeaters used for emergency dispatch. In August 2017, the government of Puerto Rico accepted FirstNet and AT&T's plan to provide a secure public safety network.[193]

2.4.3.4 Utility and Private Sector Communications

Large private sector corporations often install and operate their own microwave communications systems for security and automation reasons. For example, figure 2-32 shows four Healthcare Sector microwave systems. Similarly, PREPA has used multiple-address-system, radio-based infrastructure to support its SCADA/EMS system.[194] The system has also been used for the island's Automated Dam Data Acquisition and Alert Reporting System. Analysts were not able to determine whether PREPA still uses the radio system for SCADA/EMS or has transitioned completely to fiber (PREPANet).

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192 National Telecommunications and Information Administration, undated, "Application for Federal Assistance SF-424," https://www.ntia.doc.gov/files/ntia/publications/puerto_rico_proposal_w_line_item_budget.pdf, accessed May 14, 2018.

193 FirstNet, 2017, "Puerto Rico to Transform Communications for Public Safety; Governor Rosselló Approves Buildout Plan for First Responder Network," August 31, https://www.firstnet.gov/news/puerto-rico-transform-communications-public-safety-governor-rossell%C3%B3-approves-buildout-plan, accessed May 14, 2018.

194 Electric Light & Power, 2000, "Building a Communications Infrastructure to Maximize SCADA/EMS Investment," June 1, https://www.elp.com/articles/powergrid_international/print/volume-5/issue-5/features/building-a-communications-infrastructure-to-maximize-scada-ems-investment.html, accessed May 14, 2018.

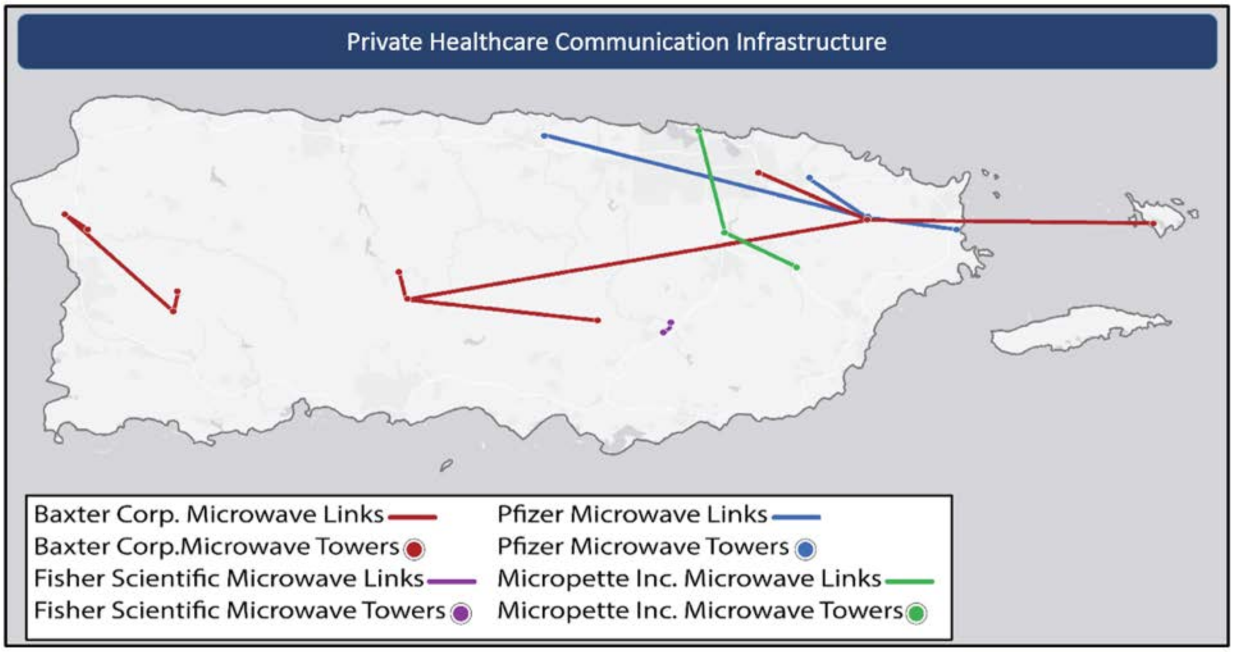

Figure 2-32: Healthcare Microwave Systems

2.4.4 System Interdependencies

The primary cross-sector dependency of the Communications Sector is on electricity, which is either provided from commercial power or by onsite generation. Water can be a dependency for facilities that require heating, ventilation, and air-conditioning or cooling (e.g., data centers). Surface transportation routes are generally necessary to enable access to communication infrastructure throughout Puerto Rico.

The following subsections highlight known dependencies for specific providers.

2.4.4.1 Claro

Infrastructure and system dependencies include the following:

- Claro's two access tandem switching facilities are essential to the island's 9-1-1 services[195] as well as interstate and intra-island switching.
- Claro operates the telephone switching centers that enable interconnection to the PSTN.
- Claro depends on PREPA for electricity.
- All of Claro's primary switching facilities are within the PRASA Metropolitan Water System and rely on those PRASA facilities for water and wastewater service.

[195] FEMA, DR-4339-PR *Consolidated Communications Restoration Plan*, 11.

Service providers that depend on Claro's physical infrastructure include the following:

- PRW.Net (DSL provider), and
- WorldNet (DSL provider).

2.4.4.2 AT&T

Infrastructure and system dependencies for AT&T include the following:

- AT&T depends on PREPA for electricity.
- AT&T depends on PREPA/PREPANet for utility pole access and attachment.
- AT&T depends on PREPANet for colocation services at the Isla Verde Cable Station (HUB787).
- Some AT&T services depend on Claro's access tandem facilities.

2.4.4.3 Liberty

Infrastructure and system dependencies include the following:

- Liberty depends on PREPA for electricity.
- Liberty depends on PREPA/PREPANet for utility pole access and attachment.
- Liberty VoIP services depend on Claro's access tandem facilities.

2.4.4.4 PREPANet

Infrastructure and system dependencies include the following:

- PREPANet depends on PREPA for electricity.
- PREPANet depends on PREPA/PREPANet for utility pole access and attachment.
- HUB 878 is within the PRASA Metropolitan Water System and rely on those PRASA facilities for water and wastewater service.
- PREPANet VoIP services depend on Claro's access tandem facilities.

2.4.4.5 Critical Hub Network

Infrastructure and system dependencies include the following:

- Critical Hub Network depends on PREPA for electricity.
- Critical Hub Network depends on PREPA/PREPANet for utility pole access and attachment.
- Critical Hub Network's data center and cable landing station are within the PRASA Metropolitan Water System and rely on those PRASA facilities for water and wastewater service.
- Critical Hub Network's VoIP services depend on Claro's access tandem facilities.

2.4.4.6 AeroNet

Infrastructure and system dependencies include the following:

- AeroNet depends on PREPA for electricity.
- AeroNet's VoIP services depend on Claro's access tandem facilities.
- AeroNet's point of presence and data center are within the PRASA Metropolitan Water System and rely on those PRASA facilities for water and wastewater service.

2.4.4.7 Neptuno

Infrastructure and system dependencies include the following:

- Neptuno depends on PREPA for electricity.
- Neptuno's VoIP services depend on Claro's access tandem facilities.
- Neptuno's point of presence and data center are within the PRASA Metropolitan Water System and rely on those PRASA facilities for water and wastewater service.

2.5 WATER SUBSECTOR CHARACTERIZATION

2.5.1 Scope

This characterization summarizes how the infrastructure system that constitutes the Water Subsector operates, with a focus on system aspects that impact resilience. This section provides a baseline understanding of how the water system functions in general, how it functions in Puerto Rico, interdependencies between the Water Subsector and other critical infrastructure systems, and the potential consequences that could result from cascading failures.

Following Hurricanes Irma and Maria substantial disruptions to the treatment and delivery of clean drinking water have plagued Puerto Rico. These disruptions were caused by direct damage to water treatment infrastructure and loss of critical water treatment dependencies, especially electrical power. Although Puerto Rico was dealing with drinking water infrastructure problems prior to the hurricanes, the storms greatly magnified the problems.

2.5.2 Sector Background: General

The Water and Wastewater Systems Sector includes ten subsectors, eight of them involving the potable water systems addressed in this section, as shown in figure 2-33.

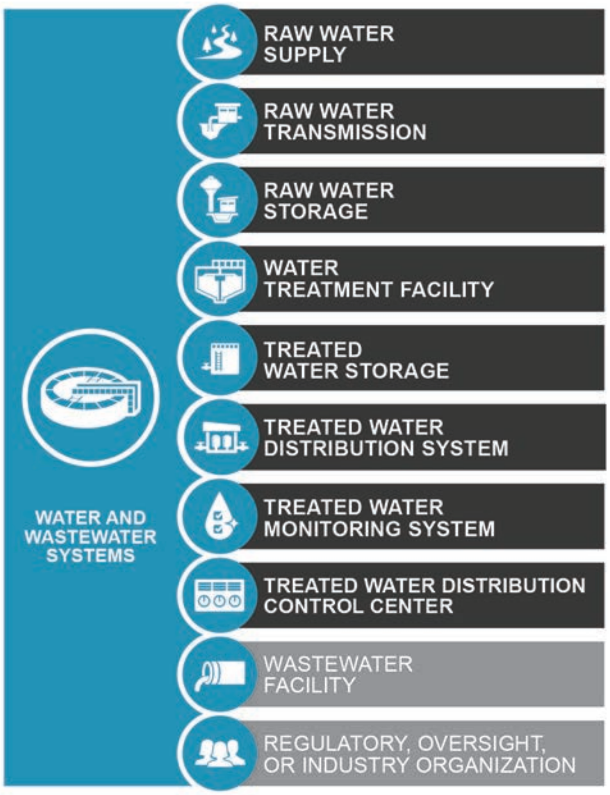

Figure 2-33: DHS Critical Infrastructure Taxonomy – Water and Wastewater Systems Sector[196]

[196] DHS, 2011, *Infrastructure Data Taxonomy, Version 4*, National Protection and Programs Directorate, Office of Infrastructure Protection, Infrastructure Information Collection Division, June.

Water used for drinking, sanitation, industrial and manufacturing processes, or safety-related activities must first be processed through a water treatment facility. Water from reservoirs, streams, and rivers often contains a variety of organisms and dissolved chemicals or metals. This material must be removed from the water to ensure that it is safe for drinking or other uses.[197]

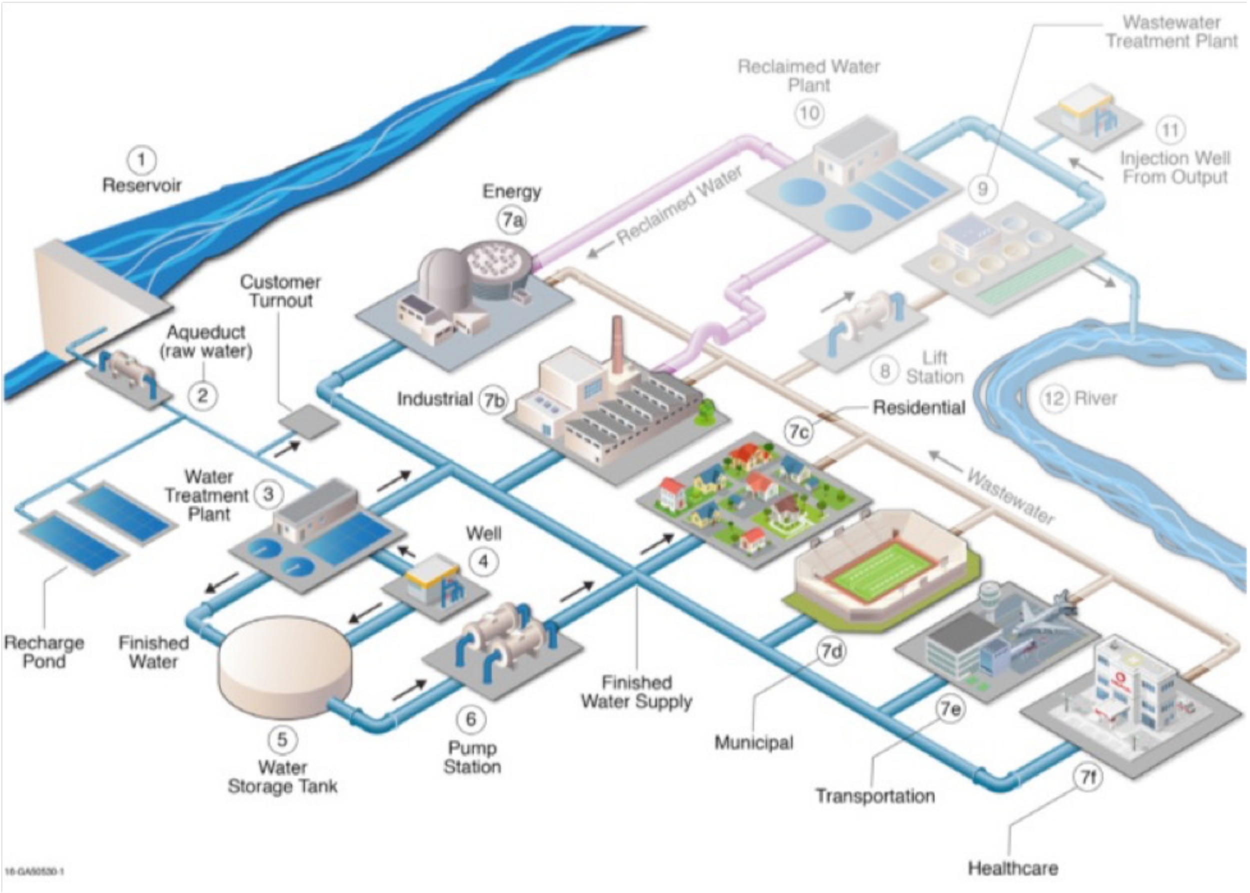

Figure 2-34: Water Treatment Operational Process[198]

Water systems contain a complex network of physical, technological, administrative, and cyber components. These systems are often distributed over a wide array of geographical regions and connected through ICSs and SCADA systems for monitoring and control of operational processes. Typical components of water systems (depicted in figure 2-34, with assets in the process denoted by numbers) include the following:

- **Water Sources** – These include surface reservoirs (1), rivers (12), and ground water from aquifers via wells (4). Utilities often use a combination of multiple water sources to ensure an uninterrupted supply.
- **Conveyance** – Raw water must be pumped or gravity-fed from a remote source to the location of treatment. Conveyance can include a complex network of manmade reservoirs (1), aqueducts (2), and canals or natural rivers (12).

[197] DHS Office of Cyber and Infrastructure Analysis (OCIA), 2014, *Sector Resilience Report: Water and Wastwater Systems.*

[198] Graphic developed by Idaho National Laboratory.

- **Treatment** – These processes include a wide variety of technological and industrial processes, both upstream and downstream from customers. Upstream processes include water treatment (3), storage (5), and pump stations (6) to maintain required water pressure. Downstream processes include wastewater treatment (9) and lift stations (8).
- **Distribution and Collection** – Water networks are similar for raw water, reclaimed water, and wastewater. They include a series of pipes (depicted in blue, purple, and brown in figure 2-35), storage tanks, pumps, valves, and gates. Flow rates are adjusted to ensure that the required pressure is available where it is needed.
- **Monitoring** – Water quality and other operational characteristics (e.g., pressure, volume, flow rate, chemistry) are continuously monitored through technological networks, helping operators maintain optimal operational conditions and ensuring that system regulations are met.
- **Cyber** – Cyber systems may include electronic components, controllers, sensors, networks, computers, human machine interfaces, displays, communications, physical security attributes, monitoring systems, and heating or ventilation used to provide water services.

2.5.3 Sector Background: Puerto Rico

Puerto Rico's residents and its thousands of businesses rely on the delivery of approximately 448 million gallons of treated water each day.[199] Approximately 97 percent of this water is captured, treated, and delivered by the Puerto Rico Aqueduct and Sewer Authority (PRASA). PRASA's water system comprises raw water supply and intake facilities (e.g., water reservoirs, river dams, intakes, groundwater wells), water treatment plants (WTPs), and distribution systems (e.g., pipelines, pump stations, and storage tanks).[200] PRASA administers its water system through five water management regions (WMRs):

- Metro (the San Juan metropolitan area),
- North,
- South,
- East (includes the islands of Culebra and Vieques), and
- West.

Each region is divided into 18 operational zones, which are further broken down into potable water service (PWS) areas that provide the local-level water service. PWS areas are served mainly by a specific WTP and its associated distribution system and are generally delineated by the area's topography and infrastructure extent.[201]

The Metro WMR serves the densely populated San Juan metropolitan area surrounding the port of San Juan. Figure 2-35 illustrates population densities within each WMR.

199 Puerto Rico Aqueduct and Sewer Authority (PRASA). 2015. *PRASA's Metro Region - Water Resources Management Plan.* s.l. : PRASA, 2015

200 Ibid.

201 Ibid.

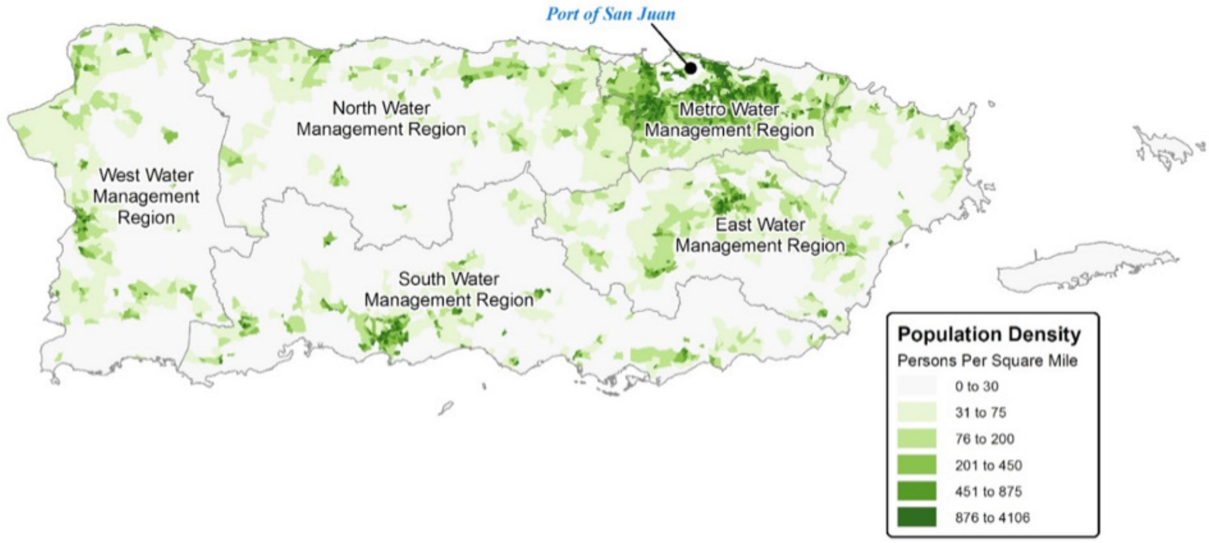

Figure 2-35: PRASA Water Management Regions and Population Densities[202]

According to U.S. Environmental Protection Agency (EPA) data, water is delivered to Puerto Rico's citizens by 404 community water systems. Of these, 205 are groundwater sources accessed through both PRASA-owned and private wells and 199 are surface water sources (rivers, streams, lakes, and reservoirs).[203] Figures 2-36 and 2-37 illustrate each of these sources and the number of citizens they serve.

Of the 404 community water systems PRASA uses as sources of drinking water, only five serve more than 100,000 people. Each of these is a surface water system (shown to the far left of the bar graph in figure 2-36). These five include the island's two largest systems—Metropolitan and Superacueducto—which serve approximately 1.3 million people along the north coast and in the greater San Juan metropolitan area.

202 U.S. Census Bureau. American Fact Finder - 2017 Population Estimate, https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml?src=bkmk, accessed March 23, 2018; State Government of Puerto Rico. Portal Datos Geograficos Gubernamentales, http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

203 EPA, 2018, *Safe Drinking Water Information System (SDWIS),* https://oaspub.epa.gov/enviro/sdw_query_v3.get_list?wsys_name=&fac_search=fac_beginning&fac_county=&fac_city=&pop_serv=500&pop_serv=3300&pop_serv=10000&pop_serv=100000&pop_serv=100001&sys_status=active&pop_serv=&wsys_id=&fac_state=PR&last_fac_name=&page=1 , accessed January 15, 2018.

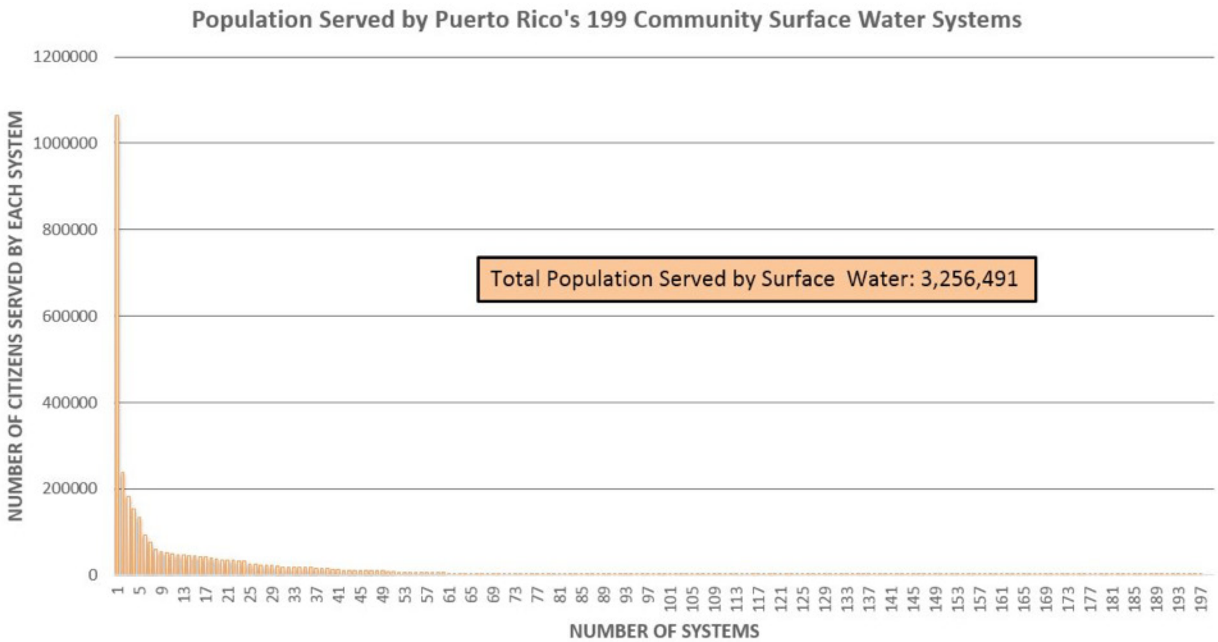

Figure 2-36: Number of Groundwater Systems in Puerto Rico and Number of People Served (EPA)

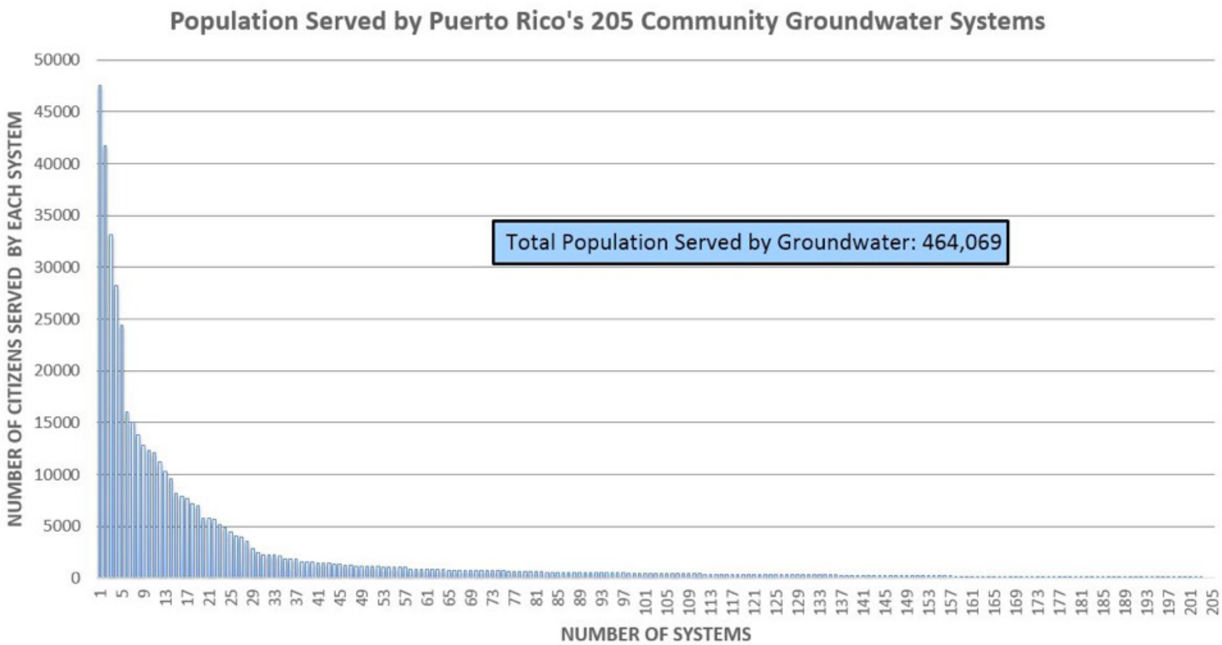

Figure 2-37: Number of Surface Water Systems in Puerto Rico and Number of People Served (EPA)

Although the 404 community water systems in Puerto Rico serve the majority of people on the island, the EPA also lists an additional 63 non-transient/non-community and private water systems. Of these, 56 are groundwater systems accessed by wells; the remaining seven are surface water systems. These systems serve hospitals, pharmaceutical manufacturing companies, power plants, farms, schools, recreation areas, and research facilities. Although business is the primary purpose of these private and non-community systems, approximately 45,600 citizens are also served by these sources.[204]

Surface water sources provide the majority of Puerto Rico's drinking water, but unlike water drawn from many of the commonwealth's freshwater wells, surface water must be treated prior to distribution and consumption. As Puerto Rico's only public water utility company, PRASA owns and operates 114 WTPs across the island.[205] Figure 2-38 shows these facility locations and their treatment capacities.

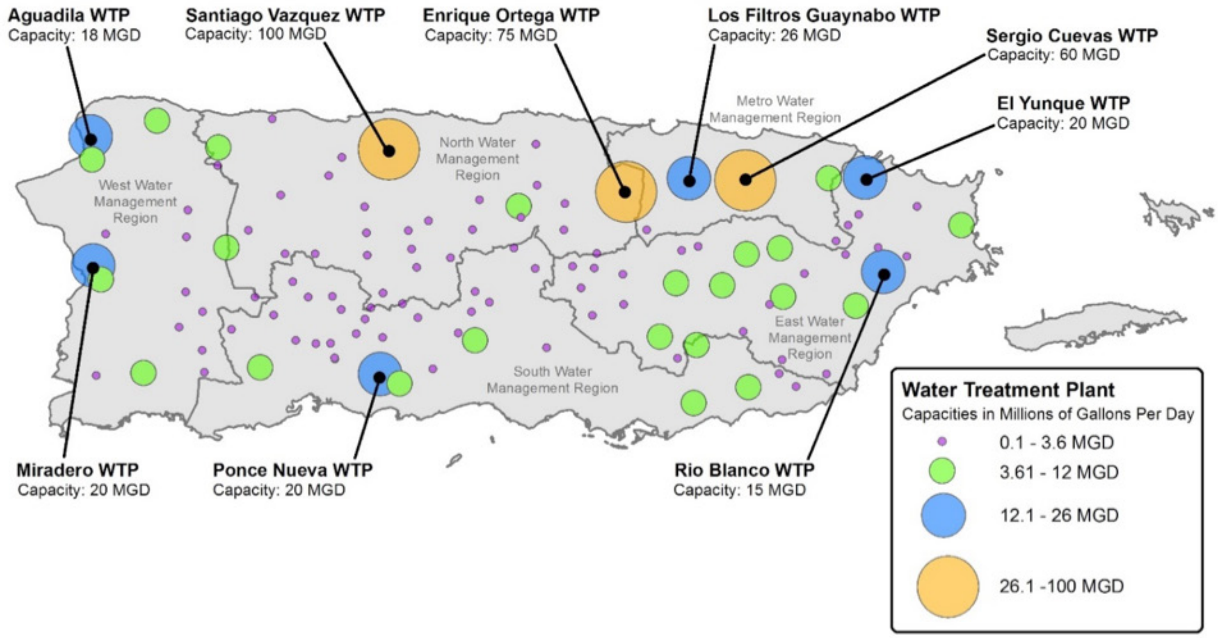

Figure 2-38: Puerto Rico Potable Water Treatment Plants and Capacities

Overall, approximately 86 percent of Puerto Rico's citizens obtain their potable water from surface resources, while the remaining 14 percent receive water from wells. Average rainfall amounts and seasonal monsoons in Puerto Rico are typically sufficient to keep reservoirs filled and to sustain potable water supplies for the island. However, periodic droughts have forced PRASA to build rationing plans for certain regions. In 2015, for instance, government rationing initiatives affected 372,000 PRASA customers in the Metro WMR.[206]

Puerto Rico's topography limits the number of useful areas for creating water storage reservoirs. According to Homeland Infrastructure Foundation-Level Data, 29 dammed reservoirs are currently operational across the commonwealth.[207] Figure 2-39 shows the locations of each of these reservoirs and the maximum capacities of each.

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204 EPA, 2018, *Safe Drinking Water Information System (SDWIS)*, https://www3.epa.gov/enviro/facts/sdwis/search.html, accessed January 15, 2018.

205 State Government of Puerto Rico, 2018, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

206 Puerto Rico Aqueduct and Sewer Authority (PRASA). 2015. *PRASA's Metro Region – Water Resources Management Plan.* s.l. : PRASA, 2015.

207 Homeland Infrastructure Foundation-Level Data, 2018, "HIFLD Open Data," https://hifld-dhs-gii.opendata.arcgis.com/, accessed March 9, 2018.

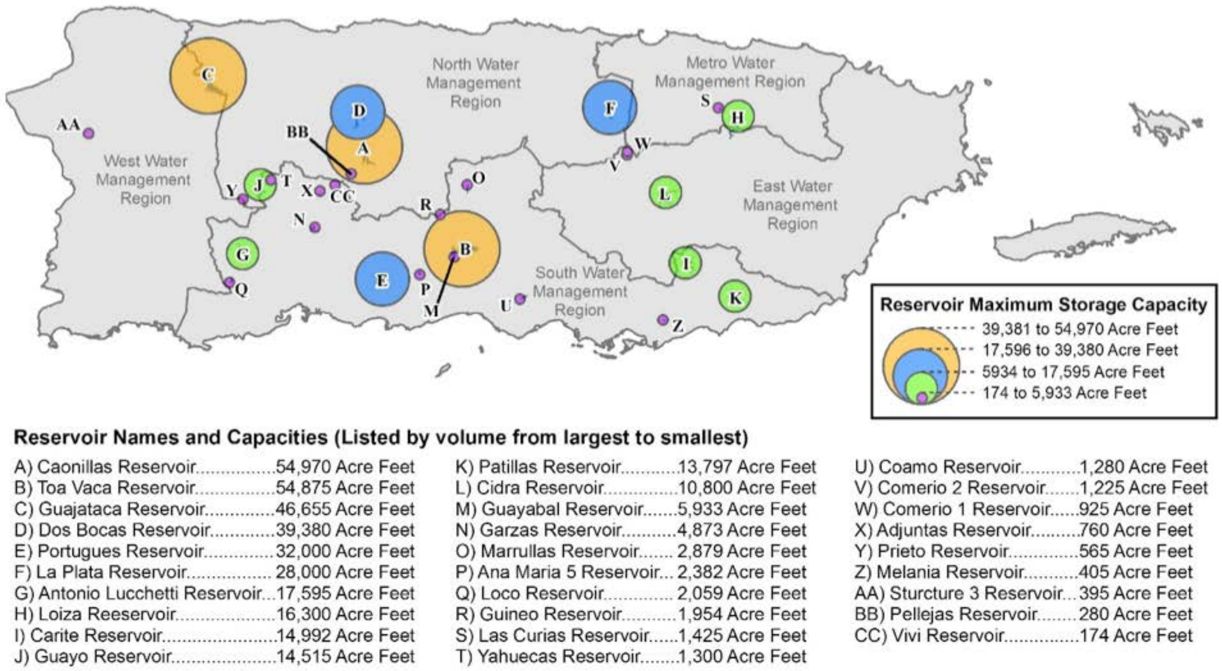

Figure 2-39: Raw Water Storage Reservoirs in Puerto Rico

Table 2-16 characterizes 62 community water systems in Puerto Rico serving populations greater than 10,000. These systems represent a subset of the 404 systems serving the Puerto Rico population.

Table 2-16: Community Water System Information

Water System Name	Municipality	City	Population Served	Primary Water Source
Metropolitano	Bayamon, San Juan and Toa Alta	Bayamon, San Juan, and Toa Alta	1,064,730	Surface water
Superacueducto	Bayamon, San Juan and Toa Alta	San Juan and Toa Baja	238,603	Surface water
Mayaguez	Anasco and Mayaguez	Anasco and Mayaguez	181,972	Surface water
Ponce Urbano	Penuelas and Ponce	Penuelas and Ponce	153,092	Surface water
Aguadilla	Aguada, Aguadilla, Moca and Rincon	Aguada	132,716	Surface water
Arecibo Urbano	Arecibo Municipio	Arecibo	92,942	Surface water
Rio Blanco, Vieques, Culedra	Las Piedras, Naguabo, and Vieques	Las Piedras, Naguabo, and Vieques	76,455	Surface water
Isabela	Isabela Municipio	Isabela	59,196	Surface water
El Yunque	Naguabo Municipio and Rio Grande	Rio Grande	54,350	Surface water
Fajardo Ceiba	Fajardo Municipio	Fajardo and Fajardo Ceiba	50,837	Surface water
Vega Baja Urbano	Vega Baja Municipio	Vega Baja	49,853	Surface water
Manatí East	Manatí Municipio	Manatí	47,519	Ground water
Lajas	Lajas Municipio	Lajas	47,310	Surface water

Table 2-16: (cont.)

Water System Name	Municipality	City	Population Served	Primary Water Source
Guayama Urbano	Arroyo Municipio and Guayama	Arroyo and Guayama	45,959	Surface water
Regional Villalba Toa Vaca	Villalba Municipio	Villalba	45,080	Surface water
Patillas Urbano	Patillas Municipio	Patillas	44,860	Surface water
Yauco	Yauco Municipio	Yauco	42,974	Surface water
Caguas Norte	Caguas Municipio	Caguas	41,971	Surface water
Santa Isabel Urbano	Santa Isabel Municipio	Ponce and Santa Isabel	41,734	Ground water
Juncos - Ceiba Sur	Juncos Municipio	Juncos	39,460	Surface water
Hatillo-Camuy	Hatillo Municipio	Hatillo and Camuy	37,453	Surface water
San Sebastian	San Sebastian Municipio	San Sebastian	34,615	Surface water
Cidra Urbano	Cidra Municipio	Cidra	34,556	Surface water
Sabana Grande	Sabana Grande Municipio	Sabana Grande	33,616	Surface water
Maguayo	Dorado Municipio	Dorado	33,154	Ground water
Quebradillas Urbano	Quebradillas Municipio	Quebradillas	32,645	Surface water
Las Piedras Humacao	Humacao and Naguabo	Humacao	31,428	Surface water
Dorado Urbano	Dorado Municipio	Dorado	28,218	Ground water
Caguas Sur	Caguas Municipio	Caguas	25,725	Surface water
Morovis Urbano	Morovis Municipio	Morovis	25,506	Surface water
Barceloneta Urbano	Barceloneta Municipio	Barceloneta	24,372	Ground water
San Lorenzo Urbano	San Lorenzo Municipio	San Lorenzo	23,276	Surface water
Cabo Rojo	Cabo Rojo Municipio	Cabo Rojo	21,987	Surface water
Penuelas	Penuelas Municipio	Penuelas	21,772	Surface water
Orocovis Urbano	Orocovis Municipio	Orocovis and Ponce	19,334	Surface water
Utuado Urbano	Utuado Municipio	Utuado	18,787	Surface water
Negros	Corozal Municipio	Corozal and Negros	17,988	Surface water
Cayey Urbano	Cayey Municipio	Cayey	17,814	Surface water
Lares Espino	Lares Municipio	Lares	17,554	Surface water
Aibonito La Plata	Aibonito Municipio	Aibonito	17,278	Surface water
Sabana Hoyos	Arecibo Municipio	Arecibo and Sabana Hoyos	16,804	Surface water
Santana	Arecibo Municipio	Arecibo	16,201	Surface water
Sabana Hoyos	Loiza Municipio and Vega Alta	Vega Alta	16,016	Ground water
Florida Urbano	Florida Municipio	Florida	15,056	Ground water
Lares Urbano	Lares Municipio	Lares	14,890	Surface water
Cotto Laurel	Ponce Municipio	Ponce	14,365	Surface water
Quebrada	Camuy and Hatillo	Camuy and Hatillo	13,923	Surface water
Cocos	Salinas Municipio	Bo Cocos and Salinas	13,850	Ground water
Gurabo Urbano	Gurabo Municipio	Gurabo	13,639	Surface water
Guanica Urbano	Guanica Municipio	Guanica	12,864	Ground water

Table 2-16: (cont.)

Water System Name	Municipality	City	Population Served	Primary Water Source
Maunabo Urbano	Maunabo Municipio	Maunabo	12,307	Ground water
Salinas Urbano	Salinas Municipio	Salinas	12,081	Ground water
Corozal Urbano	Corozal Municipio	Corozal	11,377	Surface water
Jayuya Urbano	Jayuya Municipio	Jayuya	11,248	Surface water
Hormiguero	Hormigueros Municipio	Hormiguero and Hormgueros	11,210	Ground water
Aceitunas	Villalba Municipio	Villalba	11,095	Surface water
Lago Guajataca	Isabela and San Sebastian	Isabela and San Sebastian	10,629	Surface water
Las Marias	Anasco Municipio and Las Marias	Las Marias	10,403	Surface water
Coqui	Salinas Municipio	Coqui and Salinas	10,262	Ground water
Aguas Buenas Urbano	Aguas Buenas Municipio	Aguas Buenas	10,181	Surface water
Comerio Urbano	Comerio Municipio	Comerio	10,101	Surface water

2.5.3.1 PRASA Water Treatment Management Regions

This section will provide a closer look at each of the five WMRs in Puerto Rico.

Metro Region

The smallest WMR, in terms of total land area (277 square miles), is the Metro WMR (figures 2-39 through 2-40). The Metro WMR covers the greater San Juan metropolitan area and, despite being the smallest WMR, it serves the greatest number of people: 1.15 million residents.

Seven WTPs serve the Metro region (figure 2-40). In addition, after treatment at the Santiago Vasquez WTP located in the North WMR, potable water from the Puerto Rico Superaqueduct is delivered to the Metro Region. A system comprising 2,754 miles of raw (untreated freshwater) and potable (treated for drinking) water pipelines serve this region.[208] Figure 2-39 shows the locations of both raw and potable water mains in the Metro WMR, as well as three of the region's primary freshwater sources: the La Plata, Loiza, and Las Curias Reservoirs.

[208] State Government of Puerto Rico, 2018, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

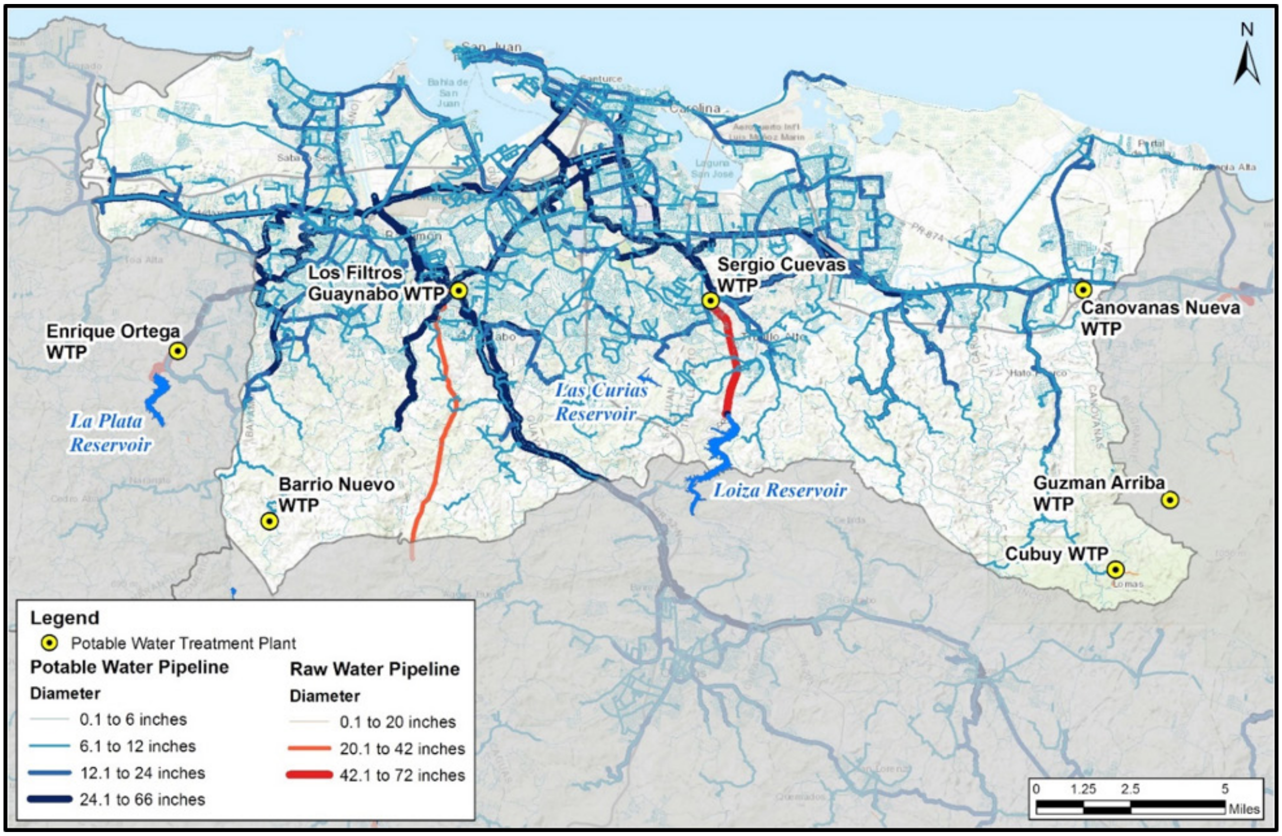

Figure 2-40: Raw and Potable Water Mains in the Metro WMR

The government of Puerto Rico lists 2,168 water storage tanks across the commonwealth, including those on the islands of Culebra and Vieques.[209] The Metro WMR contains 164 of these tanks. After raw water is treated for consumption, it flows via gravity or is pumped to one of these storage tanks. Figure 2-41 shows the locations and holding capacities of storage tanks across the Metro WMR.

209 Ibid.

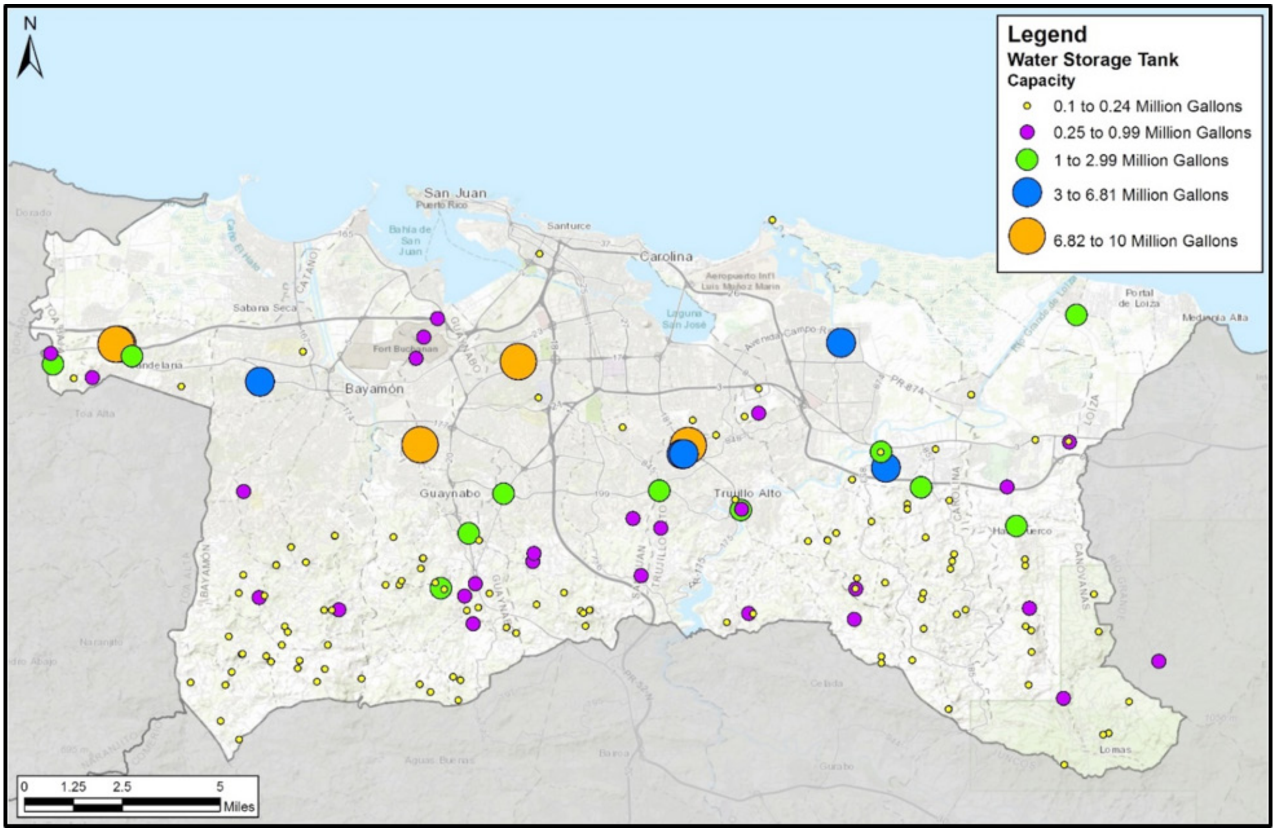

Figure 2-41: Treated Water Storage Tanks within the PRASA Metro WMR

The Metro WMR is served by 155 water pumping plants. When operating at full capacity, these plants are capable of pumping a combined total of 139,424 gallons of water per minute.[210]

North Region

Multiple industries, businesses, and food distribution centers, including pharmaceutical and medical equipment manufacturing corporations, are located in the North WMR (figure 2-42). The cities of Arecibo, Barceloneta, and Manatí are manufacturing centers located near the northern coast; all rely heavily on PRASA's treated water supply.

The largest of Puerto Rico's WTPs—the Santiago Vazquez WTP ("A" in figure 2-42)—is located in the North WMR. The plant is capable of treating 100 million gallons of water per day and provides water to the Puerto Rico Superaqueduct. The Superaqueduct carries treated water to several municipalities between Arecibo and San Juan through a 72-inch-diameter pipeline.[211]

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210 Ibid.

211 Water-Technology.net, undated, "North Coast Water Treatment Plant and Superaqueduct," http://www.water-technology.net/projects/northcoast/, accessed March 23, 2018.

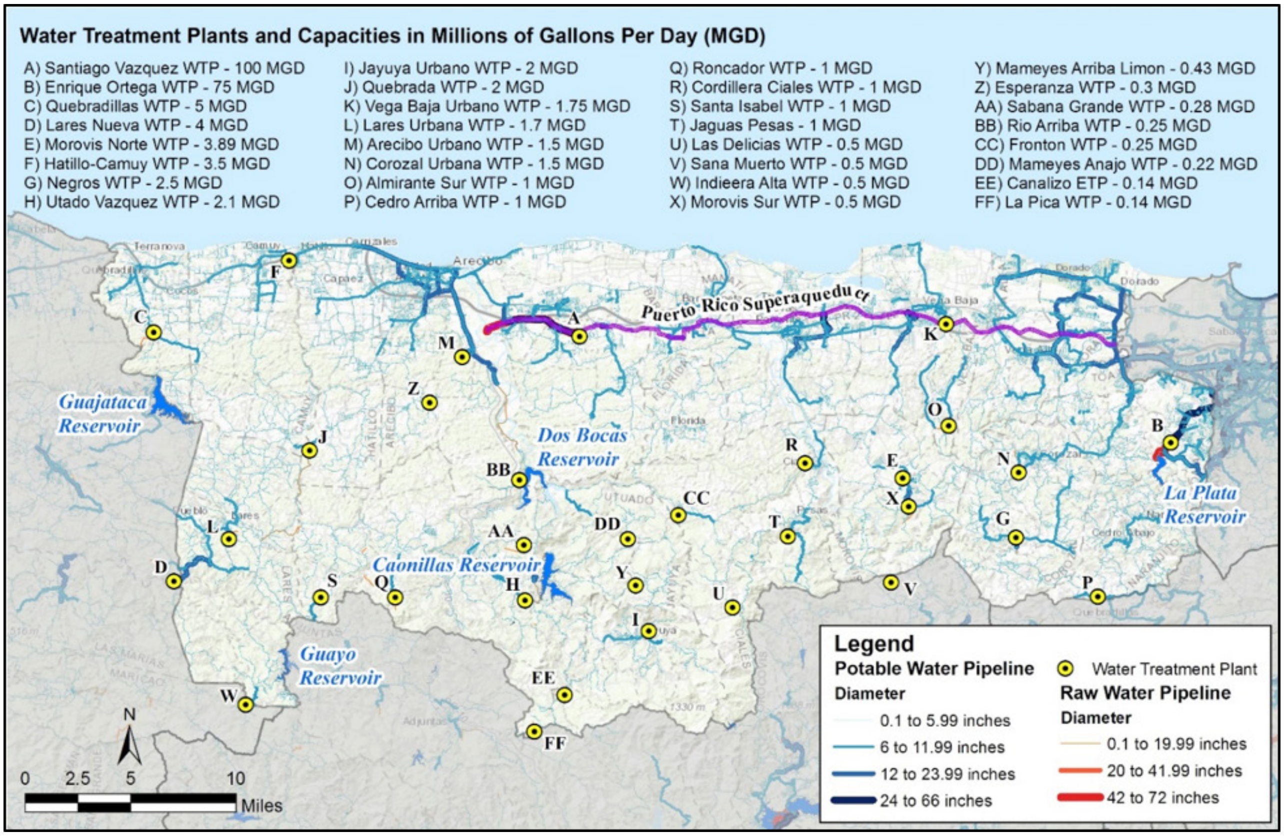

Figure 2-42: Water Treatment Plants and Pipelines in the PRASA North WMR

The North WMR houses 403 potable water storage tanks.[212] Figure 2-43 shows the locations of these storage tanks and the capacities of each.

[212] State Government of Puerto Rico, 2018, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

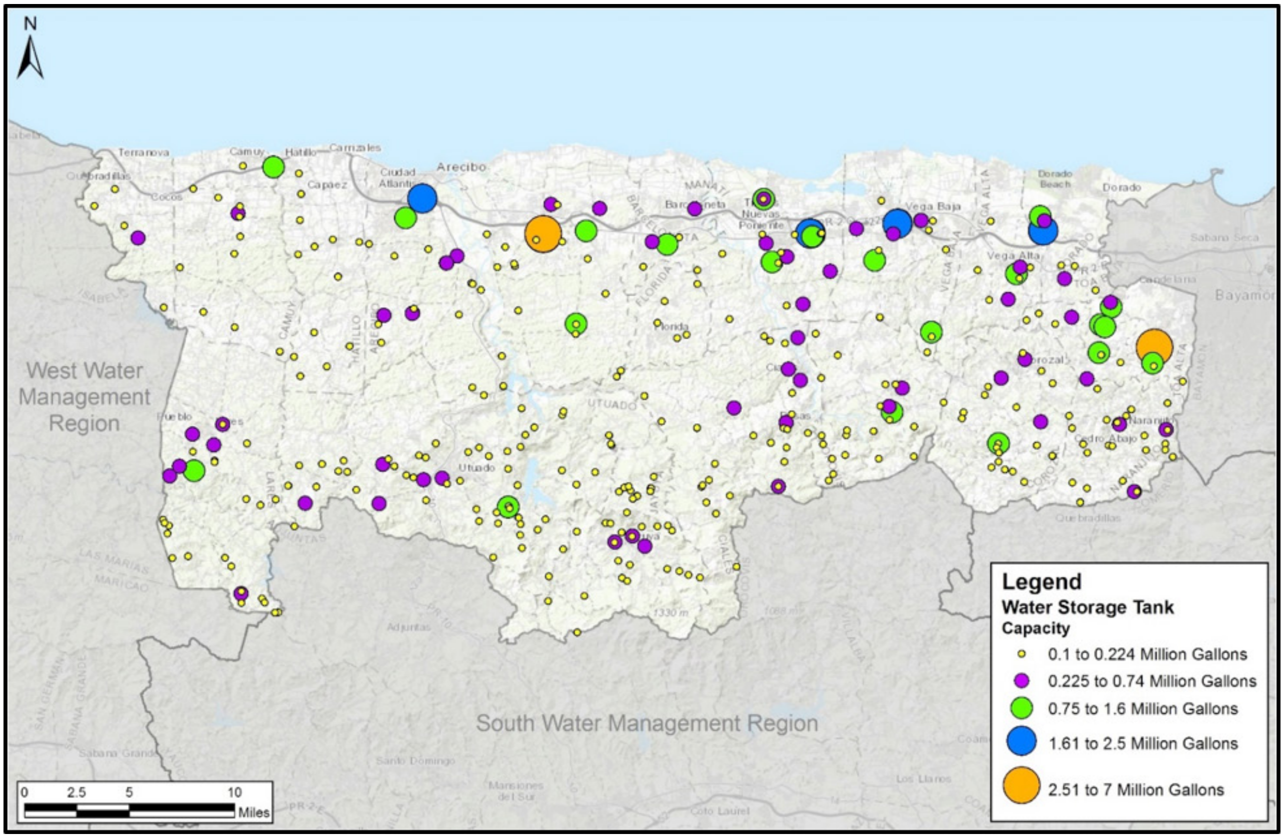

Figure 2-43: Treated Water Storage Tanks within the PRASA North WMR

The North WMR is served by 285 potable and raw water pumping stations.[213]

West Region

Like the North WMR, the West Region (figure 2-44) includes several manufacturing and research facilities. The smallest of Puerto Rico's fossil fuel power plants (Mayagüez Planta) is the only power plant located in the West WMR. As with all of the power plants on the island, a steady supply of treated fresh water is required to operate the plant's steam turbine.

213 Ibid.

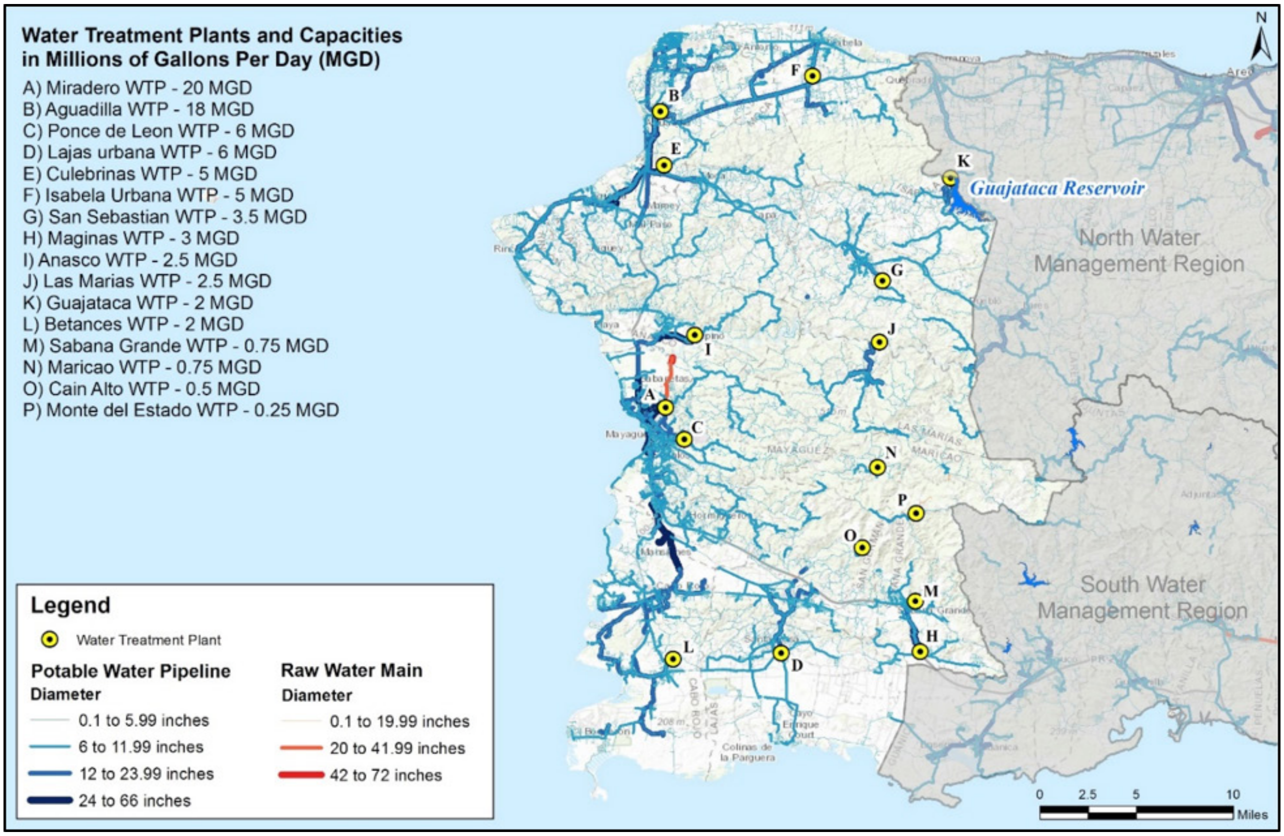

Figure 2-44: Water Treatment Plants and Pipelines in the PRASA West WMR

The West Region is the least populated of Puerto Rico's five WMRs, with the two largest cities being Mayaguez (population: 75,525) and Aguadilla (population: 53,164). Currently, 16 WTPs are operational across the West WMR, serving approximately 530,000 citizens.[214]

The West MWR houses 378 treated water storage tanks (figure 2-45). With a combined capacity of 72.53 million gallons of potable water storage, the West Region is able to store the least amount of water of PRASA's five WMRs.

214 State Government of Puerto Rico, 2018, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

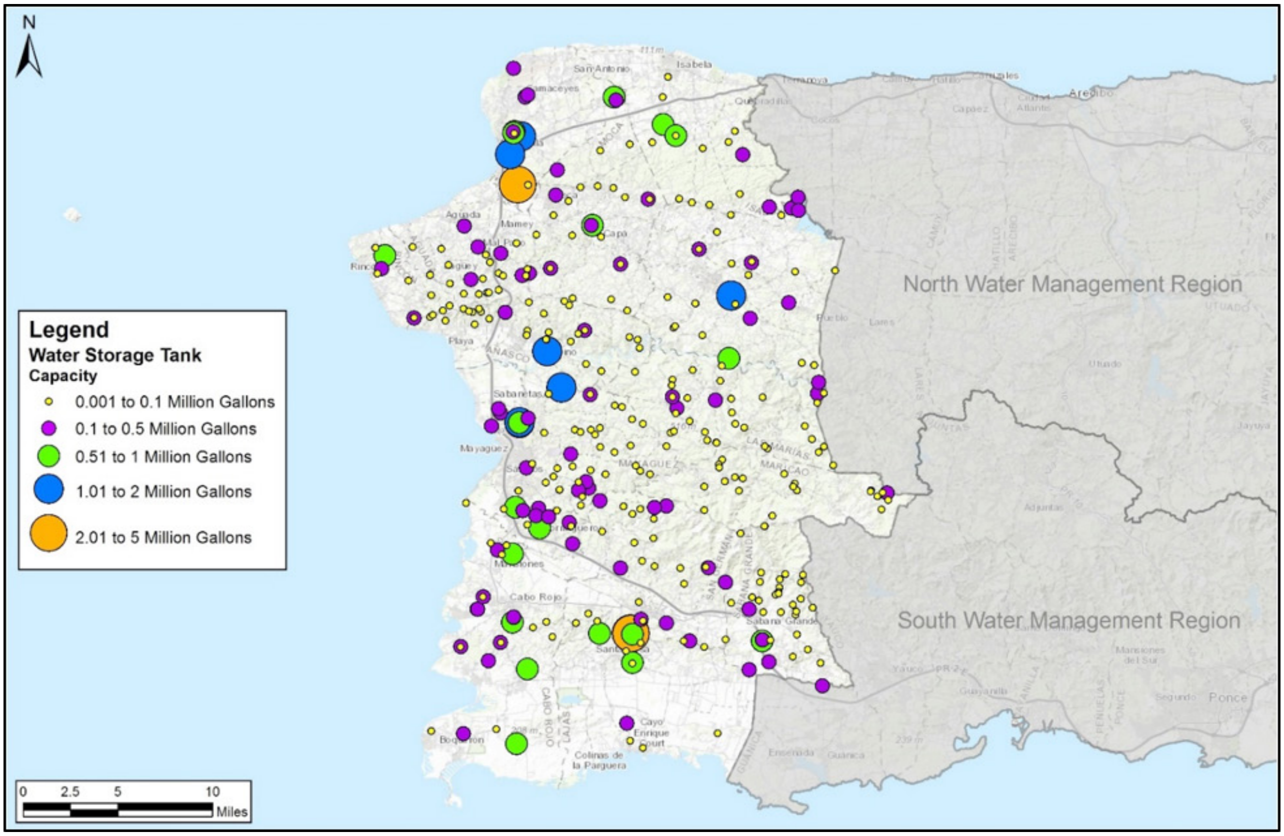

Figure 2-45: Treated Water Storage Tanks within the PRASA West WMR

The West WMR is served by 270 raw and potable water pumping stations. These stations are capable of pumping 60,010 gallons of water per minute if operating at full capacity.[215]

South Region

The city of Ponce lies within the South WMR (figure 2-46). Ponce (population: 140,859) is the fourth-largest city in Puerto Rico and the largest metropolitan area in the commonwealth outside of the San Juan metropolitan area. Although manufacturing is less prevalent in the South WMR than in the other four WMRs, the five largest power plants on the island are all located in the South Region. Because each of these power plants requires a supply of treated water to operate the large steam turbines, an uninterrupted supply of fresh water along Puerto Rico's southern coast is essential to a continuous flow of power to the island's citizens and corporations.

215 Ibid.

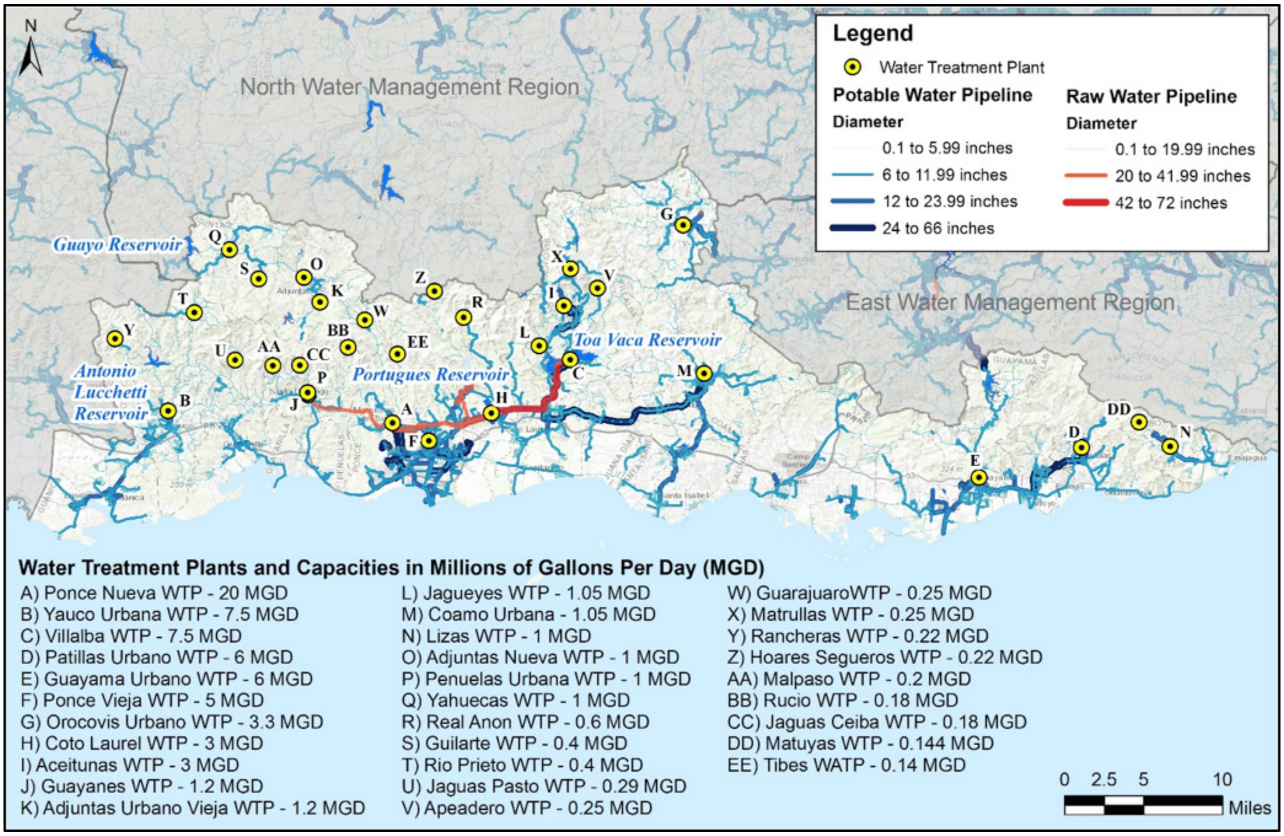

Figure 2-46: Water Treatment Plants and Pipelines in the PRASA South WMR

PRASA's South WMR houses 593 treated water storage tanks with a combined capacity of 97.17 million gallons of potable water storage. Figure 2-47 shows the locations and holding capacities of potable water storage tanks across the South Region.

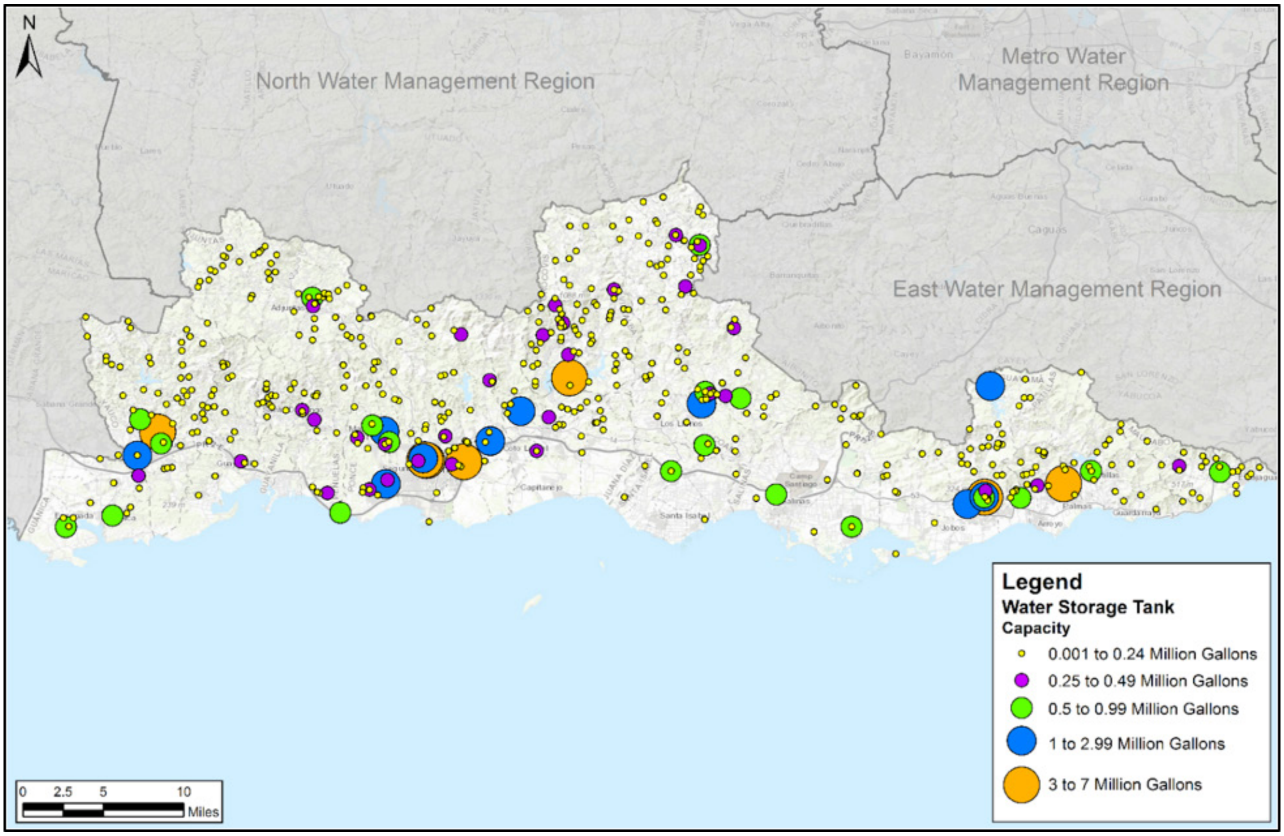

Figure 2-47: Freshwater Pumping Stations within the PRASA South WMR

The South WMR is served by 344 raw and potable water pumping stations. These stations are capable of pumping 90,809 gallons of water per minute if operating at full capacity.[216] Second only to the East WMR in number of pumping plants, the hilly and mountainous terrain in this region requires efficient pumping capability.

East Region

The East WMR, as illustrated in figure 2-48, serves the second-highest population after the Metro Region. The region includes the city of Caguas (population: 129,894),[217] as well as the islands of Vieques (population: 9,350) and Culebra (population: 1,809).

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216 Ibid.

217 U.S. Census Bureau, undated, "American Fact Finder – 2017 Population Estimate," https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml?src=bkmk, accessed March 23, 2018.

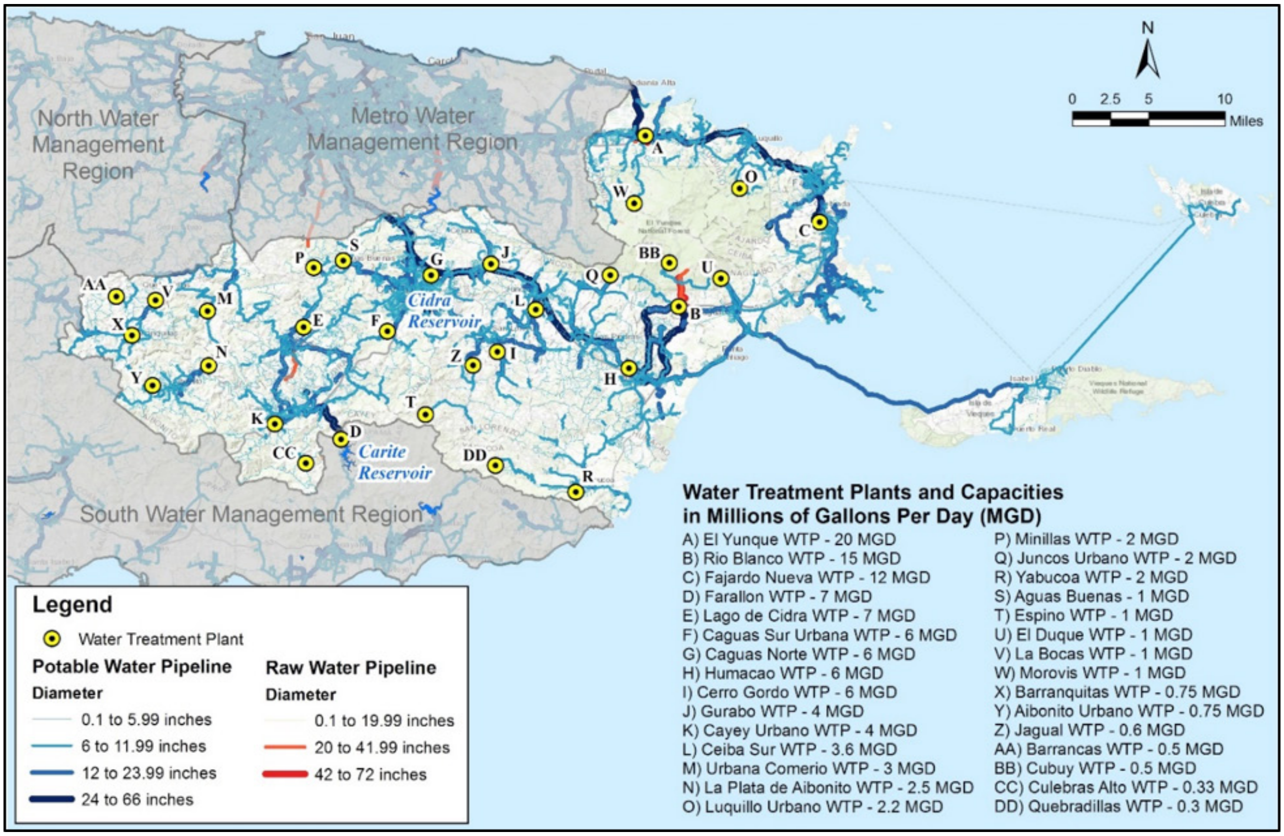


Figure 2-48: Water Treatment Plants and Pipelines in the PRASA East Water Management Region

The East WMR has 630 treated water storage tanks (figure 2-49), the most of any of PRASA's five WMRs. These include tanks on the islands of Culebra and Vieques.

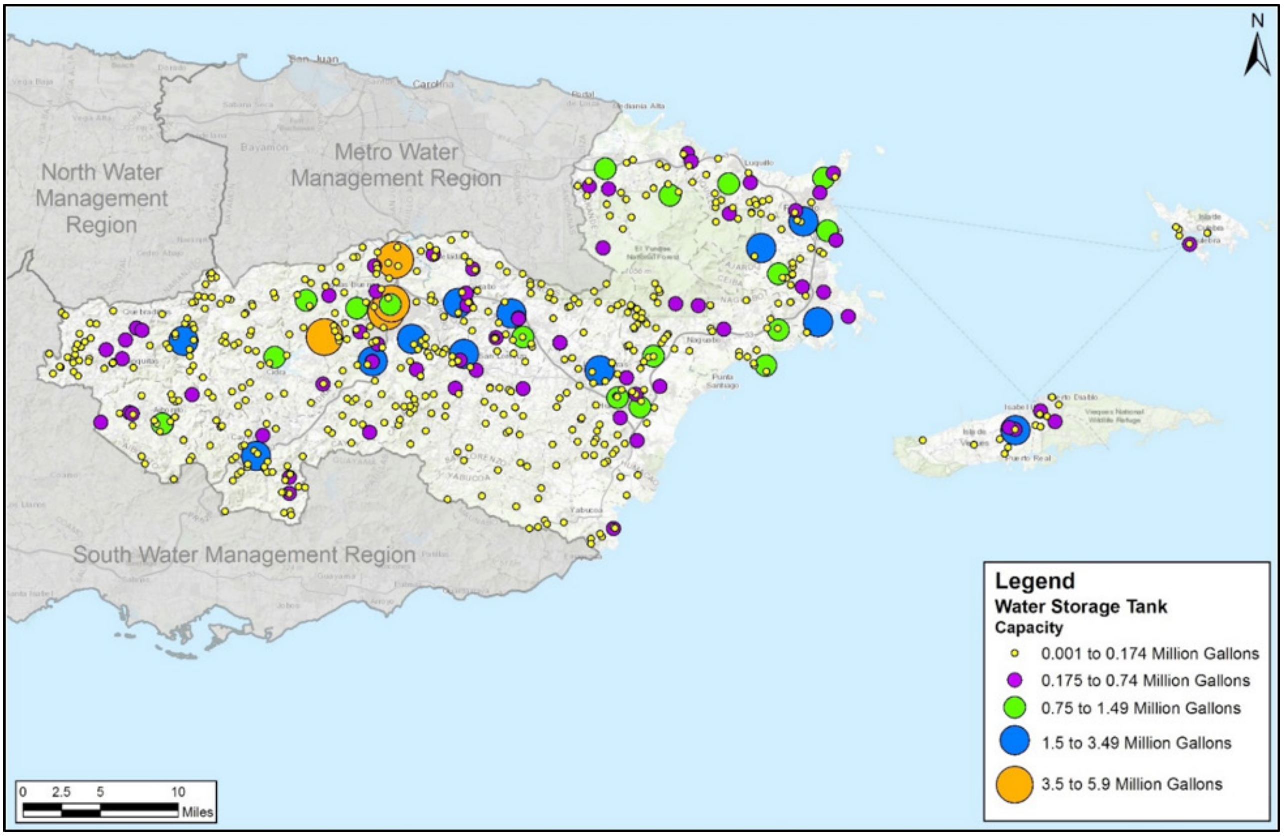


Figure 2-49: Treated Water Storage Tanks within the PRASA East Water Management Region

Lacking water treatment plants of their own, the islands of Culebra and Vieques rely on pumping plants to deliver potable water from mainland Puerto Rico through undersea pipelines, and treated water storage tanks as a hedge against disruption to these single points of failure.

2.5.4 System Interdependencies

A key finding from a 2016 U.S. National Infrastructure Advisory Council report on Water Sector resilience in the United States found that, among infrastructure facilities that depend on water for core operations, services degrade 50 percent or more within 8 hours of losing drinking water services.[218] Furthermore, a 2014 DHS Office of Cyber and Infrastructure Analysis (OCIA) study highlighted key findings related to water dependencies, including the following:

- Of the 2,661 sites across all 16 critical infrastructure sectors that received DHS assessments (2011–2014), 75 percent depend on external water for operations.
- The majority of facilities that DHS assessed depend on water and/or wastewater for domestic uses, cooling, or core operations. Many of these facilities lack an alternate source or onsite backup. The data indicate that more attention should be focused on preparing contingency or continuity plans for service interruption or priority restoration plans in coordination with the water utility service.

Additional potential impacts that a disruption in water service could cause include the following:[219]

- Loss of water for cooling, resulting in impacts to electrical and telecommunications equipment;
- Lack of water for consumption, cooking, bathing, flushing, fire suppression, etc.;
- Loss of water for commercial irrigation, food supply, and production to meet consumer needs;
- Decreased public confidence in water supply;
- Need to access alternate water supplies and/or issue a public notice to boil water; and [220]
- Adverse economic effects as industry and local government experience water service interruptions.

Table 2-17 illustrates the importance of clean water to each industrial sector and the Water Subsector's dependency on these other services to maintain operations.

[218] National Infrastructure Advisory Council. *Water Sector Resilience – Final Report and Recommendations.* https://www.dhs.gov/sites/default/files/publications/niac-water-resilience-final-report-508.pdf, accessed May 17, 2018.

[219] EPA, 2018, *Safe Drinking Water Information System,* https://oaspub.epa.gov/enviro/, accessed January 15, 2018.

[220] DHS OCIA, 2014, *Sector Resilience Report: Water and Wastewater Systems.*

Table 2-17: Interdependencies between Sectors and Drinking Water Supply[221]

Sector	Sector Dependency on Drinking Water	Drinking Water Dependency on Sector
Chemical	□ Manufacturing operations □ Office operations	□ Chlorine and other treatment chemicals □ Office operations
Commercial Facilities	□ Facility operations	□ Bottling
Communications	□ Equipment cooling □ Common rights-of-way	□ Emergency communications with responders □ General operations □ SCADA □ Monitoring
Critical Manufacturing	□ Water as a product constituent □ Equipment cooling	□ Operational and process equipment
Dams	□ N/A	□ Storage; reservoirs □ Flood mitigation
Defense Industrial Base	□ Office operations □ Equipment cooling	□ Production of parts
Emergency Services	□ Continuity of operations □ Firefighting and hazardous material (HAZMAT) spill and event responses □ Decontamination services □ Emergency water supplies □ Equipment maintenance	□ Special weapons and tactics and tactical operations □ Coordination with the ICS □ Law enforcement □ Explosive ordnance disposal □ Emergency (medical and firefighting) responders □ HAZMAT responders
Energy	□ Cooling and scrubbing □ Steam generation □ Mining operations □ Ore processing □ Refining □ Pollution control □ Raw material (e.g., hydrogen production) □ Waste management □ Common rights-of-way □ Office operations	□ Process power □ Pump, wells, treatment, operations □ Office operations □ Common rights-of-way □ Repair/recovery operations □ Deliver of power materials □ Backup power requirements
Financial Services	□ Office operations □ Equipment cooling	□ Facility financial operations, bonds, grants, loans, etc.
Food and Agriculture	□ Food processing □ Facility cleaning □ Restaurant operation □ Irrigation □ Animal drinking, feeding, and cleaning operations	□ Hydroelectric power □ Source water quality
Government Facilities	□ Office operations □ Equipment cooling □ Provision of public facilities	□ Water rates and spending authority □ Research

221 DHS and EPA, 2015, *Water and Wastewater Systems Sector-Specific Plan*, https://www.dhs.gov/sites/default/files/publications/nipp-ssp-water-2015-508.pdf, accessed May 15, 2018.

Table 2-17: (cont.)

Sector	Sector Dependency on Drinking Water	Drinking Water Dependency on Sector
Healthcare and Public Health	☐ Laboratory services ☐ Sanitation services ☐ Pharmaceutical, device, and supply manufacturing ☐ Nursing home operations ☐ Hospital and clinic operations ☐ Transportation of equipment and supplies	☐ Laboratory services ☐ Personal protective equipment donning and doffing guidance ☐ Conditions for public notice ☐ Information on treatment and response ☐ Vaccination and inoculation ☐ Medical and health clinics
IT	☐ Common rights-of-way ☐ Equipment cooling ☐ Office operations	☐ Common rights-of-way ☐ E-communications with emergency responders ☐ Remote monitoring ☐ SCADA ☐ General operations
Nuclear Reactors, Materials, and Waste	☐ Office operations ☐ Cooling and scrubbing	☐ Power delivery
Transportation Systems	☐ Office operations ☐ Equipment maintenance ☐ Common rights-of-way	☐ Common rights-of-way ☐ Transport of emergency responders and equipment ☐ Company operations ☐ Delivery of components and materials ☐ Delivery of treatment materials ☐ Operations, maintenance, and repair

2.6 WASTEWATER SUBSECTOR CHARACTERIZATION

2.6.1 Scope

This characterization summarizes how the infrastructure that constitutes the Wastewater Subsector operates, with a focus on system aspects that impact resilience. This section provides a baseline understanding of how the wastewater system functions in general, how it functions in Puerto Rico, interdependencies between the Wastewater Subsector and other critical infrastructure systems, and the potential consequences that could result from cascading failures.

2.6.2 Sector Background: General

The Water and Wastewater Systems Sector includes ten subsectors, one of which focuses on wastewater facilities (figure 2-50).

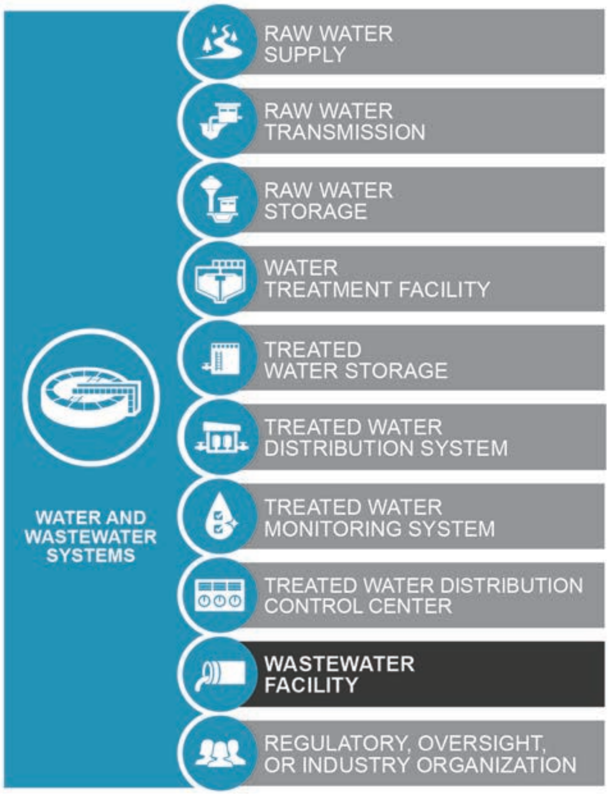


Figure 2-50: DHS Critical Infrastructure Taxonomy—Water and Wastewater Sector[222]

Hurricane Maria caused significant and prolonged disruptions to wastewater operations in Puerto Rico because of the loss of electricity and communications, direct facility damage, and other impacts. As the commonwealth pursues long-term recovery from this disaster, the future dependability and resilience of its wastewater infrastructure will be an important consideration that will have relevance for other infrastructure sectors and industries because of the important inter-relationships that exist among them. Continuous treatment of wastewater and release of the resulting effluent is needed to maintain the normal water cycle that is critical for residents, businesses and industrial operations, governments, and other institutions. Disruption to wastewater operations can have serious human safety and environmental impacts and can hamper certain business operations.

Wastewater is the byproduct of residential, industrial, manufacturing, and other process water and materials usage. Wastewater systems move raw wastewater (and pre-treated industrial and manufactured wastewater) from the producer (residential, industrial, manufacturing, public, and others) to wastewater treatment plants (WWTPs) via a collection system. The treatment plants remove hazardous materials from the wastewater to meet regulatory requirements prior to discharging the treated water safely into approved outflow locations, typically reservoirs, streams, rivers, the ocean, etc. Figure 2-51 depicts the wastewater treatment process. Collection systems may move raw wastewater via gravity feed or, if needed due to terrain, using small facilities known as pump or lift stations.

The infrastructure assets that typically comprise a wastewater system include wastewater collection systems, including sewage pipelines and lift/pump stations; WWTPs; discharge system outflows; and business offices. The operation of an integrated wastewater system relies on a wide network of inputs and resources that external organizations provide, such as power companies, communications and technology vendors, equipment and materials suppliers, transportation providers, chemicals used in the treatment process, and by-product processing, among others.

222 DHS, 2011, *Infrastructure Data Taxonomy, Version 4*, National Protection and Programs Directorate, Office of Infrastructure Protection, Infrastructure Information Collection Division, June.

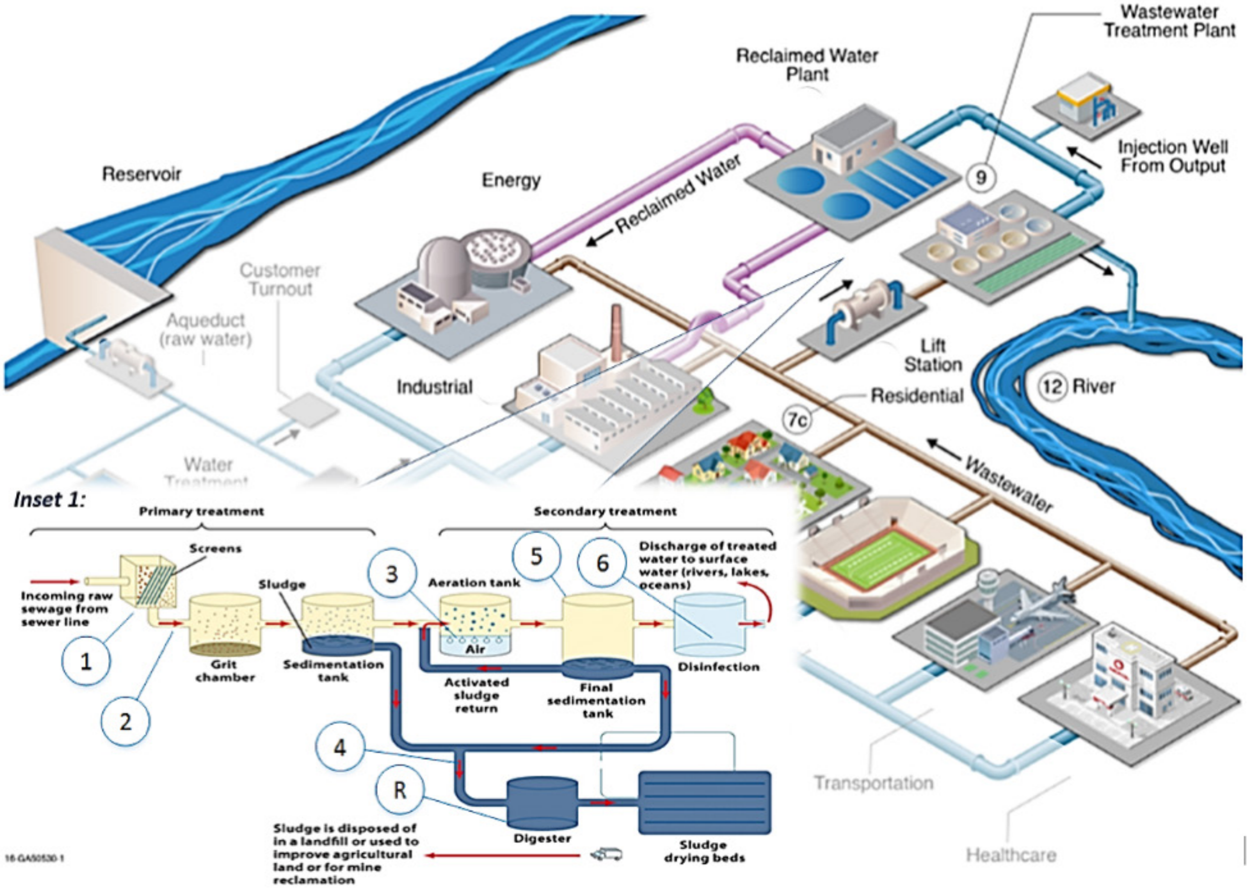


Figure 2-51: Wastewater Collection and Treatment Process[223]

223 Graphic developed by Idaho National Laboratory. Inset courtesy of http://www.schoolofpe.com.

2.6.3 Sector Background: Puerto Rico

2.6.3.1 Physical Market in Puerto Rico

PRASA is the commonwealth's only wastewater utility and is responsible for the majority of wastewater operations in Puerto Rico, including on the islands of Vieques and Culebra. PRASA has more than 1.2 million customer accounts. Puerto Rico's 3.4 million residents, 5 million annual visitors, and thousands of businesses and institutions generate an average of 206 million gallons per day (MGD) of wastewater. Vieques and Culebra, with populations of 9,301 and 1,818, respectively, generate an average of 0.297 MGD of wastewater. This wastewater must be transported to, treated at, and released by, the commonwealth's network of 51 WWTPs (figure 2-52). Smaller community systems, residential sewage septic systems, and other localized systems provide the remainder of the Puerto Rico wastewater infrastructure.

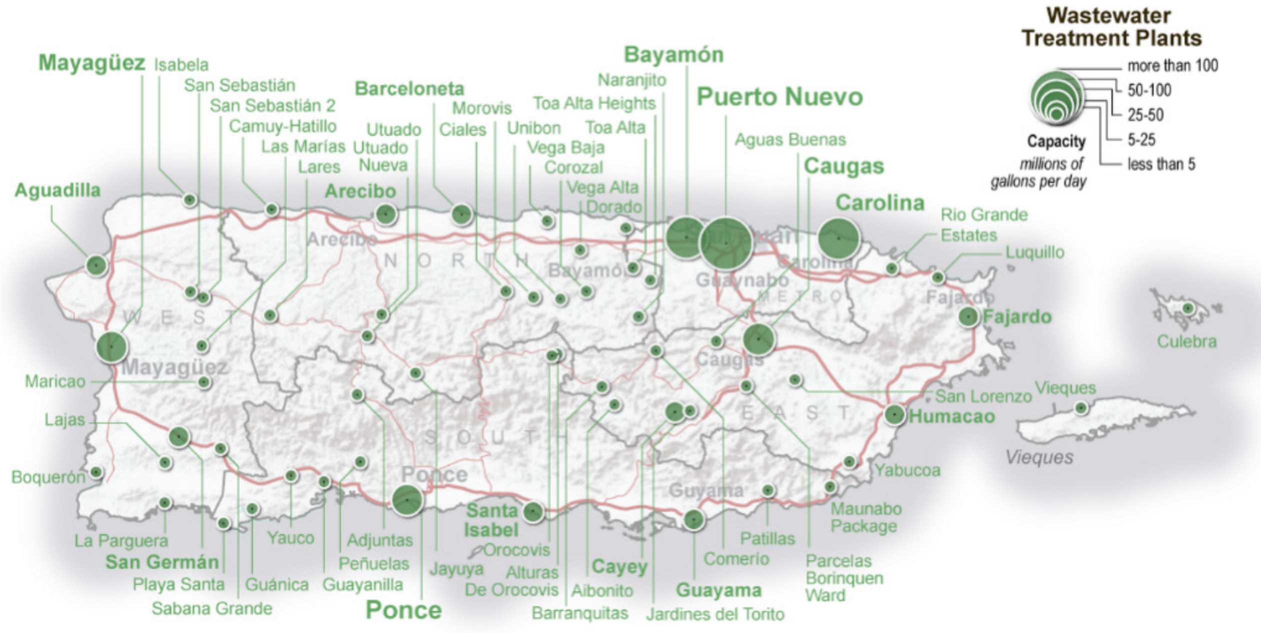


Figure 2-52: PRASA WWTP Locations and Capacities (Maximum Treatment per Day)[224]

Figure 2-53 shows data from 2015 for PRASA wastewater operations. The PRASA wastewater system is divided into five water management regions—Metro, North, West, South and East—as shown in figure 2-54. The islands of Vieques and Culebra are part of the East Region.

[224] State Government of Puerto Rico, undated, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

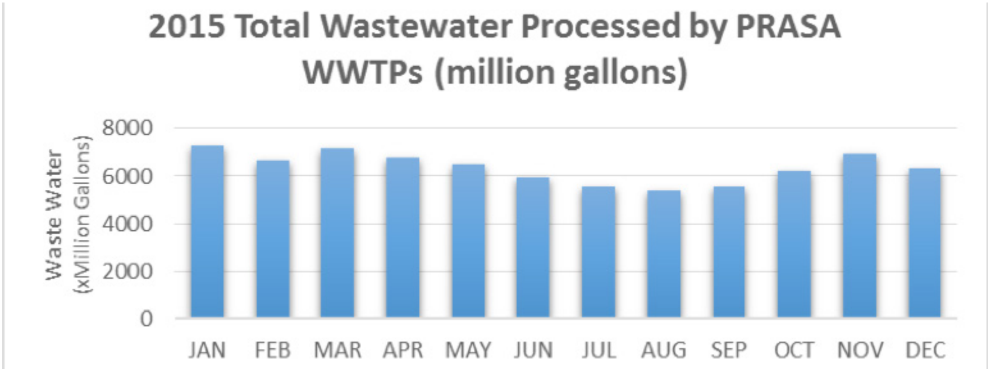


Figure 2-53: Monthly Wastewater Processed by PRASA in 2015[225]

Puerto Rico is an island with varied topography, isolated demographic distributions, and a diverse mix of water users.[226] PRASA has a somewhat fragmented and localized system of water sources, treatment systems, and collection and delivery systems. Thus, PRASA has a high degree of diversity of assets in terms of size, treatment technologies, and age. Its infrastructure includes nearly 6,000 miles of sewage pipeline, 715 lift/pump stations, 51 treatment plants, and 12 business offices.

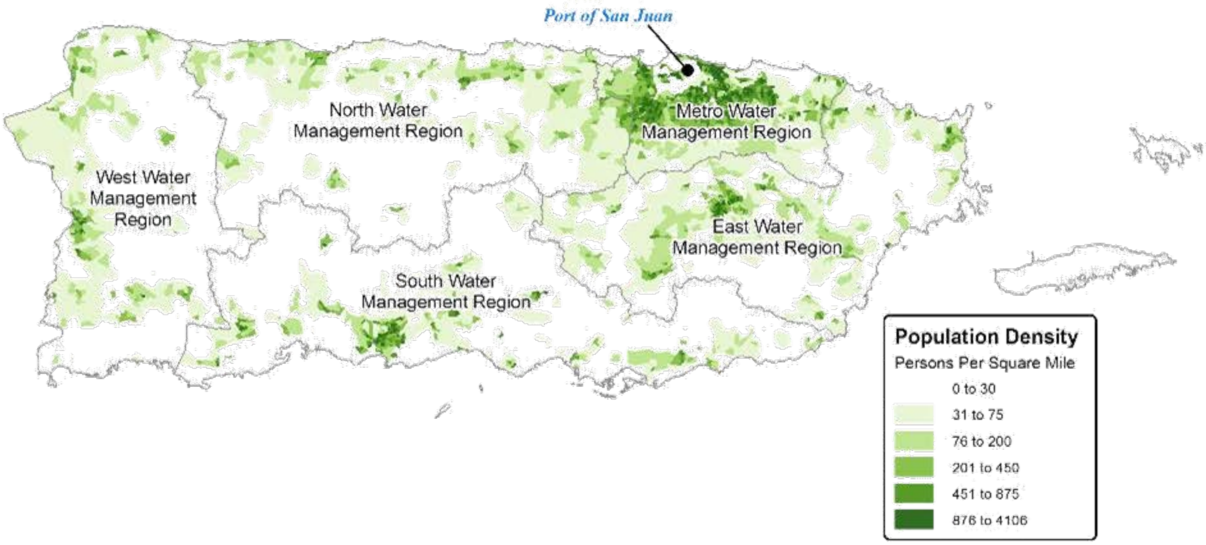


Figure 2-54: Puerto Rico Population Density and PRASA Regions[227]

225 State Government of Puerto Rico, undated, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

226 Arcadis, 2016, *Fiscal Year 2015 Consulting Engineer's Report for the Puerto Rico Aqueduct and Sewer Authority*, December, https://www.acueductospr.com/INVESTORS/download/Consulting%20Engineer's%20Reports/FY2015_Consulting_Engineers_Report.pdf, accessed May 15, 2018.

227 U.S. Census Bureau, undated, "American Fact Finder – 2017 Population Estimate," https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml?src=bkmk, accessed March 23, 2018; State Government of Puerto Rico, undated, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

The following sections describe each PRASA Region, including PRASA wastewater infrastructure, WWTPs, lift/ pumping stations, and wastewater piping (differentiated as either gravity-fed or pressurized/ pumped [forced] piping). Industry sites in the areas of critical interest are included in separate diagrams.

Metro Region

The Metro Region, which includes San Juan, is the most densely populated on the island. The San Juan metropolitan area accounts for 54.8 percent of PRASA's daily treatment of wastewater. The Metro Region wastewater infrastructure includes the three largest WWTP facilities on the island: the Puerto Nuevo, Bayamon, and Carolina WWTPs. These facilities treat 23.1 percent, 20.2 percent, and 11.5 percent, respectively, of PRASA's average daily total, as shown in table 2-18. The three WWTPs treat all of the Metro Region's wastewater (17,636, 15,408, and 8,774 million gallons per year, respectively). Figure 2-55 shows industries in the region. Most industry sites and WWTPs are in areas outside of those with the greatest hurricane risk, with the exception of the Bayamon WWTP, which may be susceptible to a Category 5 storm surge, which is significant because of the service it provides to a cluster of industrial sites.

Table 2-18: Metro Region WWTPs

Name	Capacity (in MGD)	Treated in 2015 (in MG)	% of PR Total Treated in 2015	Treatment Type	Install Year
Puerto Nuevo WWTP	144	17,637	23.12	Unknown	1957
Bayamón RWWTP	88	15,408	20.20	Unknown	1980
Carolina RWWTP	90	8,774	11.50	Unknown	1987

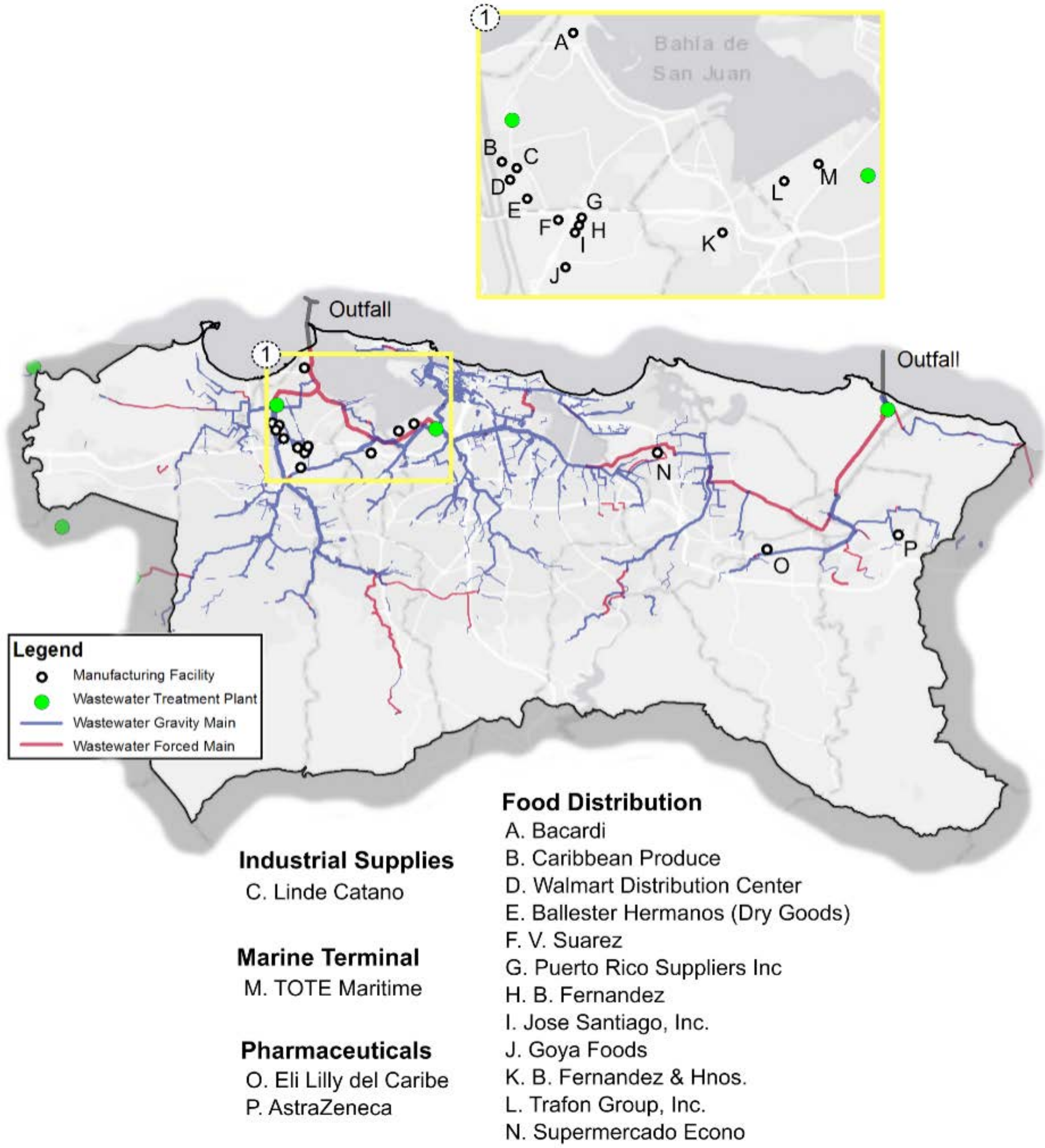


Figure 2-55: PRASA Metro Region with Industry Information

North Region

Table 2-19 and figure 2-56 show the wastewater infrastructure in the North Region.[228] The Arecibo, Barceloneta, and Camuy-Hatillo WWTPs treat 61 percent of the PRASA North Region's wastewater (1,910, 1,769, and 669 million gallons per year, respectively) and 9.3 percent of PRASA's island-wide total. The North Region supports major industrial corridors, including the Manatí and Barceloneta municipalities. The Barceloneta WWTP is the sole provider serving the Manatí area. Major industry producers in those two municipalities include BASF Agrochemical, Ortho McNeil, Bristo-Myers Squibb, Ortho Biologics, Abbott Biotechnology, Abbott, Merck and Pfizer (figure 2-56).

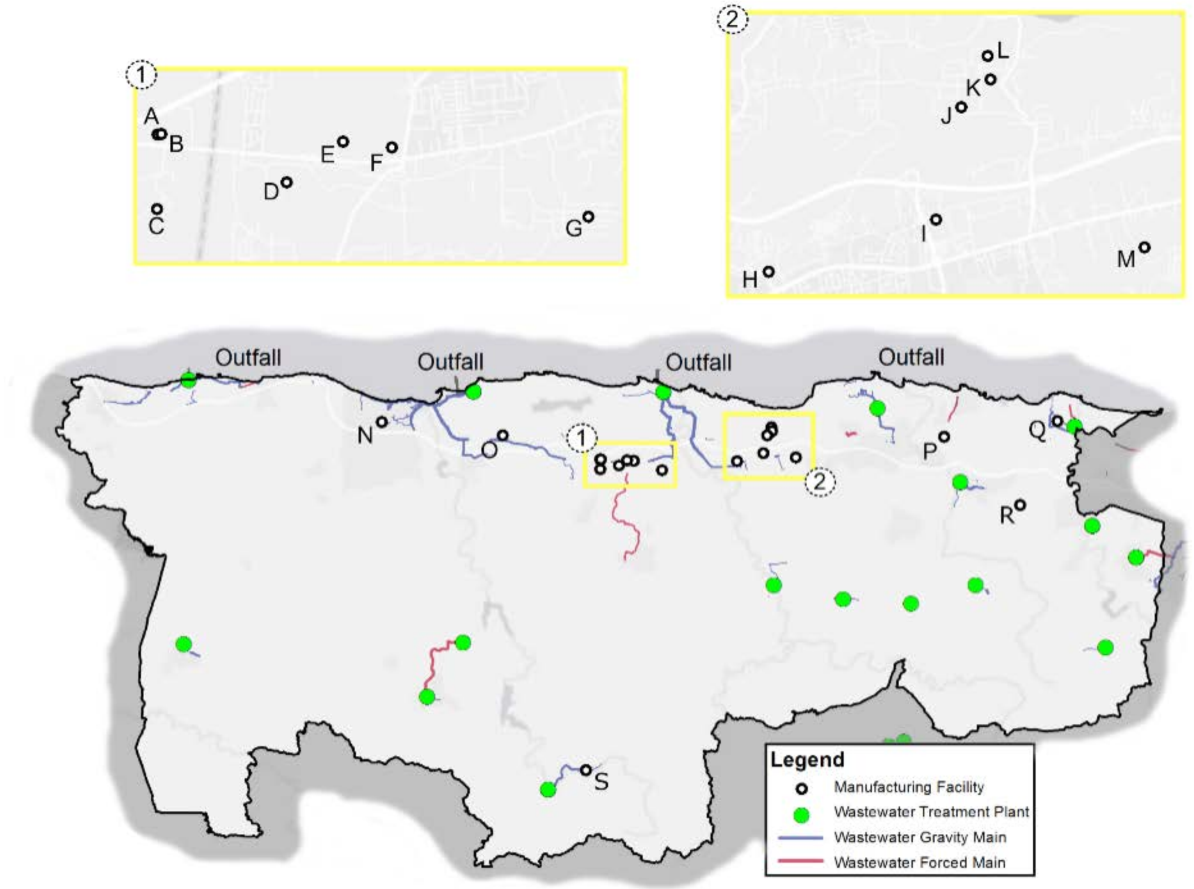
The Vega Baja WWTP may be susceptible to Category 3–5 storm surge, which is significant because of the service it provides to the area, which includes the Pfizer Vega Baja industry site.[229]

Table 2-19: North Region WWTPs

Name	Capacity (in MGD)	Treated in 2015 (in MG)	% of PR Total Treated in 2015	Treatment Type	Install Year
Arecibo RWWTP	10.0	1,909.8	2.50	Unknown	1976
Barceloneta RWWTP	8.3	1,768.7	2.32	Oxidation lagoon	1972
Camuy-Hatillo RWWTP	3.0	669.2	0.88	Biofilter	1980
Vega Baja WWTP	4.2	567.6	0.74	Biofilter	1970
Dorado WWTP	4.1	402.8	0.53	Biofilter	1960
Vega Alta WWTP	2.0	374.9	0.49	Oxidation lagoon	1980
Corozal WWTP	1.3	257.0	0.34	Oxidation lagoon	1979
Morovis WWTP	0.5	206.5	0.27	Biofilter	1960
Utuado Nueva WWTP	2.0	188.1	0.25	Oxidation lagoon	2002
Toa Alta Heights WWTP	1.1	180.4	0.24	Oxidation lagoon	1976
Lares WWTP	1.2	178.0	0.23	Biofilter	1994
Jayuya WWTP	1.0	147.5	0.19	Oxidation lagoon	1994
Ciales WWTP	0.6	147.0	0.19	Oxidation lagoon	1976
Naranjito WWTP	0.8	76.2	0.10	Oxidation lagoon	1975
Unibon WWTP	0.1	26.9	0.04	Oxidation lagoon	1985

228 State Government of Puerto Rico, undated, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

229 Esri NOAA National Storm Surge Hazard Maps can be referenced on the dynamic NOAA/NWS/NHC Storm Surge Unit website: http://noaa.maps.arcgis.com/apps/MapSeries/index.html?appid=d9ed7904dbec441a9c4dd7b277935fad&entry=2, last accessed May 3, 2018



Pharmaceuticals

A. Avara
B. Merck Sharp & Dohme Arecibo
C. Pfizer Arecibo
D. Abbvie I
E. Abbvie II
F. Ffizer Barceloneta
G. Sanofi
L. Bristol Myers-Squibb Manati
M. Johnson & Johnson Manati
P. Pfizer Vega Baja
S. Baxter Jayuya

Agro-Chemical

H. BASF Barceloneta
I. BASF Manati
J. FMC Technologies

Electronics

N. General Electric Arecibo
O. Eaton

Food Distribution

Q. Ballester Hermanos (Cold Food Goods)
R. Supermercado Selectos

Medical Devices and Supplies

K. DOW-Dupont Manati

Figure 2-56: PRASA North Region with Industry Information

West Region

The Mayaguez, Aguadilla, and San German WWTPs treat the majority of the wastewater generated in PRASA's West Region (4,473, 1,868, and 691 million gallons per year, respectively). Table 2-20 and figure 2-57 show the infrastructure in the West Region.[230] These facilities treat 86 percent of the wastewater generated in PRASA's West Region and 10.7 percent of PRASA's island-wide total. Figure 2-57 also shows major industry facilities and supporting wastewater infrastructure. The Boqueron WWTP may be susceptible to Category 3–5 storm surge, which is significant because of the service it provides to the local coastline service area.

Table 2-20: West Region WWTPs

Name	Capacity (in MGD)	Treated in 2015 (in MG)	% of PR Total Treated in 2015	Treatment Type	Install Year
Mayagüez RWWTP	28.0	4,472.8	5.86	Oxidation lagoon	1987
Aguadilla RWWTP	8.0	1,867.5	2.45	Unknown	1983
San Germán WWTP	8.0	690.9	0.91	Oxidation lagoon	1968
Isabela WWTP	2.0	366.1	0.48	Oxidation lagoon	1974
San Sebastián Nueva WWTP	1.0	361.9	0.47	Biofilter	1991
Lajas WWTP	1.2	242.4	0.32	Another	1989
San Sebastián Vieja WWTP	0.4	134.3	0.18	Biofilter	1989
Maricao WWTP	0.2	24.0	0.03	Oxidation lagoon	1971
Las Marías WWTP	0.3	23.5	0.03	Contact Stabilization	1988

230 State Government of Puerto Rico, undated, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

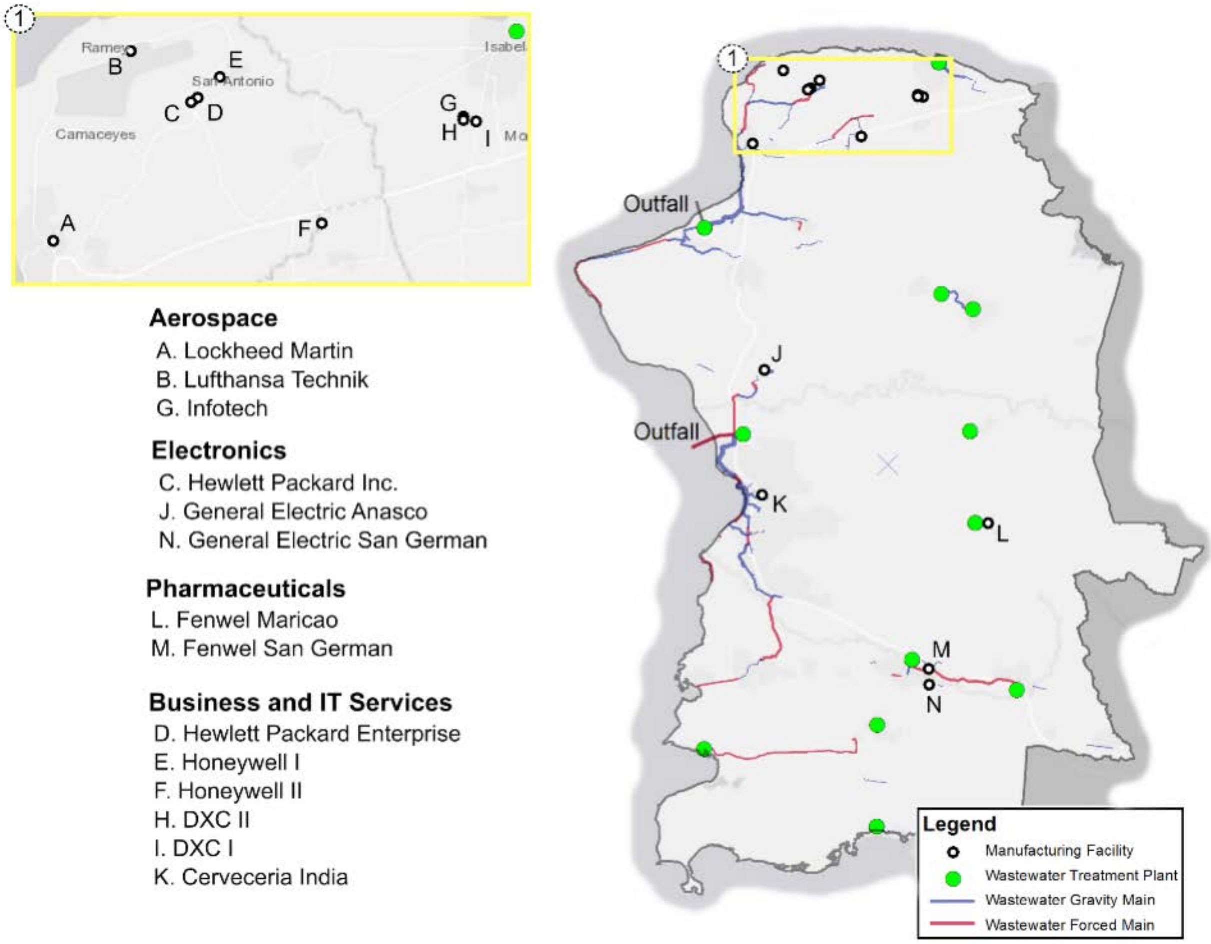


Figure 2-57: PRASA West Region with Industry Information

South Region

Ponce, Guayama, and Santa Isabel WWTPs treat the majority of the South Region's wastewater (5,881, 1,740, and 465 million gallons per year, respectively). These facilities treat 86 percent of the wastewater generated in PRASA's South Region and 12.3 percent of PRASA's island-wide total. Table 2-21 and figure 2-58 show WWTPs in the South Region.[231] Major industry facilities and their supporting wastewater infrastructure are also shown in figure 2-58. The Playa Santa and Guanica WWTPs may be susceptible to Category 3–5 storm surge, which is significant because of the service it provides to the local area, which includes the Linde Guayanilla industry site.

[231] State Government of Puerto Rico, 2018, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

Table 2-21: South Region WWTPs

Name	Capacity (in MGD)	Treated in 2015 (in MG)	% of PR Total Treated in 2015	Treatment Type	Install Year
Ponce RWWTP	27.0	5,880.5	7.71	Unknown	1972
Guayama RWWTP	10.0	1,739.6	2.28	Biofilter	1988
Santa Isabel RWWTP	5.5	464.5	0.61	Biofilter	1977
Yauco (BNR) WWTP	3.0	403.1	0.53	Biofilter	1960
Guánica WWTP	2.1	185.6	0.24	Activated sludge	1989
Patillas WWTP	1.1	167.6	0.22	RBC	1989
Guayanilla WWTP	0.6	147.6	0.19	Oxidation lagoon	1962
Adjuntas WWTP	0.6	135.5	0.18	Oxidation lagoon	1987
Maunabo Package WWTP	1.0	103.6	0.14	Oxidation lagoon	1990
Peñuelas WWTP	0.8	92.9	0.12	Oxidation lagoon	1988
Orocovis WWTP	0.5	52.0	0.07	Unknown	1973

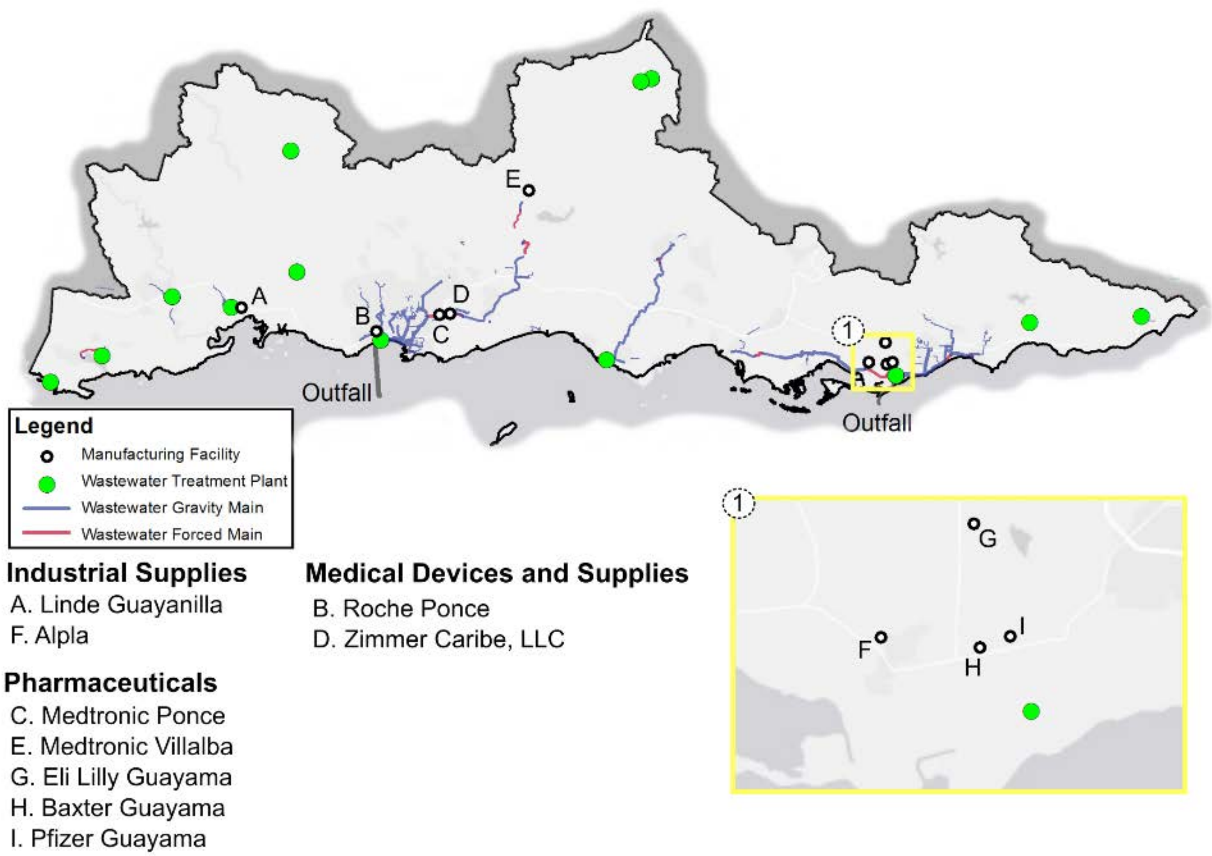


Figure 2-58: PRASA South Region with Industry Information

East Region

Table 2-22 shows that the Caguas, Humacao, and Fajardo WWTPs treat the majority of the East Region's wastewater (4,227, 1,584, and 1,503 million gallons per year, respectively). These facilities treat 75 percent of the wastewater generated in PRASA's East Region and 12.9 percent of PRASA's island-wide total. Figure 2-59 shows East Region WWTPs.[232] Figure 2-59 also shows major industry facilities and their associated wastewater infrastructure. No WWTPs appeared to be located within a flood surge zone, although the Rio Grande Estates WWTP borders the Category 5 zone and should be further evaluated for potential flooding risk.

Table 2-22: East Region WWTPs

Name	Capacity (in MGD)	Treated in 2015 (in MG)	% of PR Total Treated in 2015	Treatment Type	Install Year
Caguas WWTP	40.0	4,227.3	5.54	Oxidation lagoon	1996
Humacao RWWTP	8.2	1,584.1	2.08	Biofilter	1990
Fajardo RWWTP	9.2	1,503.5	1.97	Unknown	2005
Cayey RWWTP	14.5	1,252.7	1.64	Biofilter	1989
Yabucoa WWTP	1.5	318.7	0.42	Unknown	1970
Aibonito WWTP	1.8	289.1	0.38	Biofilter	1989
Comerío WWTP	1.0	147.8	0.19	Biofilter	1991
Rio Grande Estates	0.8	139.2	0.18	Oxidation lagoon	1980
Barranquitas WWTP	0.6	119.8	0.16	Oxidation lagoon	1992
Vieques WWTP	0.5	79.5	0.10	Unknown	1990
Aguas Buenas WWTP	0.6	73.4	0.10	Oxidation lagoon	2000
Parcelas Borinquen Ward WWTP	0.3	61.2	0.08	RBC	1994
Culebra WWTP	0.2	22.7	0.03	Oxidation lagoon	2005

232 State Government of Puerto Rico, undated, "Portal Datos Geograficos Gubernamentales," (in Spanish), http://www2.pr.gov/agencias/gis/Pages/default.aspx, accessed February 28, 2018.

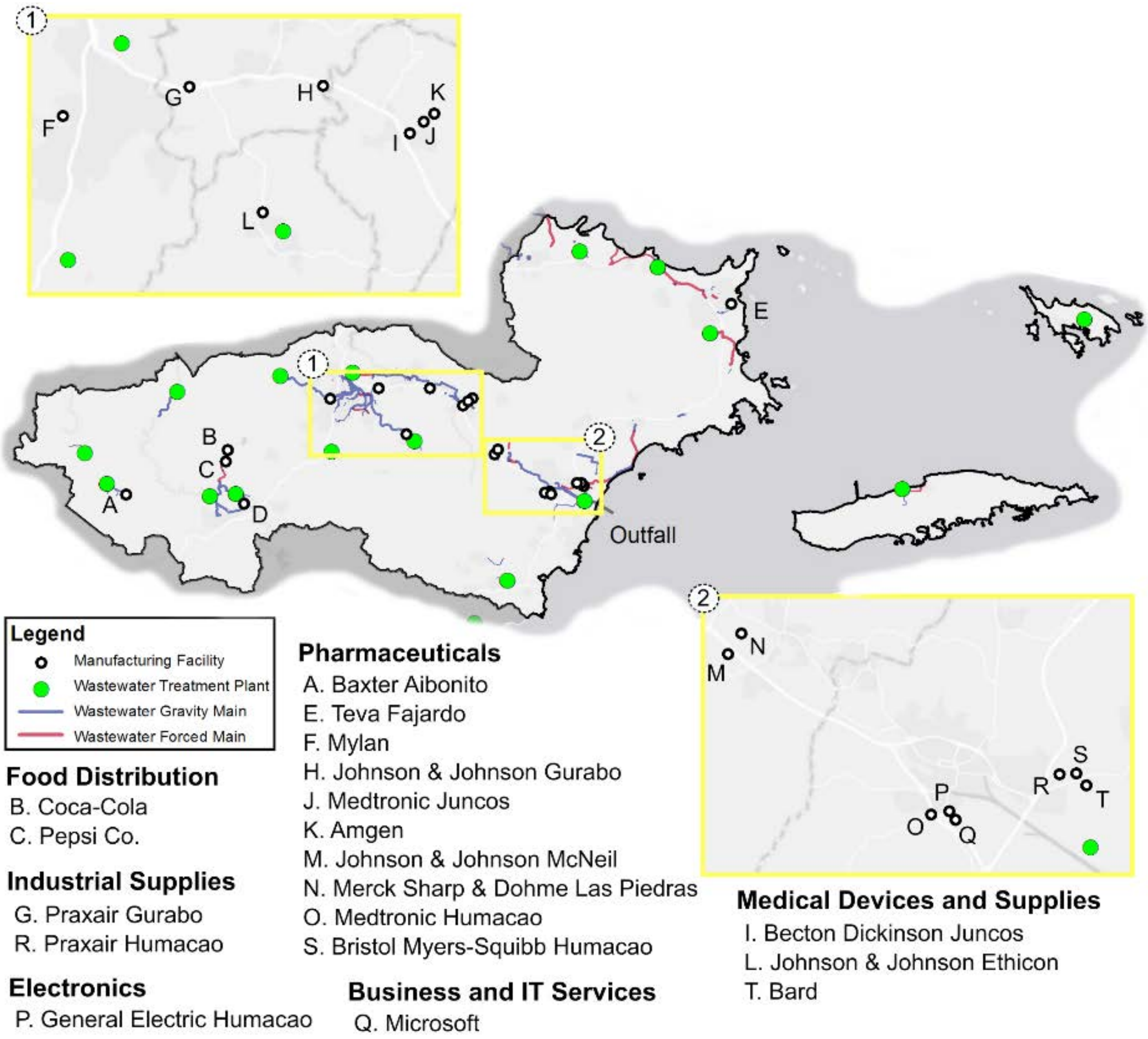


Figure 2-59: PRASA East Region with Industry Information

2.6.4 System Interdependencies

Wastewater systems in Puerto Rico depend on a variety of external inputs and resources to maintain normal operations. A wide range of physical infrastructure in industries and other critical infrastructure relies heavily on the proper functioning of wastewater systems.

Figure 2-60 shows end-to-end dependencies between each wastewater process element and critical dependencies including communications, IT, and electricity. The Wastewater Sector depends on the Chemical Sector for the chemical additives used in WWTPs and on the Transportation Sector to transport treatment by-products and chemicals for the wastewater treatment process.

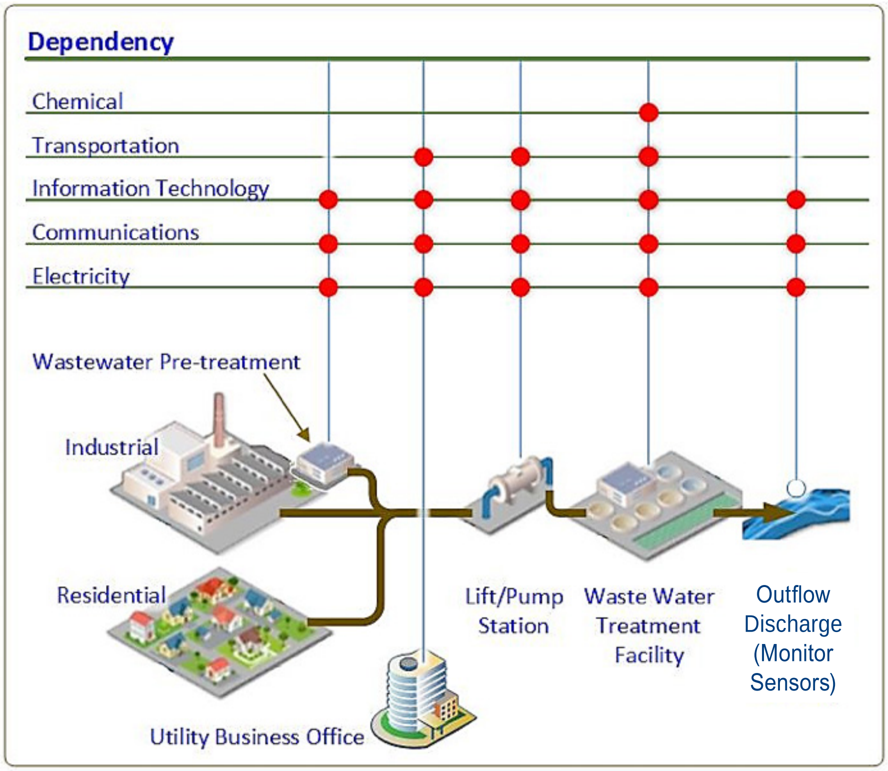


Figure 2-60: Wastewater Dependency Chart

Tables 2-23 through 2-29 describe dependencies for wastewater infrastructure, including collection, lift/pump stations, and WWTPs. The tables provide insights into the potential impacts of disruption on Puerto Rico wastewater and other systems.

Table 2-23: Wastewater Dependencies – Collection System (Pipes)

Sector	Dependency	Impact of Loss	Puerto Rico Context
Electricity	Energize industrial control system (ICS) monitoring and controls at remote sites, including IT and Communications equipment.	Control center loses ability to monitor and control piping systems and raw sewage flows.	Loss of electricity disrupts remote site operations unless backup power is available.
IT	Support local and remote site data collection and transmission.	Control center loses ability to monitor and control piping systems and raw sewage flows.	Loss of data communications means loss of field site situational awareness by system operators.
Communications	Needed to transmit data to and from the PRASA control center operations system.	Loss of monitoring of pipeline status, loss of situational awareness.	Disruption of controls and monitoring data prevents situational awareness of flow blockages or pipe breaks by control center personnel, resulting in potential raw sewage discharge to surrounding environments.
Transportation	Support field personnel movement to site areas for monitoring and repairs.	Personnel cannot reach remote piping infrastructure to monitor and repair.	Pipe breaks at remote sites go undetected and unrepaired until transportation is recovered. Piping must be manually isolated if gravity fed system or flow will continue as long as source material flows.

Table 2-24: Wastewater Dependencies – Lift/Pump Stations (Core Functions)

Sector	Dependency	Impact of Loss	Puerto Rico Context
Electricity	Functioning of entire facility.	Loss of function, loss of security controls.	Rely on PREPA for electricity; backup power from fueled or solar source. Because of previous PREPA system failures, many industry facilities and water facilities have private generation. If auto-start on power loss, then generator will operate until fuel depleted or replenished. If manual-start, will operate when operator can reach the site. If solar, dependent upon physical condition of the site solar infrastructure. Loss of power will cause security controls to fail as designed.
IT	ICS may not operate fully without control center communications.	Some functionality may continue if not dependent on remote communications.	Fiber may be damaged upon loss of power lines if strung on poles; loss of wireless towers prevents redundant data communications. Satellite communications insufficient to support sustained ICS monitoring and controls.
Communications	Local personnel cannot communicate with control center.	Any local operation will depend upon local indications and procedures.	Communications and data media often run on same power line infrastructure. Damage takes both out. Satellite communications insufficient to provide backup operations.
Transportation	Loss of vehicle access precludes local/manual operation.	No personnel access to remote sites.	Piping, facilities, and roads damaged to the point that system repairs not possible until right-of-ways cleared and repaired.

Table 2-25: Wastewater Dependencies – Lift/Pump Stations (Upstream)

Sector	Dependency	Impact of Loss	Puerto Rico Context
Electricity	Raw sewage may require pump at source, or be gravity fed.	If pumped from source and source loses power, complete failure.	If sewage needs to be pretreated, the treatment system must be operating. If the system is gravity discharge, no impact to the upstream function should occur. If pumping is required, sewage discharge is prevented, unless backup power is available; in that case, operations will be limited by the capacity of the power source and by fuel or charging capacity.
IT	Sensor monitoring of upstream sewer lines.	Loss could result in system miss-operation or required manual operation.	If pump station operation uses any upstream parameter data to supply the control logic, loss of upstream monitoring may require override or manual operation at the pump site. If systems damaged, could cause further sewage discharge to environment or system damage to occur.
Communications	Communications to/from user sites.	Operations cannot communicate with personnel at remote pump sites.	If systems are damaged, could cause further sewage discharge to environment or system damage to occur. Local personnel are operating with only local indications.
Communications	Personnel communications with control center operations – possible data communications.	Personnel cannot coordinate remote operations and repairs with control center or business operations. ICS cannot monitor and control equipment.	Much of the communications infrastructure was impaired or destroyed by Maria, resulting in loss of communications across the island.
Transportation	Access by vehicles to piping runs and user sites.	Personnel cannot reach sites to evaluate system condition.	Many roads were damaged by erosion and blocked by vegetation fall preventing access to remote sites.

Table 2-26: Wastewater Dependencies – Lift/Pump Stations (Downstream)

Sector	Dependency	Impact of Loss	Puerto Rico Context
Electricity	Pump and controls operation. Access control operation.	Loss of electricity downstream prevents system remote operations. Security controls will not communicate with downstream control center.	System would have to be manually operated or operated at the local sites if power is available there. Control center will lose situational awareness of security controls.
IT	ICS and security system operation.	Loss could result in system misoperation or required manual operation. Cannot monitor security controls.	If pump station operation uses any down-stream parameter data to supply the control logic then loss of downstream monitoring may require override or manual operation at the pump site. If systems damaged, could cause further sewage discharge to environment or system damage to occur. Lose security situational awareness of the remote sites affected.
Communications	Communications to and from remote sites.	Local personnel cannot communicate with control center. Loss could result in system misoperation or required manual operation. Cannot monitor security controls.	Lose the ability to manually operate by local operations personnel coordination with control center personnel (if remote power is available to operate.) Lose security situational awareness of the remote sites affected.

Table 2-26: (cont.)

Sector	Dependency	Impact of Loss	Puerto Rico Context
Transportation	Access by vehicles to pump and user sites.	Personnel cannot reach sites to evaluate system condition.	Generator fuel cannot be replenished if the generator is at remote sites. Personnel cannot evaluate site conditions or perform repairs until transportation access is recovered.

Table 2-27: Wastewater Dependencies – WWTP (Core Functions)

Sector	Dependency	Impact of Loss	Puerto Rico Context
Electricity	Functioning of entire facility.	Cannot receive or process raw wastewater.	Rely on PREPA – backup power is used as long as it is operable. Many WWTPs use backup power due to a history of power instability in the PREPA systems; backup power from fuel generators provide energy until fuel is depleted; backup power from solar could be leveraged assuming operable; backup power from waste product recovery dependent upon facility operation to provide fuel material and black-start capability of the systems on PREPA power loss.
IT	ICS, communications and security system operation.	Process operations disruption if ICS not functional, have to operate manually if possible – requires additional trained personnel. Loss of security monitoring and access controls.	Restart of lost operations requires trained personnel and electrical source power. Control system function is required to operate systems, may be able to operate with limited to full function using manual operations if additional trained personnel are available to support and procedures exist to perform in manual mode. Additional security forces may perform security functions where security controls are unavailable.
Communications	Communications to and from business operations and remote sites.	Cannot coordinate operations with business emergency operations or with remote manned sites.	Communications may affect disruption of voice and data communications to the WWTP operation. Continued operation would be required on a stand-alone emergency basis. Emergency operations procedures are needed for support.
Transportation	Access by vehicles to transport personnel, chemicals, and fuel as needed. WWTP by-product removal.	Cannot operate systems without trained personnel, chemicals to support treatment operations, or fuel to run the backup-powered generation.	Personnel need to be transported to and from the WWTP. Additional personnel may need to be available to support emergency operations and security functions. Generator fuel and chemicals need to be replenished as needed to continue operations.
Chemicals	Chemical inventory to support parts of the treatment process.	May limit effectiveness of operation. Lack of storage protection could allow chemical loss to the environment.	Chemical treatment is crucial to support some treatment functions. Discharge of chemicals to the environment can occur if hazardous chemicals breach storage barriers.

Table 2-28: Wastewater Dependencies – Wastewater Treatment Plant (Upstream)

Sector	Dependency	Impact of Loss	Puerto Rico Context
Electricity	Pump and controls operation. Access control operation.	Loss of electricity upstream prevents system remote operations and pump operations. Security controls will not communicate with WWTP control center.	System could continue to operate if sewage feeds are gravity fed. Control center will lose situation awareness of upstream process status and operations and security controls status.
IT	ICS, communications and security system operation.	Process operations would be limited to WWTP controls and status only. May lose voice over Internet protocol (VoIP) communications with remote sites. Loss of remote site security monitoring and access controls.	May be able to operate with limited to full function basing operations on local incoming raw sewage parameters. May require additional monitoring of source sewage depending on the control system configuration.
Communications	Communications to and from pump/lift sites and other piping monitoring.	Operations cannot communicate with personnel at remote pump sites. May impact data communications if using same infrastructure.	Control center personnel could not communicate with upstream systems or personnel to coordinate operations and monitor system piping status. Local personnel are operating with only local indications.
Transportation	Access by vehicles to pump stations and piping inspection.	Personnel cannot reach sites to evaluate system condition or perform repairs.	Generator fuel and chemical inventory cannot be replenished to maintain operation. Personnel cannot evaluate site conditions or perform repairs until transportation access is recovered.

Table 2-29: Wastewater Dependencies – Wastewater Treatment Plant (Downstream)

Sector	Dependency	Impact of Loss	Puerto Rico Context
Electricity	Pump and controls operation. Access to control operations.	Loss of electricity downstream may prevent system outfall discharge monitoring and control operations.	Control center will lose situational awareness of upstream process status and operations and security controls status.
IT	ICS system operation for quality monitoring and control.	Process operations limited to WWTP controls and status.	May be able to operate with limited to full function basing operations on local treated discharge water parameters. May not be able to monitor outfall discharge quality parameters.
Communications	Communications to and from discharge piping and outfall monitoring.	Operations personnel cannot communicate with outfall sites. May impact data communications if using same infrastructure.	Control center personnel will not have communications with outfall systems or field personnel to coordinate operations and monitor system outfall operational status.

2.6.4.1 Concerns, Needs, and Challenges

Industrial Wastewater Systems

Often, industrial plants are required to perform pre-treatment of wastewater prior to its release into the sewage pipeline because of specific chemical and effluent properties associated with the waste material. Pumping sewage effluent may also be required at the plant site. In some cases, facilities have onsite wastewater pre-treatment systems that discharge to PRASA treatment plants. For example, the TEVA Manatí facility has an onsite wastewater pre-treatment system that discharges to PRASA's Barceloneta WWTP for final wastewater treatment and release. In other instances, facilities may have dedicated lines from their sites to PRASA treatment plants. In the Manatí area, Bristol-Myers Squibb has a dedicated wastewater line to the Barceloneta WWTP. When that plant was operating at reduced capacity, the Bristol-Myers Squibb facility faced limitations in the amount of wastewater that it could discharge, limiting its production activity.

General Wastewater Systems

Water quality challenges have been an ongoing issue in Puerto Rico for many years. Both water supply processes and wastewater processing contribute to the quality problems because they operate in a process cycle. The overall quality of water can be improved by increasing system resilience, but such resilience improvements necessitate improvements to the entire water life cycle. Specific failures in the systems related to Hurricane Maria only highlight failures that have been plaguing the water/wastewater infrastructure and dependent infrastructures for years. General areas of weakness observed post-storm include failure of aging infrastructure, non-operational site back-up power generators, dependence on fragile communications and electricity resources, inadequate maintenance, and transportation and chemical inventory challenges.

For example, damage to piping and lift pump infrastructure around Puerto Rico suggests a need for redundant facilities that are hardened to hurricane-type weather conditions. Similar considerations are relevant to electricity and communications since they are a required dependency in the wastewater chain. An additional concern is chemical storage, ensuring sufficient inventories are on-hand for treatment plant operations and while also preventing hazardous releases into the surrounding environment. Moreover, some wastewater facilities lacked adequate back-up generation, which caused problems for manufacturers who then had nowhere to send wastewater from production processes. Finally, siting issues, where existing facilities are located in areas that are vulnerable to hazards, are also worth evaluating to enhance resilience to future events.

EPA Water Pollution Concerns

Puerto Rico water pollution data compiled by the EPA[233] during the 2016 reporting cycle provides insight into the overall contribution of water pollution related to the wastewater infrastructure. Figure 2-61 illustrates that wastewater systems are significant probable sources for water pollution-related impairment in Puerto Rico, with the primary sources being septic tank and collection system failures. These EPA findings further illustrate the issues with aged wastewater infrastructure in Puerto Rico and the challenges in maintaining a robust periodic monitoring and maintenance program.

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[233] U.S. Environmental Protection Agency, 2018, "Puerto Rico Water Quality Assessment Report," https://iaspub.epa.gov/waters10/attains_state.control?p_state=PR&p_cycle=2016, accessed May 15, 2018.

Probable Source Group	Size of Assessed Waters with Probable Sources of Impairments			
	Rivers and Streams (Miles)	Lakes, Reservoirs, and Ponds (Acres)	Bays and Estuaries (Square Miles)	Coastal Shoreline (Miles)
Agriculture	4,747.9	6,554.0	6.0	41.0
Construction				4.2
Hydromodification			.5	138.0
Industrial	3,126.3		.5	107.3
Land Application/Waste Sites/Tanks	2,134.7	560.0	.8	39.7
Legacy/Historical Pollutants				32.7
Municipal Discharges/Sewage	5,316.5	6,623.0	10.3	365.7
Natural/Wildlife			2.5	
Recreational Boating And Marinas	18.8		.6	140.2
Resource Extraction	189.2			7.5
Unknown	11.8		1.1	52.2
Urban-Related Runoff/Stormwater	3,252.7	1,413.0	8.7	305.8

Figure 2-61: EPA Puerto Rico Water Quality Assessment Report Findings (2016)

2.7 MARITIME TRANSPORTATION SYSTEM CHARACTERIZATION

2.7.1 Scope

The characterization summarizes how the infrastructure system that constitutes the Maritime Subsector operates, with a focus on system aspects that impact resilience. This section provides a baseline understanding of how the maritime transportation system functions in general, how it functions in Puerto Rico, interdependencies between the Maritime Subsector and other critical infrastructure systems, and the potential consequences that could result from cascading failures.

2.7.2 Sector Background: General

The Transportation Systems Sector consists of seven key subsectors, or modes, as shown in figure 2-62.

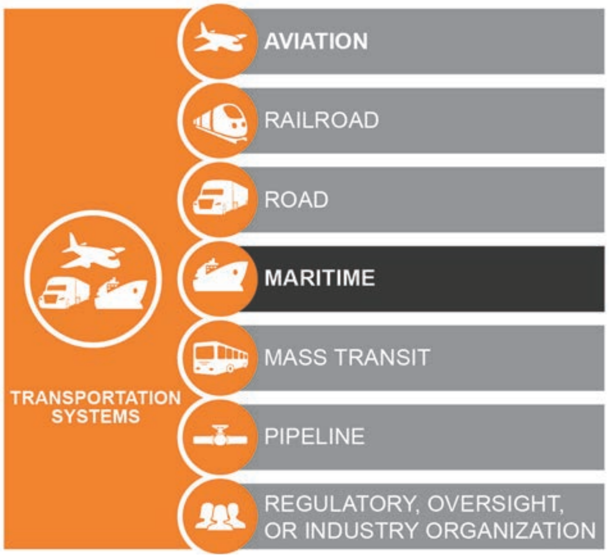

Figure 2-62: DHS Infrastructure Taxonomy–Transportation Systems Sector[234]

As an island, Puerto Rico has a disproportionate reliance on maritime systems compared with other transportation systems subsectors. Shipping and supporting functions (e.g., fuel, electric power, coastal highways, and trucking) are required for trade, commerce, and commodities to maintain daily life, economic activity, and government services in Puerto Rico.

The U.S. Maritime Transportation System (MTS) is a geographically complex and diverse system of waterways, ports, and intermodal landside connections. From a systems perspective, the MTS is a network of maritime operations that interfaces with shoreside operations at intermodal connections as part of overall global supply chains or domestic commercial operations. The MTS includes vessels, vehicles, system users, harbors, waterways, ports, and intermodal connections. The MTS also includes port terminals and their associated slips or docks, many of which are privately owned or operated. Figure 2-63 illustrates the general flow of cargo through the MTS.

234 DHS, 2011, *Infrastructure Data Taxonomy, Version 4*, National Protection and Programs Directorate, Office of Infrastructure Protection, Infrastructure Information Collection Division, June.

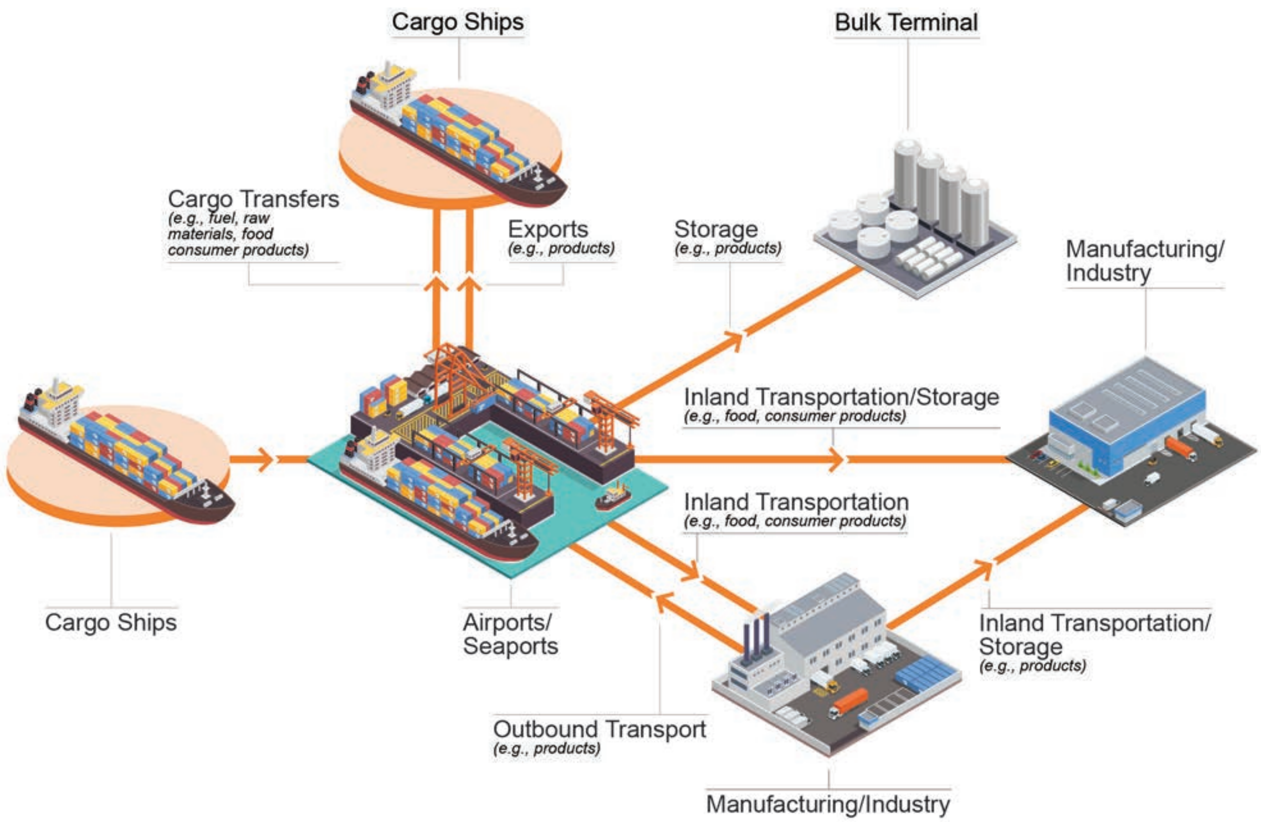

Figure 2-63: Diagram of the Maritime Transportation System Flow for Cargo

In 2015, maritime container shipping accounted for approximately 26 percent of U.S. foreign trade with more than $735 billion in goods and resources imported to the United States and more than $239 billion exported using container vessels. U.S. ports handled 31.9 million loaded 20-foot equivalent units (TEUs): 19.9 million TEUs in imports and 12 million TEUs in exports. Between 1976 and 2016, the compound annual global growth rate of container trade volume was approximately 9 percent; however, the most dramatic increase occurred between 1996 and 2016, when the total container trade volume more than tripled. The capacity of the total global container fleet as of 2016 exceeded 20 million TEUs.

The United States relies almost entirely on foreign-owned container shipping companies for the import and export of cargo. Of the 30 largest container companies—representing more than 75 percent of global container shipping capacity—none is based in the United States. The foreign ownership and operation of these companies limit U.S. insight into the finances, operations, and decisions that these groups make.[235]

235 DHS, 2017, *Consequences to Critical Infrastructure from Container Shipping Disruptions, Critical Infrastructure Security and Resilience Note*, National Protection and Programs Directorate, OCIA, April 25.

2.7.3 Sector Background: Puerto Rico

2.7.3.1 Physical Market in Puerto Rico

Puerto Rico depends on external resources to maintain many of its critical lifeline functions and industries. The port system, along with its supporting infrastructure, plays a key role in the transport of numerous essential consumable resources (e.g., fuels, chemicals, machinery/electrical equipment, food, transport vehicles, consumer goods) and produced commodities (e.g., pharmaceuticals, medical devices, and equipment). Figure 2-64 shows the approximate distribution (by weight) of domestic and foreign cargo throughput for Puerto Rico's ports.[236]

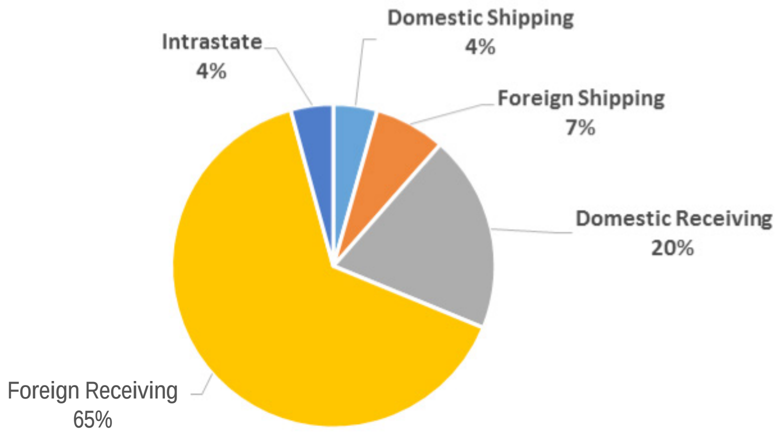

Figure 2-64: Total Cargo Throughput in Puerto Rico by Weight (2016)

The U.S. Census Bureau's Division of Economic Indicators publishes data that include air and water shipments from Puerto Rico to the United States. These data are compiled from information furnished by Electronic Export Information (EEI), which must be filed with U.S. customs officials, and shipments by qualified exporters who submit data directly to the Census Bureau. Table 2-30 lists the top 10 commodities (by dollar value) shipped by vessel from Puerto Rico to the continental United States in 2016. The table also includes shipping weight data.

[236] U.S. Census Bureau, 2016, "USA Trade Online," https://usatrade.census.gov/, accessed May 15, 2018.

Table 2-30: Top 10 Commodities Shipped from Puerto Rico to the United States (2010)[237]

Schedule B#	Commodity Description	Value in U.S. Dollars (USD) (Thousands)	Shipping Weight (1,000 Kilograms)
3002100290	Blood fractions	16,605,663	1,281
2106906573	Preparations for manufacture of beverages	2,656,072	71,133
3004909120	Cardiovascular medicaments	1,899,854	887
3302100000	Mixtures odoriferous substance used in food/ drink	1,369,021	24,941
3004909190	Medications in measurable doses for retail sale	1,270,831	2,086
3004390050	Medications with hormones	664,492	995
3004909130	Anticonvulsants, hypnotics, and sedatives for retail sale	592,784	495
8418690180	Refrigeration/freezing equipment	506,149	21,606
9018908000	Instruments and appliances for medical, surgical, etc.	491,801	10,514
3004909125	Analgesics, antipyretics, and non-hormone anti-inflammatory	473,448	8,777
	PUERTO RICO TO U.S. TOTAL	**31,900,432**	**502,590**

The Puerto Rico Ports Authority (PRPA) operates 11 seaports (see Figure 2-65) under Puerto Rico's Department of Transportation and Public Works. The Port of the Americas Authority operates the twelfth seaport, the Port of Ponce. The three major seaports in Puerto Rico are the Port of San Juan, Port of Ponce, and Port of Fajardo, which together accounted for approximately 99 percent of the total value[238] and weight[239] of all foreign throughputs in 2016.[240] A significant majority of this throughput transits the Port of San Juan.

The Port of San Juan, located on the northern coast, is Puerto Rico's primary commercial port, handling the majority of the maritime cargo moving through the island's seaports. It also serves cruise passengers from both homeporting ships and port-of-call visits. The Port of Ponce, to the south, also moves a variety of cargo and has limited port-of-call cruise operations. The Port of Fajardo, in the west, primarily deals with non-crude oils and is the hub for recreational boating and a popular launching point to Culebra, Vieques, and the United States and British Virgin Islands. The Port of Mayagüez is a multi-purpose seaport that handles various types of cargo and is a key part of domestic freight and passenger connectivity flows.

The remaining seaports, such as Arecibo and Aguadilla, have decreased in importance following the decline of local agricultural activity. Specialized ports in Guayanilla and Yabucoa, among others, have at times been of particular value in the commerce of petroleum derivates or other commodities.[241] In addition, the PRPA acquired the deep water port facilities at the former Roosevelt Road Naval Station in Ceiba after its closure in 2004.

Tables 2-31 and 2-32 present some of the characteristics of seaports in Puerto Rico.

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237 U.S. Census Bureau, 2017, "U.S. Trade with Puerto Rico and U.S. Possessions 2016," May 30, https://www.census.gov/library/publications/2017/econ/ft895-16.html, accessed May 15, 2018.

238 The value of goods imported as appraised by U.S. Customs and Border Protection. This value is generally defined as the price actually paid or payable for merchandise when sold for exportation to the United States. It excludes U.S. import duties, freight, insurance, and other charges incurred in bringing the merchandise to the United States (General Imports).

239 The gross weight in kilograms of shipments made by seafaring vessel at customs.

240 U.S. Census Bureau, 2016, "USA Trade Online," https://usatrade.census.gov/, accessed May 15, 2018.

241 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan*, December, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 15, 2018.

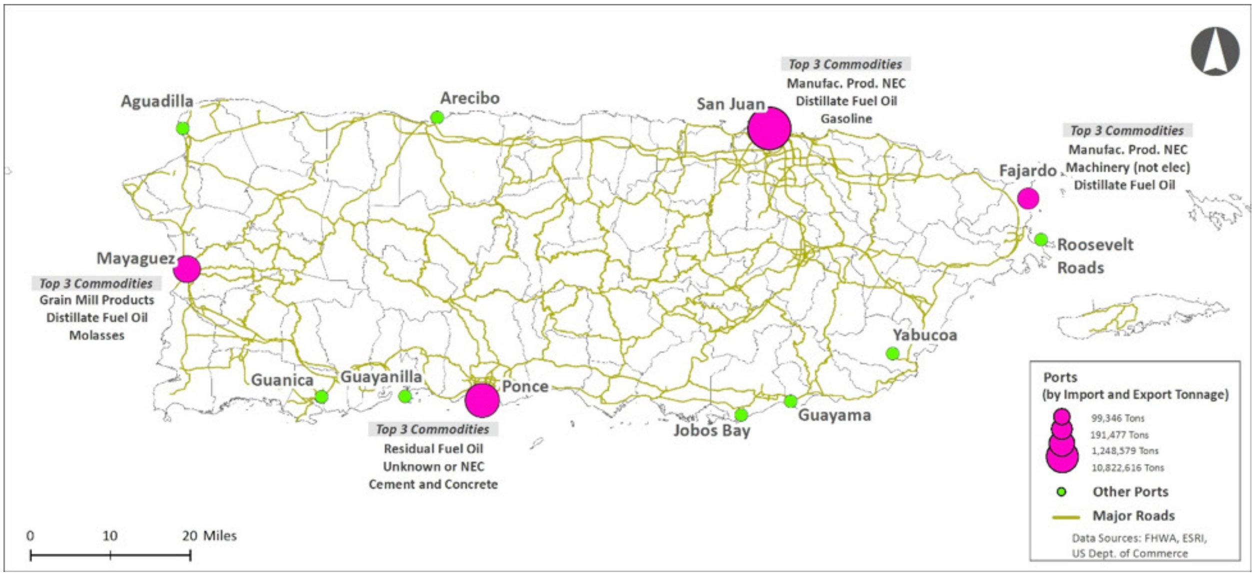

Figure 2-65: Maritime Seaports in Puerto Rico[242]

Table 2-31: Puerto Rico Port Characteristics[243]

Asset Name	Channel Depth (ft.)	Cargo Pier Depth (ft.)	Oil Terminal Depth (ft.)	Lift Capacity (tons)	Cranes
Port of Aguadilla	66-75	36-40	26-30	–	–
Port of Arecibo	21-25	21-25	16-20	–	–
Port of Fajardo	21-25	6-10	–	0-100	Mobile
Port of Guanica	31-35	26-30	21-25	0-24	Fixed
Port of Guayanilla	26-30	26-30	36-40	–	–
Port of Yabucoa	46-50	–	46-50	–	–
Port of Jobos Bay	11-15	26-30	26-30	–	–
Port of Guayama	31-35	36-40	41-45	–	–
Port of Mayagüez	16-20	26-30	–	0-24	Fixed
Port of Ponce	21-25	26-30	–	100+	Mobile
Port of San Juan	41-45	31-35	31-35	100+	Mobile, fixed, floating
Roosevelt Roads	41-45	31-35	31-35	0-24	Mobile, fixed

242 Federal Highway Administration, ESRI.

243 The depth of water varies constantly with the tide. Therefore, the depths on the chart represent an imaginary level know as chart datum, which indicates charted depths displayed on a nautical chart. Source: World Port Source, undated, http://www.worldportsource.com/ports/PRI.php, accessed May 15, 2018.

Table 2-32: Main Port Services and Ship Supplies Available[244]

Asset Name	Port Services	Ship Supplies Available
Port of Aguadilla	Longshore	Water, fuel oil, diesel oil
Port of Arecibo	Longshore	Provisions, fuel oil
Port of Fajardo	Longshore, electrical, electrical repair	Provisions, water, fuel oil, diesel oil
Port of Guanica	Longshore, electrical, electrical repair	Provisions, water, fuel oil,
Port of Guayanilla	Electrical repair	Provisions, water, fuel oil, diesel oil, engine
Port of Yabucoa	Navigation equipment	Provisions, water, fuel oil, diesel oil
Port of Jobos Bay	Longshore	Provisions, water
Port of Guayama	Longshore	Provisions, water, fuel oil
Port of Mayagüez	Longshore, electrical	Provisions, water, fuel oil, diesel oil
Port of Ponce	Longshore, electrical	Provisions, water, fuel oil, diesel oil, engine
Port of San Juan	Longshore, electrical, electrical repair, steam	Provisions, water, fuel oil, diesel oil, engine
Roosevelt Roads	Longshore	Provisions, water, fuel oil

Port of San Juan

The Port of San Juan serves both cargo and passenger movements. It is the only harbor on the northern coast of Puerto Rico that affords some protection in all weather. The principal cruise and tourism facilities are on the south side of San Juan Island (Old San Juan) and on the north side of Isla Grande. Container cargo terminals are located at Puerto Nuevo in the southeast part of the bay (see figure 2-66).

The PRPA owns most of the port terminal property and docks, but each of these is leased by privately owned entities that are responsible for the security, safety, and supporting infrastructure within their properties. These port terminals serve as exchange sites where cargo is unloaded from ships and transferred to alternate means of transportation. For the Port of San Juan, this alternate transportation method is primarily truck, given the absence of any freight rail and only limited pipeline transportation on the island.

244 Ibid.

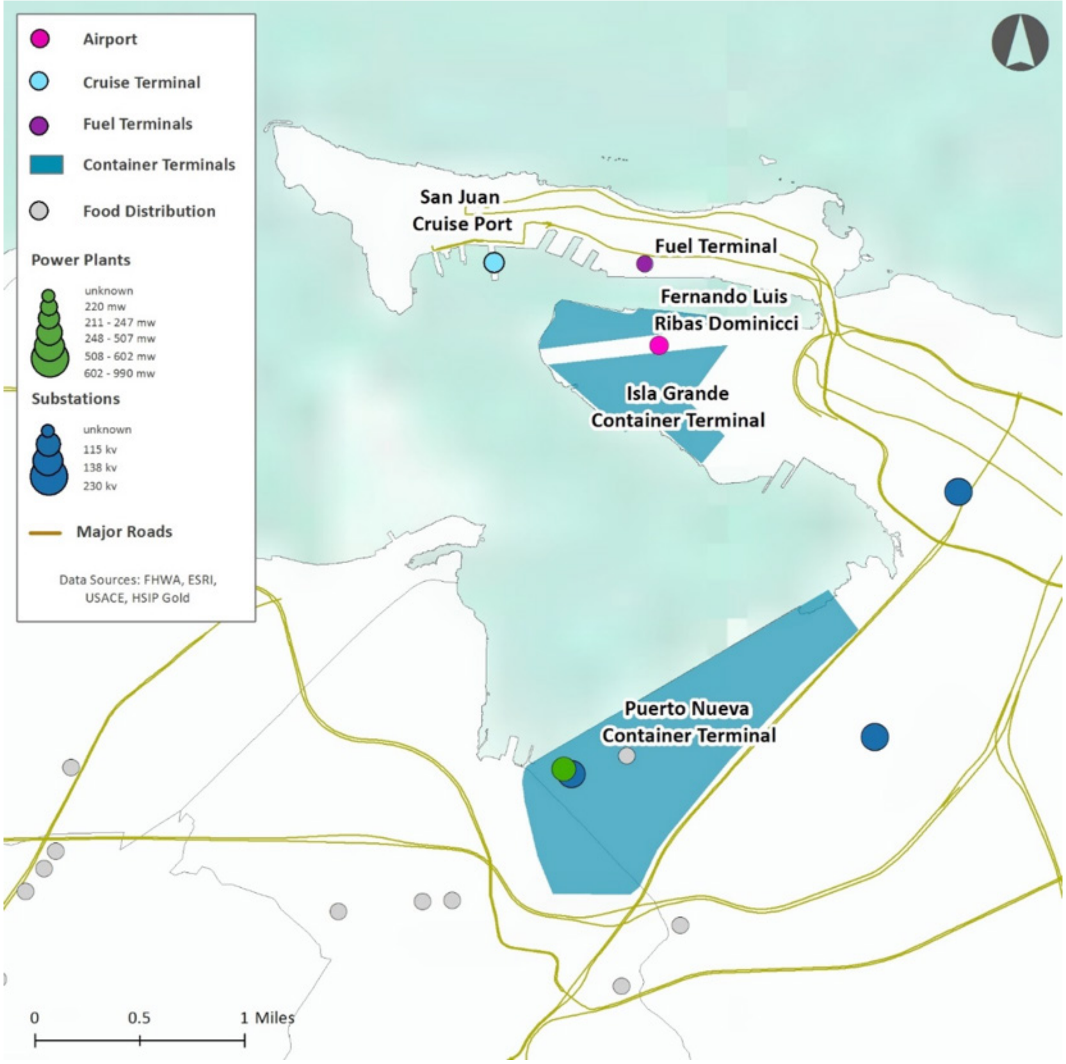

Figure 2-66: Port of San Juan Area

The Port of San Juan handles virtually all types of cargo from ocean-going vessels: bulk cargo, general cargo, construction materials, containerized cargo, automobiles and other roll-on/roll-off cargo, fuel and chemicals, and others.[245] The port's main public cargo facilities are located in the Puerto Nuevo complex, which handles containerized and break-bulk cargoes with and without shore-side cranes. Containers are also handled at the private Isla Grande barge terminal. Additional private facilities handle containers (in roll-on/roll-off and barge service) and bulk commodities.[246] The port has 34 docks and 46 berths in total.[247]

245 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan*, December, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 15, 2018.

246 U.S. Department of Transportation Bureau of Transportation Statistics, 2017, *Port Performance Freight Statistics Program 2017: Annual Report to Congress,* https://www.bts.gov/port-performance-2017, accessed May 15, 2018.

247 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan*, December, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 15, 2018.

The Port of San Juan is the busiest port in Puerto Rico in terms of cargo movements. More than half (54 percent) of the commodity shipments into and out of the Port of San Juan are via foreign traffic. In 2016, the Port of San Juan moved approximately 81 percent of the total value and 40 percent of the total weight of all foreign throughputs.[248]

The major imported commodities handled at the port include fuel oil (non-crude), transport vehicles and parts, organic chemicals, machinery/electrical equipment, foodstuffs, and consumer goods. Major exported commodities handled at the port include pharmaceuticals, medical equipment, chemicals, chemical products, and machinery/electrical equipment.[249] The total tonnage of domestic and foreign cargo receipts and shipments through the Port of San Juan was more than 10.8 million tons in 2016.[250] Table 2-33 lists the top 10 commodities shipped through the Port of San Juan.

Often referred to as the cruise capital of the Caribbean, the Port of San Juan has the largest cruise ship harbor in the Eastern Caribbean. It serves as the main harbor for several cruise ship companies because of its strategic location—only 3 to 4 days from most locations on the East Coast, 10 days from the West Coast, and 2 weeks from Europe. In 2016, the Port of San Juan served approximately 1.3 million passengers aboard over 500 vessels.[251] Table 2-34 provides cruise ship passenger and vessel data for the Port of San Juan from the last 10 years.[252]

Table 2-33: Port of San Juan Top 10 Commodity Shipments, Domestic and Foreign (2016)[253]

Commodity Name	Rank by Tonnage	All Traffic Directions	Receipts	Shipments
Manufac. Prod. Not Elsewhere Classified (NEC)	1	1,466,442	1,160,107	306,335
Distillate Fuel Oil (e.g., diesel)	2	1,307,766	1,099,180	208,586
Gasoline	3	1,192,517	1,191,150	1,367
Groceries	4	780,871	676,050	104,821
Kerosene	5	533,604	524,613	8,991
Grain Mill Products	6	411,603	409,004	2,599
Food Products NEC	7	392,531	242,769	149,762
Machinery (Not Electric)	8	299,976	64,230	235,746
Vegetables and Produce	9	296,094	276,238	19,856
Residual Fuel Oil	10	279,927	279,927	0
Other	–	3,861,285	3,322,906	538,379
TOTAL	**–**	**10,822,616**	**9,246,174**	**1,576,442**

Table 2-34: Port of San Juan Cruise Ship Data

Types	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Passengers (mil)	1.3	1.4	1.5	1.2	1.2	1.2	1.1	1.0	1.2	1.5	1.3
Vessels	550	563	581	470	466	475	470	391	436	554	502

248 U.S. Census Bureau, 2016, "USA Trade Online," https://usatrade.census.gov/, accessed May 15, 2018.

249 Ibid.

250 U.S. Army Corps of Engineers, 2016, Waterborne Commerce Statistics Center.

251 Puerto Rico Ports Authority, 2017, *P3 Summit Puerto Rico*, April 20, http://p3summitpr.com/wp-content/uploads/2017/04/P3-SUMMIT-MARITIME-PORTS-AIRPORTS-FINAL.pdf, accessed May 15, 2018.

252 Ibid.; Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan,* December, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf; American Association of Port Authorities, https://www.aapa-ports.org/unifying/content.aspx?ItemNumber=20921, all accessed May 15, 2018.

253 U.S. Army Corps of Engineers, 2016.

Port of Ponce

The Port of Ponce, also known as the Port of the Americas, is located along the southern coast of Puerto Rico and moves a variety of cargo with limited port-of-call cruise operations. Located in the middle of the Mona Passage, a main shipping route between the Atlantic Ocean and the Panama Canal, the Port of the Americas has the capacity to become a world-class international transshipment port (figure 2-67).

The redevelopment of this port into a world-class deep-water seaport could greatly expand Puerto Rico's share in global shipping and build upon the important role already being played by the Port of San Juan. It would also provide Puerto Rico with greater maritime transportation redundancy in the event of a disruption to the Port of San Juan. Over the years, despite numerous challenges, changing economic trends, fluctuating public opinion, and varying political environments, the Port of Ponce has remained an essential element in the economic development of the south coast of Puerto Rico and Ponce itself.[254]

Phased work to expand and modernize the port began in the early 2000s. The Port of Americas currently has a modern post-Panamax berth, with 50-foot depth, and a container yard with capacity of up to 250,000 TEUs per year. As of 2013, improvements and investments of $250 million have been made to the port, and two post-Panamax cranes have been installed. Additional investments are required to take the port to its intended annual container capacity of up to 500,000 TEUs and storage capacity of 2.2 million TEUs.[255] However, at present, the port is not serving its full capacity.

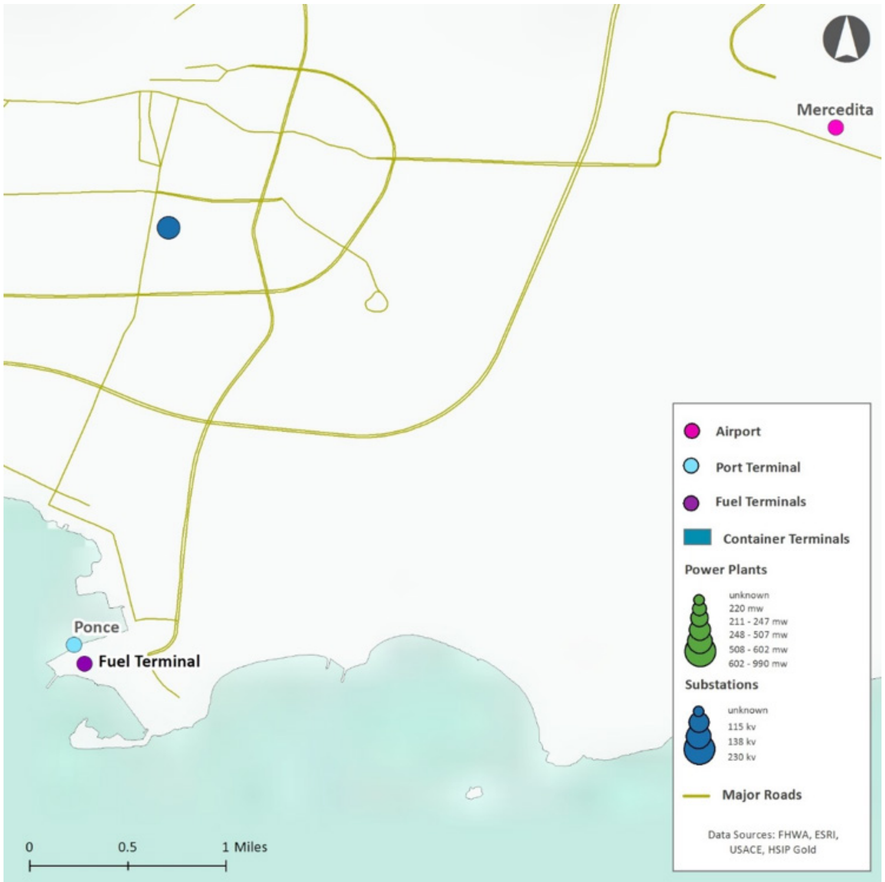

Figure 2-67: Port of Ponce

254 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan*, December, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 15, 2018.

255 Ibid.

The Port of Ponce currently handles dry bulk, general and liquid bulk cargoes, as well as roll-on/roll-off vessels and aims to attract further volume in these sectors. In general, 72 percent of the commodity shipments into and out of the Port of Ponce are via foreign traffic. In 2016, the Port of Ponce moved approximately 11 percent of the total value and 38 percent of the total weight of all foreign throughputs.

Major imported commodities handled at the port include fuel oil (non-crude), coal, petroleum products, gaseous hydrocarbons, foodstuffs, cement, and iron and steel. Exported commodities handled at the port are iron and steel scrap, cement, and concrete. The total tonnage of domestic and foreign cargo receipts and shipments through the Port of Ponce was approximately 1.25 million tons in 2016.[256] Table 2-35 lists the top 10 commodities shipped through the Port of Ponce.

Table 2-35: Port of Ponce Top 10 Commodity Shipments, Domestic and Foreign (2016)[257]

Commodity Name	Rank by Tonnage	All Traffic Directions	Receipts	Shipments
Residual Fuel Oil	1	324,240	324,240	0
Unknown or NEC	2	316,368	316,368	0
Cement and Concrete	3	162,713	76,854	85,859
Coal and Lignite	4	159,310	159,310	0
Iron and Steel Scrap	5	91,050	1,543	89,507
Molasses	6	89,866	89,866	0
Hydrocarbon and Petrol Gases, Liquefied and Gaseous	7	69,462	69,462	0
Distillate Fuel Oil	8	16,848	16,848	0
Fruit Juices	9	8,689	8,689	0
Sugar	10	7,474	7,474	0
Other	–	1,215	1,215	0
TOTAL	**–**	**1,248,579**	**1,073,213**	**175,366**

Port of Fajardo

The Port of Fajardo, along Puerto Rico's eastern coast, is a hub for recreational boating and features the largest marina in the Caribbean, called Puerto del Rey. The Port of Fajardo is a popular launching port to Culebra, Vieques, and the U.S. and British Virgin Islands. In 2013, 1.2 million passengers traveled the routes between Fajardo and Culebra and Vieques, for an average of nearly 3,300 passengers per day.[258]

In 2016, the Port of Fajardo moved approximately 8 percent of the total value and 21 percent of the total weight of all foreign throughputs. Imported commodities handled at the port are machinery (non-electric), fuel oil (non-crude) and manufactured products. Exported commodities handled at the port are manufactured products and machinery (non-electric).[259] The total tonnage of domestic and foreign cargo receipts and shipments through the Port of Fajardo was approximately 190,000 tons in 2016.[260] Table 2-36 lists the three commodities shipped through the Port of Fajardo.

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256 U.S. Army Corps of Engineers, 2016.

257 Ibid.

258 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan*, December, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 15, 2018.

259 U.S. Census Bureau, 2016, "USA Trade Online," https://usatrade.census.gov/, accessed May 15, 2018.

260 U.S. Army Corps of Engineers, 2016.

Table 2-36: Port of Fajardo Top Commodity Shipments, Domestic and Foreign (2016)[261]

Commodity Name	Rank by Tonnage	All Traffic Directions	Receipts	Shipments
Manufactured Products NEC	1	152,306	4,503	147,803
Machinery (Not Electric)	2	32,781	31,221	1,560
Distillate Fuel Oil	3	6,390	6,390	0
TOTAL	**–**	**191,477**	**42,114**	**149,363**

Port of Mayagüez

The Port of Mayagüez is a multi-purpose seaport that handles various types of cargo and is an important part of the domestic freight and passenger connectivity flows. Currently, the Port of Mayagüez is the only port on Puerto Rico's western coast capable of docking large cruise ships. It receives weekly visits by ships serving the Dominican Republic.[262] In 2016, major commodities handled at the port included fuel oil (non-crude), grain mill products, and molasses. The total tonnage of domestic and foreign cargo receipts and shipments through the Port of Mayagüez was nearly 100,000 tons in 2016.[263] Table 2-37 shows the top commodities shipped through the Port of Mayagüez.

Table 2-37: Port of Mayagüez Top Commodity Shipments, Domestic and Foreign (2016)[264]

Commodity Name	Rank by Tonnage	All Traffic Directions	Receipts	Shipments
Grain Mill Products	1	82,815	82,815	0
Distillate Fuel Oil	2	11,008	11,008	0
Molasses	3	5,512	5,112	0
Electrical Machinery	4	5	0	5
Fabricated Metal Products	5	3	0	3
Plastics	5	3	0	3
TOTAL	**–**	**99,346**	**99,335**	**11**

Other Ports

The other smaller ports in Puerto Rico serve various types of cargo, occasional cruise calls, and recreational boating. Some of these seaports, such as Arecibo and Aguadilla, have lost importance following the decline of local agricultural activity. Specialized ports in Guanica, Guayanilla, Jobos Bay, Yabucoa, and Guayama have, at times, been of particular value in the commerce of petroleum derivates, chemicals, or some other specific commodity, but are no longer.[265] In addition, the PRPA acquired the deep-water port facilities at the former Roosevelt Road Naval Station in Ceiba after its closure in 2004; it is not currently a functional commercial port facility.

261 Ibid.

262 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan*, December, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 15, 2018.

263 U.S. Army Corps of Engineers, 2016.

264 Ibid.

265 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan*, December, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 15, 2018.

2.7.3.2 Commercial Activities in Puerto Rico

Major imported commodities that the Puerto Rico MTS handles include fuel oil (non-crude), transport vehicles and parts, organic chemicals, machinery/electrical equipment, foodstuffs, and consumer goods. Major exported commodities include pharmaceuticals, medical equipment, chemicals, chemical products, and machinery/electrical equipment. Specifically related to pharmaceutical products, Puerto Rico is the world's largest international shipper of pharmaceutical products (by dollar value), distributing more than $30 billion in pharmaceutical products around the globe each year. The pharmaceutical industry relies heavily on the Port of San Juan for the export of around 85 percent of all pharmaceuticals leaving Puerto Rico.

Table 2-38 summarizes the value of foreign commodity shipments into and out of the ports of Puerto Rico. In 2016, the Puerto Rico MTS imported foreign commodities valued at more than $7.5 billion.

Table 2-38: Port Dollar Value Data for Foreign Trade (2016)[266]

Asset Name	Total Imports Million $US	Total Exports Million $US
Port of San Juan	5,400	4,645
Port of Ponce	1,355	39
Port of Fajardo	710	198
Port of Yabucoa	70	1
Port of Aguadilla	6	39

Figures 2-68 and 2-69 provide an overview of the primary commodity imports and exports (by dollar value and shipping weight) for the Puerto Rico MTS.[267] Foreign exports totaled approximately 1.9 million tons valued at around $4.9 billion.[268]

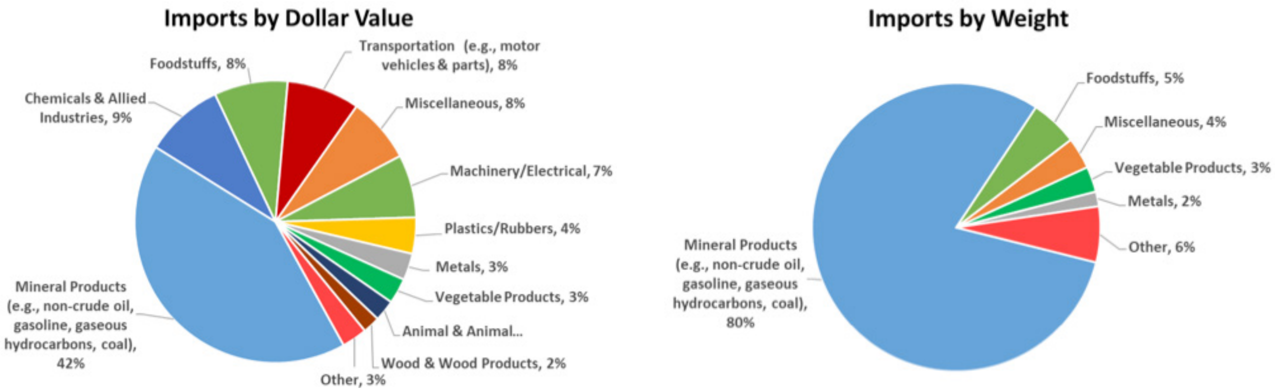

Figure 2-68: Summary of Foreign Commodity Imports for Puerto Rico (2016)

266 U.S. Census Bureau, 2016, "USA Trade Online," https://usatrade.census.gov/, accessed May 15, 2018.

267 Data represents commodities that pass through U.S. Customs to/from foreign markets; data do not account for imports from or exports to the United States.

268 U.S. Census Bureau, 2016, "USA Trade Online," https://usatrade.census.gov/, accessed May 15, 2018.

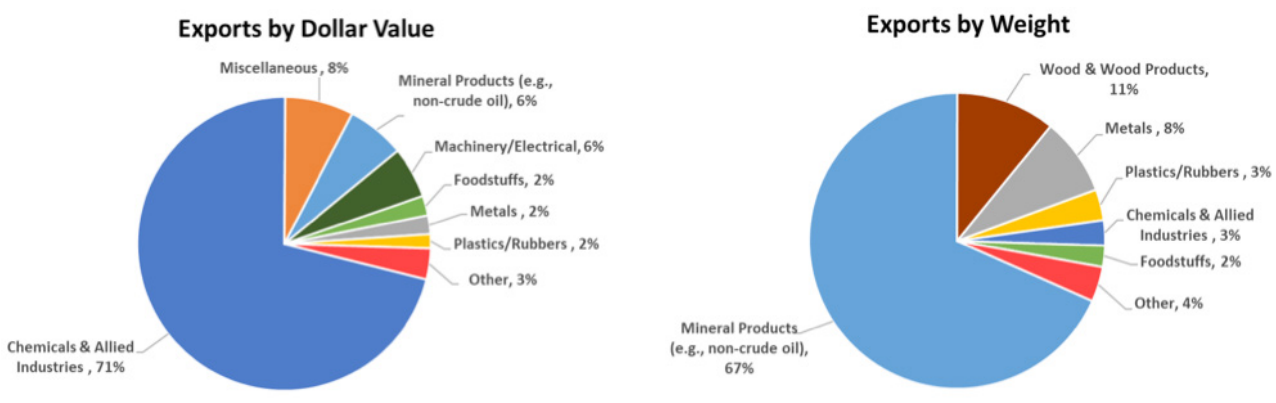

Figure 2-69: Summary of Foreign Commodity Exports for Puerto Rico (2016)

2.7.4 System Interdependencies

Puerto Rico's dependence on maritime shipping can have cascading impacts on other critical infrastructure, including the Energy, Agriculture and Food, Critical Manufacturing, Chemical, Commercial Facilities, and Healthcare and Public Health Sectors. Therefore, the resilience of the island's ports—in particular the largest, Port of San Juan—is essential to the resilience of Puerto Rico. Identifying system dependencies of the MTS and improving the resilience of those supporting infrastructure should help to ensure the continued delivery of commodities to the entire island.

Operations at ports depend on services and resources from supporting regional lifeline infrastructure. Dependencies and interdependencies of port facilities and systems include electric power, fuels, transportation routes, communications, IT, water, and wastewater. Figure 2-70 provides a high-level overview of the sector-level physical dependencies and interdependencies. The light grey shading indicates critical infrastructure sectors that depend on maritime resources; the dark grey shading indicates critical infrastructure sectors that are interdependent with the Maritime Subsector. Table 2-39 presents an overview of the Maritime Subsector's upstream dependencies.

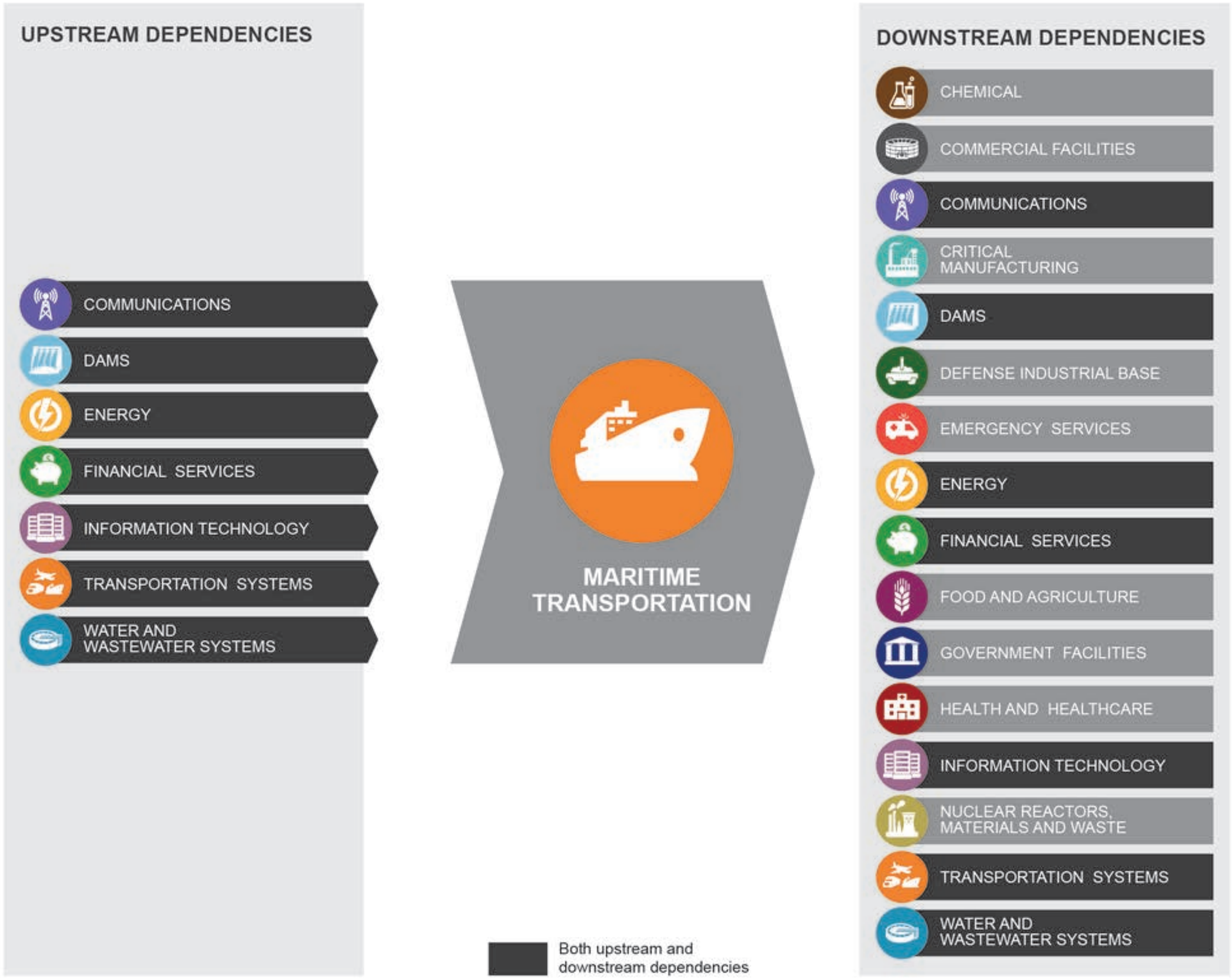

Figure 2-70: Maritime Subsector Interdependencies

Table 2-39: Maritime Subsector Upstream Dependencies

Sector	Asset	Service/Resources Provided
Communications	Wired, wireless, satellite, and Internet	Telecommunication for daily operations; industrial control systems and supervisory control and data acquisition system
Dams	Water retention and conveyance structures	Management of navigable waters for shipping
Energy	Terminals, fuel storage tanks, substations	Fuels, electric power for running equipment (e.g., cranes)
Financial Services	Payment systems, financial markets	Daily business operations of ports
IT	Security hardware, routing and switching equipment, data storage, software, electronic devices	Business management and coordination; Internet services; identity management
Water and Wastewater Systems	Pumping stations, storage, treatment facilities, transmission and distribution mains, collection/removal infrastructure	Temperature control (e.g., cooling of equipment); fire suppression; potable water; wastewater removal service

As an island, in Puerto Rico all sectors have downstream dependencies and therefore would be impacted by a loss of the MTS. Global supply chains are particularly critical for island economies such as Puerto Rico, which must rely on the MTS to bring in almost all of the products consumed (both domestic and industrial consumption) on the island. Therefore, Puerto Rico is highly dependent on ports that ship commodities to the island and uniquely vulnerable to disruptions at these major ports of embarkation (e.g., Port of Jacksonville).

2.7.4.1 Concerns, Needs, and Challenges

The Maritime Subsector is a critical enabling subsector for virtually all activity in Puerto Rico. The total portfolio of food, fuels, manufacturing, and consumer products depends on the steady flow of maritime traffic from the United States and international points of origin. The Port of San Juan, in particular, is the single most important set of infrastructure assets (e.g., docks, berths, cargo facilities, warehouses, cranes, intermodal connections) on the island. If rendered inoperable, the Port of San Juan represents a potential single point of failure for critical supply chains that satisfy lifeline needs of the commonwealth and the Nation.

Considerations for Interdependent Lifeline Infrastructure in Puerto Rico

As noted in both the electricity and fuels system characterizations (Sections 2.2 and 2.3), the Puerto Rico MTS is critical to the delivery of raw energy materials for electric power generation. In a report prepared for PREPA examining the future generation fuel mix, Siemens Industry noted that "supplies of cleaner and more cost-effective fuels are needed on both the southern and northern sides of Puerto Rico in order to best meet the generation and environmental compliance requirements facing PREPA."[269] This diversification in the fuel and electric power generation portfolio for the island is also intended to reduce the overall stress placed on the 10 maritime terminals that presently handle the movement of energy raw materials.[270]

Considerations for Dependent Industries and Community Functions in Puerto Rico

Every private industry stakeholder that DHS-IP consulted and that conducts manufacturing operations depends on maritime transportation through one of the ports for either inbound delivery of materials and supplies or for outbound shipments of finished products. Stakeholders reported rising operating costs that are principally associated with island transportation requirements and growing demands on the finite storage and intermodal capabilities at these maritime facilities. Stakeholders overwhelmingly suggested that investments in current and future points of intermodal exchange at western and southern coastal seaports will improve the overall resilience posture and economic outlook of the entire commonwealth.

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269 Siemens Industry, 2015, *Integrated Resource Plan Volume I: Supply Portfolios and Futures Analysis*, https://www2.aeepr.com/Documentos/Ley57/PREPA%20IRP%20Volume%20I%20%E2%80%93%20Draft%20for%20PREC%20review.PDF, accessed May 15, 2018.

270 Ibid.

2.8 AVIATION SYSTEM CHARACTERIZATION

2.8.1 Scope

This characterization summarizes how the infrastructure system that constitutes the Aviation Subsector operates, with a focus on aspects of the system that impact resilience. This section provides a baseline understanding of how the aviation subsector functions in general, how it functions in Puerto Rico, the interdependencies between the Aviation Subsector and other critical infrastructure systems, and the potential consequences that could result from cascading failures.

2.8.2 Sector Background: General

The Transportation Systems Sector consists of seven key subsectors, or modes: Aviation, Highway and Motor Carrier, Maritime, Mass Transit and Passenger Rail, Pipeline Systems, Freight Rail, and Postal and Shipping (figure 2-71).

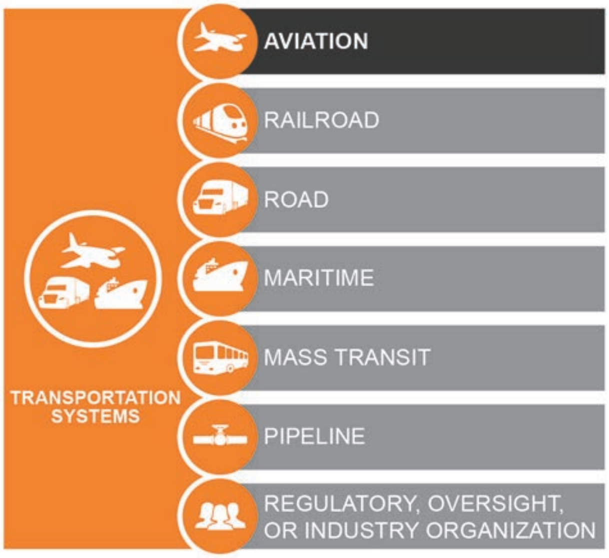

Figure 2-71: DHS Infrastructure Taxonomy—Transportation Systems Sector[271]

The Aviation Subsector in the United States includes aircraft; air traffic control systems; and about 19,700 airports, heliports, and landing strips. Commercial aviation services are provided at about 500 civil and joint-use military airports, heliports, and sea plane bases. Across the United States, approximately 780,000 passenger flights take place each month. In addition, the Aviation Subsector includes commercial and recreational aircraft (manned and unmanned) and a wide-variety of support services, such as aircraft repair stations, fueling facilities, navigation aids, and flight schools.[272] Figure 2-72 illustrates the general flow of cargo through an aviation transportation system.

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[271] DHS, 2011, *Infrastructure Data Taxonomy, Version 4*, National Protection and Programs Directorate, Office of Infrastructure Protection, Infrastructure Information Collection Division, June.

[272] DHS, 2015, *Transportation Systems Sector-Specific Plan (TS SSP),* https://www.dhs.gov/sites/default/files/publications/nipp-ssp-transportation-systems-2015-508.pdf, accessed May 2018; DHS, 2017, "Transportation Systems Sector," https://www.dhs.gov/transportation-systems-sector, accessed May 2018.

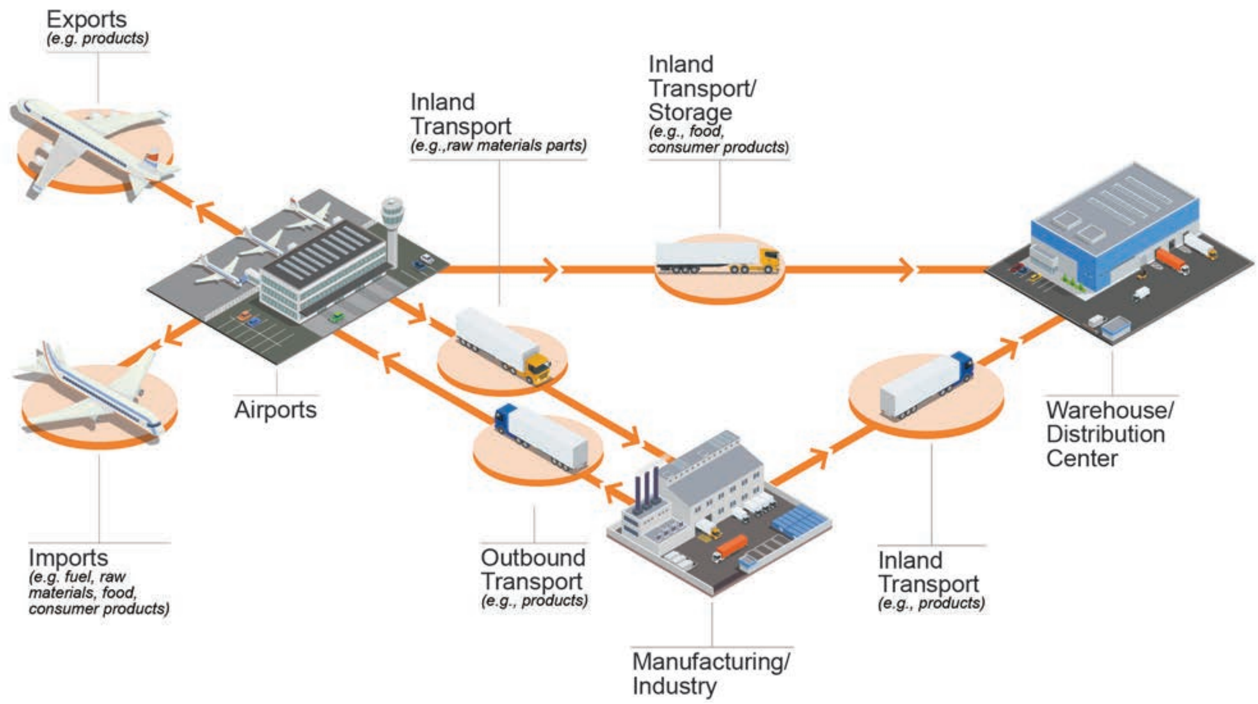

Figure 2-72: Diagram of the Aviation Transportation System Flow for Cargo

2.8.3 Sector Background: Puerto Rico

2.8.3.1 Physical Market in Puerto Rico

As an island, Puerto Rico depends on external resources to maintain many of its critical lifeline functions. The airport system—most notably, the Luis Muñoz Marín and Rafael Hernández International Airports, along with their supporting infrastructure—plays a key role in transporting many essential consumable resources (e.g., food and consumer goods) and produced commodities (e.g., pharmaceuticals). Figure 2-73 shows Puerto Rico's total cargo throughput for foreign trade by airport.[273]

[273] U.S. Department of Commerce, 2016[a], "U.S.A Trade Online," U.S. Census Bureau, https://usatrade.census.gov/, accessed May 14, 2018.

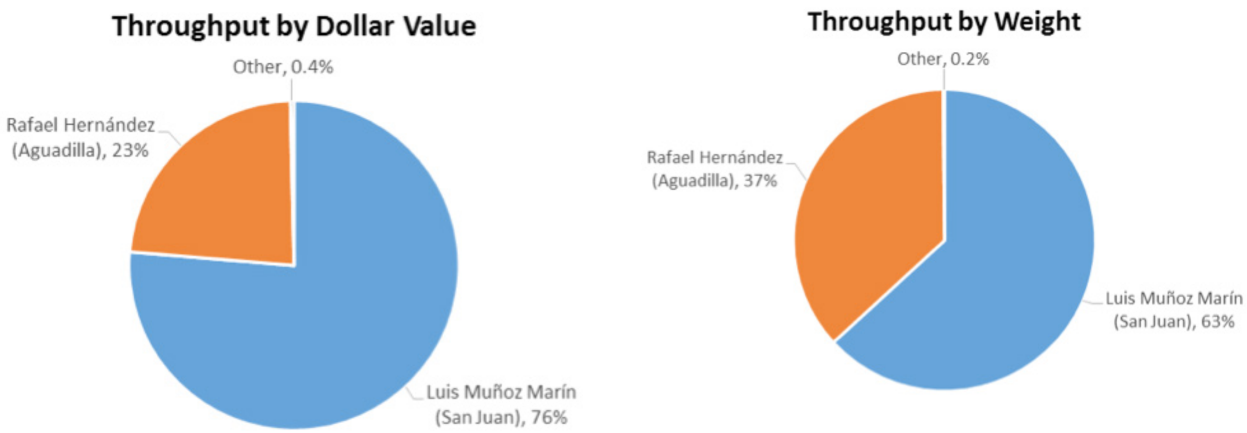

Figure 2-73: Total Cargo Throughput for Foreign Trade by Airport (2016)[274]

The U.S. Census Bureau's Division of Economic Indicators publishes data that include air and water shipments from Puerto Rico to the United States. These data are compiled from (1) information that EEI furnished, which must be filed with customs officials, and (2) shipments by qualified exporters, who submit data directly to the Census Bureau. Table 2-42 lists the top ten commodities (by dollar value) shipped by air from Puerto Rico to the continental United States in 2016. The table also includes shipping weight data.

Table 2-40: Top 10 Commodities Shipped by Air from Puerto Rico to the United States (2016)[275]

Schedule B#	Commodity Description	Value in USD (thousands)	Shipping Weight (1,000 kg)
3002100290	Blood fractions	11,599,322	594
9021900002	Appliances worn/carried/implanted and parts	1,871,762	1,152
3004909190	Medicaments in measurable doses for retail sale	1,324,798	460
9021390000	Other artificial parts of the body, parts & accessories	1,207,036	541
3004909135	Antidepressants, tranquilizers, other psych agents	752,444	455
3004909115	Antineoplastic and immunosuppressive medicaments	711,303	177
2937120000	Insulin and its salts	612,201	8
3004909120	Cardiovascular medicaments	583,916	250
9018908000	Instruments & appliances for medical, surgical, etc.	516,503	1,982
8544420000	Electrical conduits with connectors >1000v	398,089	367
---	**PUERTO RICO TO U.S. TOTAL**	**23,929,303**	**23,524**

274 Ibid.

275 U.S. Department of Commerce, 2016[b], *U.S. Trade with Puerto Rico and U.S. Possessions, FT895/16*, https://www.census.gov/content/dam/Census/library/publications/2017/econ/ft895-16.pdf, accessed May 14, 2018.

The Puerto Rico Ports Authority operates 11 airports, described in table 2-40 and shown in figure 2-74.[276] San Juan's Luis Muñoz Marín International Airport dominates air cargo and passenger traffic in Puerto Rico; this airport accounted for approximately 76 percent of the total value and 63 percent of the total weight of all foreign throughputs of air cargo in Puerto Rico in 2016.[277] Rafael Hernández International Airport in Aguadilla has the longest runway in the region and is capable of handling some of the largest cargo aircraft in the world. Total throughput for Rafael Hernández was approximately 23 percent of the total value and 37 percent of the total weight of all foreign throughputs in 2016.[278] The remaining nine airports have paved runways that are lighted for 24-hour operations, but they accounted for less than half a percent of the total value and total weight of all airport throughputs in 2016.[279] Two of these smaller airports are located on the off-shore islands of Vieques and Culebra; one is in San Juan.

276 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan,* www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 14, 2018.

277 U.S. Department of Commerce, 2016[a], "U.S.A Trade Online," U.S. Census Bureau, https://usatrade.census.gov/, accessed May 14, 2018.

278 Ibid.

279 Ibid.

Table 2-41: Puerto Rico Airport Characteristics[280]

Asset Name	Location	Aircraft Operations (%)	Average Daily Flights	Runway Length x Width (m)
Luis Muñoz Marín (SJU)	Carolina	48 air taxi 40 commercial 10 transient general aviation 1 military <1 local general aviation	467	3,170 × 61 2,443 × 46
Fernando Luis Ribas Dominicci (SIG)	Isla Grande	45 transient general aviation 39 local general aviation 13 air taxi 3 military	262	1,688 × 30
Rafael Hernández (BQN)	Aguadilla	32 local general aviation 27 military 23 transient general aviation 10 commercial 7 air taxi	133	3,567 × 61
Benjamín Rivera Noriega (CPX)	Culebra	93 air taxi 4 transient general aviation 4 local general aviation	97	792 × 18
Antonio Rivera Rodríguez (VQS)	Vieques	66 air taxi 26 commercial 6 transient general aviation 2 military	85	1,311 × 23
Jose Aponte de la Torre (NRR)	Ceiba	88 air taxi 7 local general aviation 5 transient general aviation <1 military	34	3,353 × 46
Mercedita (PSE)	Ponce	66 local general aviation 27 commercial 7 military	17	2,440 × 46
Eugenio María de Hostos (MAZ)	Mayagüez	62 air taxi 19 local general aviation 10 military 9 transient general aviation	12	1523 × 30
Antonio (Nery) Juarbe Pol (ARE/ABO)	Arecibo	50 transient general aviation 50 local general aviation <1 military	10	1,208 × 18
Dr. Hermenegildo Ortiz Quinones Airport (HUC/X63)	Humacao	48 local general aviation 40 air taxi 10 military 2 transient general aviation	7	747 × 18
Patillas (X64)	Patillas	Closed	-	2,000 × 50

280 Airport IQ 5010, 2016, "Airport Master Records and Reports," http://www.gcr1.com/5010WEB/, accessed May 14, 2018; AirNav.com, undated, "Browse Airports Puerto Rico," http://www.airnav.com/airports/pr, accessed May 14, 2018.

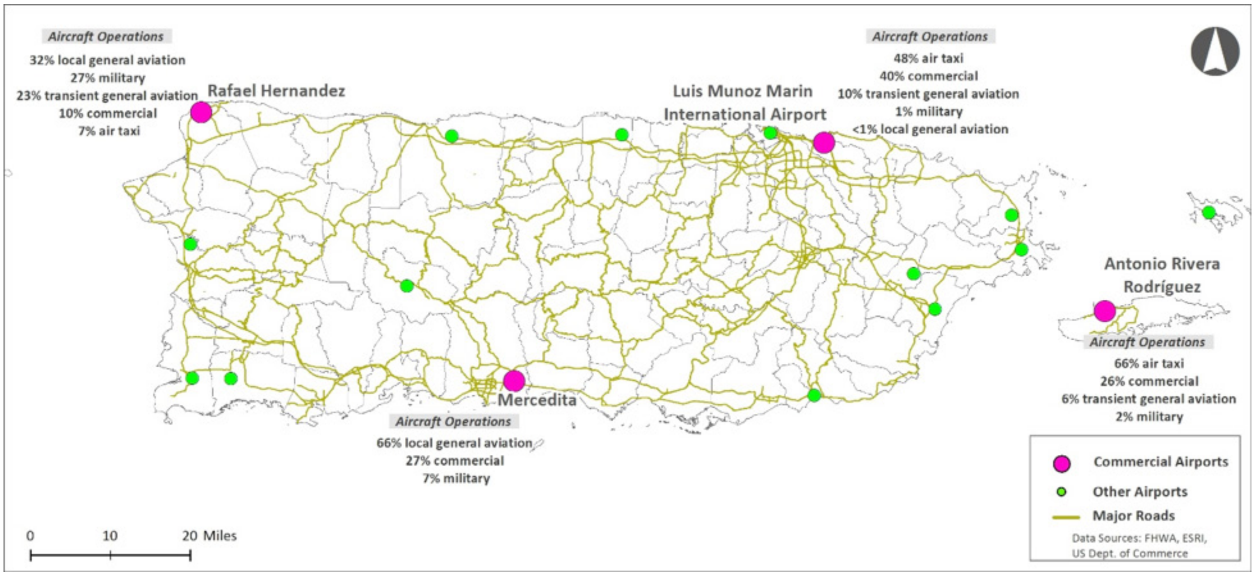

Figure 2-74: Airports in Puerto Rico[281]

Luis Muñoz Marín International Airport

Luis Muñoz Marín International Airport is located in Carolina on the northern coast of Puerto Rico and is the principal aviation gateway for the island, serving Puerto Rico's capital and largest city, San Juan. The airport has one main terminal building with four concourses and a separate terminal with one concourse.

The Luis Muñoz Marín International Airport serves as a regional hub for the Caribbean islands, providing connections to stateside destinations in the eastern half of the United States. The busiest U.S. destinations are New York City, Orlando, Miami, Atlanta, Fort Lauderdale, Philadelphia, Tampa, Charlotte, Newark, and Boston. Destinations and services to Europe (i.e., Germany, Luxembourg) and Latin America (i.e., Columbia, Panama, Venezuela) are limited.[282]

The main commercial airport in Puerto Rico, Luis Muñoz Marín International Airport reported around 9 million passengers in 2016.[283] Twenty-two different airlines provide service as of April 2018, some of it seasonal, and ten air charter operations provide seasonal and year-round service. In addition, the airport functions as a joint civil-military airport, housing facilities for the U.S. Air Force Air National Guard and the Puerto Rico Air National Guard.[284]

The Luis Muñoz Marín International Airport also boasts the greatest cargo activity in the Caribbean, annually moving approximately 445 million tons of cargo. Eight ground/cargo handlers currently service the airport.[285] Major imported commodities handled at the airport include chemicals, machinery and parts, live/cut plants, pharmaceuticals, medical

281 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan*, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 14, 2018.

282 CAPA Center for Aviation, 2018, "San Juan Luis Munoz Marin International Airport (Puerto Rico)," https://centreforaviation.com/data/profiles/airports/san-juan-luis-munoz-marin-international-airport-puerto-rico-sju, accessed May 14, 2018.

283 Instituto de Estadísticas de Puerto Rico, 2017, "Carga y pasajeros aéreos y marítimos," (in Spanish) http://www.estadisticas.gobierno.pr/iepr/Estadisticas/InventariodeEstad%C3%ADsticas/tabid/186/ctl/view_detail/mid/775/report_id/9485fbd8-efa5-4583-a8a4-a39c74eb846f/Default.aspx, accessed May 14, 2018.

284 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan*, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 14, 2018.

285 CAPA Center for Aviation, 2018, "San Juan Luis Munoz Marin International Airport (Puerto Rico)," https://centreforaviation.com/data/profiles/airports/san-juan-luis-munoz-marin-international-airport-puerto-rico-sju, accessed May 14, 2018.

devices and instruments, apparel, and consumer goods. Major exported commodities handled at the airport include chemicals, machinery and parts, pharmaceuticals, and medical devices and instruments.[286]

Rafael Hernández International Airport

Rafael Hernández International Airport, the former Ramey Air Force Base, is the second-busiest airport on the island, serving the northwest city of Aguadilla. This civil-military airport is the officially designated reliever airport for Luis Muñoz Marín International Airport in San Juan.

However, the airport it is not well positioned to serve passengers or freight destined for the San Juan region, and it offers very limited passenger services, primarily to the U.S. mainland. Few flights service Europe (Netherlands) and Latin America (Columbia, Venezuela) from Rafael Hernández International Airport. As a commercial passenger airport, Rafael Hernández reported approximately 520,000 passengers in 2016, less than 6 percent of the total at Luis Muñoz Marín International Airport.[287]

More significant as a cargo facility, the Rafael Hernández International Airport is located on a 1,100-acre site and has a 3,567-meter-long runway that is capable of handling the largest cargo aircraft in the world. The Commonwealth of Puerto Rico is trying to leverage this unique resource by marketing the airport as an international air cargo and logistics center for the Caribbean and possibly Latin America. In 2016, the airport logged nearly 77,800 tons of cargo. Two ground cargo handlers service Rafael Hernández International Airport. The cargo section of the airport is also divided in two sections, the Main Terminal and the FedEx Terminal.

The government of Puerto Rico is assessing factors that may influence further development of the tourism industry at the western end of the island. In this increased tourism scenario, Rafael Hernández International Airport would serve as a destination airport to provide tourists with air access closer to new western recreational and tourism developments. Regional land-use planning anticipates the development of residential and related retail and service activities to support commercial and industrial land use around the airport.[288]

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286 U.S. Department of Commerce, 2016[a], "U.S.A Trade Online," U.S. Census Bureau, https://usatrade.census.gov/, accessed May 14, 2018.

287 Instituto de Estadísticas de Puerto Rico, 2017, "Carga y pasajeros aéreos y marítimos," (in Spanish) http://www.estadisticas.gobierno.pr/iepr/Estadisticas/InventariodeEstad%C3%ADsticas/tabid/186/ctl/view_detail/mid/775/report_id/9485fbd8-efa5-4583-a8a4-a39c74eb846f/Default.aspx, accessed May 14, 2018.

288 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan*, www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 14, 2018.

Other Airports

In addition to Luis Muñoz Marín and Rafael Hernández, Puerto Rico has eight other functioning regional airports that can accommodate limited passenger service and carry small amounts of air cargo. Several of these airports also conduct specialized activities.[289] One airport, Patillas, has closed permanently. Operations at the remaining airports are summarized below.

- **Mercedita Airport** is a public use airport located east of Ponce's central business district. The airport has been enlarged on various occasions; most recently, its runway was extended to accommodate additional air traffic operations. In 2016, the airport reported about 230,000 passengers and 7,850 tons of cargo.
- **Antonio Rivera Rodríguez Airport** is a small public use commercial air facility located on the island of Vieques. Since the exit of the U.S. Navy from the island in 2003, the airport has become an even more important part of the economy of Vieques, which derives most of its revenue from tourism.[290] Airlines offering flights to Vieques fly from airports on the main island, such as Luis Muñoz Marin, Fernando Luis Ribas Dominicci, and Jose Aponte de la Torre. In 2016, Antonio Rivera Rodríguez reported approximately 132,000 passengers and nearly 400 tons of cargo.
- **Benjamín Rivera Noriega Airport** is located on the island of Culebra. Because of the short length of the runway, commercial airlines are limited to air taxi service using propeller aircraft with 10 seats or fewer.[291] This general aviation, public use airport had nearly 83,000 passengers and 100 tons of cargo in 2016. Currently, four commercial airlines serve this airport.
- **Fernando Luis Ribas Dominicci Airport** is located in San Juan, near the San Juan harbor. This airport provides general aviation activity and a low level of commercial aviation service, and houses a small military unit. The airport reported about 50,000 passengers and 607 tons of cargo in 2016.[292] Passenger service connects to the islands of Vieques, Culebra, St. Croix, and St. Thomas. The airport also has a charter airline and small military presence.[293]
- **Antonio (Nery) Juarbe Airport** is a small general aviation airport located just southeast of Arecibo's central business district and about 50 miles west of San Juan. Frequented by light sport aircraft and ultra-lights, this airport is a center of sport aviation on the island and is popular with skydivers.[294] In 2016, Antonio (Nery) Juarbe Airport reported approximately 10,000 passengers and 180 tons of cargo.
- **Eugenio María de Hostos Airport** is the principal airport in southwest Puerto Rico, located north of the Mayagüez central business district. It is one of the regional airports that has service to the Luis Muñoz Marín International Airport in San Juan, from which connecting flights depart for the United States and the Caribbean. The airport reported nearly 12,000 passengers and 320 tons of cargo in 2016.

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289 Ibid.

290 Vieques.com, 2018, "Antonio Rivera Rodríguez Airport, Isla de Vieques, Puerto Rico," https://vieques.com/airport-vieques/, accessed May 14, 2018.

291 Culebra Airport, 2018, "Benjamin Rivera Noriega Airport (CPX)," https://culebrapuertorico.com/culebra-airport-benjamin-rivera-noriega/, accessed May 14, 2018.

292 Instituto de Estadísticas de Puerto Rico, 2017, "Carga y pasajeros aéreos y marítimos," (in Spanish) http://www.estadisticas.gobierno.pr/iepr/Estadisticas/InventariodeEstad%C3%ADsticas/tabid/186/ctl/view_detail/mid/775/report_id/9485fbd8-efa5-4583-a8a4-a39c74eb846f/Default.aspx, accessed May 14, 2018.

293 Puerto Rico Highway and Transportation Authority, 2013, *Puerto Rico 2040 Long Range Transportation Plan,* www.dtop.gov.pr/fotos/pr-islandwide-lrtp-final-dec-2013.pdf, accessed May 14, 2018.

294 Ibid.

- **Humacao Airport, or Dr. Hermenegildo Ortiz Quinones Airport,** is a small, general aviation airport located in Humacao, near the southeast coast just off the PR-53 toll road. The airport caters to recreational and tourism aviation activity.[295] In 2016, the Humacao Airport reported approximately 1,150 passengers, but no cargo.
- **Jose Aponte de la Torre Airport** is a public use airport located near Ceiba. The airport opened in November 2008 on the site of the former Roosevelt Roads Naval Station, replacing the Diego Jiménez Torres Airport in Fajardo.[296] The airport also offers scheduled passenger service to the islands of Vieques and Culebra. In 2016, the airport reported approximately 100,000 passengers, but no cargo. This facility is also being used as a testing site for Google Loon, a project to deliver high-speed internet using hot air balloons.[297]

2.8.3.2 Commercial Activities in Puerto Rico

Puerto Rico's airport systems handle major imported commodities including chemicals, machinery and parts, pharmaceuticals, stone/glass, textiles, foodstuffs, and consumer goods. Major exported commodities include chemicals, machinery and parts, pharmaceuticals, foodstuffs, and consumer goods.[298]

Table 2-42 summarizes the foreign commodity shipments into and out of the airports of Puerto Rico. In 2016, the airport system imported approximately 7,400 tons of foreign commodities valued at nearly $8.5 billion. Exports totaled around 13,000 tons valued at more than $10.9 billion.[299] Table 2-43 lists cargo data for some of the smaller airports. Figures 2-75 and 2-76 provide an overview of the primary commodity imports and exports (by dollar value and shipping weight) for Puerto Rico's airport system.[300] Airports in Puerto Rico also handle a large number of air travelers. Table 2-44 lists commercial passenger data the last 4 years for the various airports of Puerto Rico.

Table 2-42: Airport Throughput for Foreign Trade (2016)[301]

	Total Imports		Total Exports	
Asset Name	Million $US	Tons	Million $US	Tons
Luis Muñoz Marín (SJU)	6,242	4,232	8,561	8,691
Rafael Hernández (BQN)	2,172	3,184	2,348	4,315

295 Ibid.

296 PRDayTrips, 2018, "Catch a Flight at the Ceiba International Airport," updated January 14, http://www.puertoricodaytrips.com/ceiba-airport/, accessed May 14, 2018.

297 Endi El Nuevo Día, 2016, "Google Uses Puerto Rico as Launch Pad: The Tech Giant Already Employs 30 People in Ceiba for Project Loon," March 23, https://www.elnuevodia.com/english/english/nota/googleusespuertoricoaslaunchpad-2177502/, accessed May 14, 2018.

298 U.S. Department of Commerce, 2016[a], "U.S.A Trade Online," U.S. Census Bureau, https://usatrade.census.gov/, accessed May 14, 2018.

299 Ibid.

300 Data represent commodities that pass through U.S. Customs to/from foreign markets; data do not account for imports from or exports to the United States.

301 U.S. Department of Commerce, 2016[a], "U.S.A Trade Online," U.S. Census Bureau, https://usatrade.census.gov/, accessed May 14, 2018.

Table 2-43: Cargo Tonnage Data for Foreign Commodity Shipments (2013–2016)[302]

Asset Name	2013	2014	2015	2016
Mercedita (PSE)	6,222	6,691	7,005	7,848
Antonio Rivera Rodríguez (VQS)	380	390	395	392
Jose Aponte de la Torre (NRR)	-	-	-	-
Benjamín Rivera Noriega (CPX)	97	94	116	100
Fernando L. Ribas Dominicci (SIG)	465	426	496	607
Eugenio María de Hostos (MAZ)	1	154	429	321
Antonio (Nery) Juarbe Pol (ARE/ABO)	124	256	154	179
Dr Hermenegildo Ortiz Quinones Airport (HUM/X63)	-	-	-	-

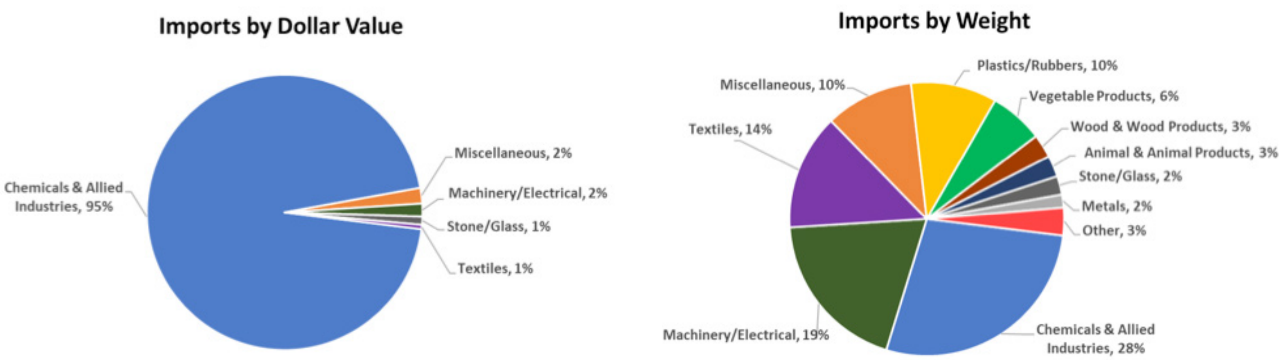

Figure 2-75: Summary Commodity Imports for Puerto Rico Airports (2016)

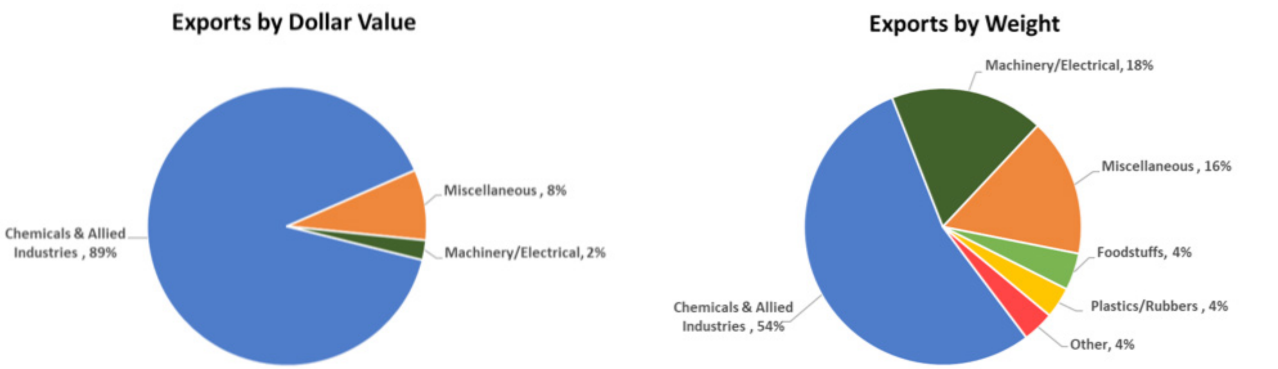

Figure 2-76: Summary of Commodity Exports for Puerto Rico Airports (2016)

302 Ibid.

Table 2-44: Passenger Data for Airports in Puerto Rico (2013–2016)[303]

Asset Name	2013	2014	2015	2016
Luis Muñoz Marín (SJU)	8,347,119	8,569,622	8,733,161	9,037,134
Rafael Hernández (BQN)	407,664	428,413	412,565	519,553
Mercedita (PSE)	200,916	201,645	207,655	231,598
Antonio Rivera Rodríguez (VQS)	144,926	150,843	156,207	131,980
Jose Aponte de la Torre (NRR)	82,981	81,815	90,593	97,037
Benjamín Rivera Noriega (CPX)	60,859	73,843	79,462	82,612
Fernando L. Ribas Dominicci (SIG)	51,865	51,981	51,131	50,231
Eugenio María de Hostos (MAZ)	12,909	14,499	13,290	11,835
Antonio (Nery) Juarbe Pol (ARE/ABO)	9,744	8,496	4,305	10,139
Dr Hermenegildo Ortiz Quinones Airport (HUM/X63)	1,691	1,389	4,040	1,154

2.8.4 System Interdependencies

2.8.4.1 Overview

Puerto Rico's dependence on the Aviation Subsector can have cascading impacts on other critical infrastructure sectors, including the Agriculture and Food, Critical Manufacturing, and Commercial Facilities (i.e., tourism) Sectors. Therefore, the resilience of the island's airports—in particular the two largest, Luis Muñoz Marín and Rafael Hernández International Airports—is important to the resilience of Puerto Rico as a whole. Identifying system dependencies of the airport system and improvement to the resilience of those supporting infrastructure systems should help to ensure the continued delivery of commodities and passengers to the island.

Operations at airports depend on services and resources from supporting regional lifeline infrastructure. Dependencies and interdependencies of aviation facilities and systems include electric power, fuels, communications, financial services, IT, water, and wastewater. Figure 2-77 provides a high-level overview of the sector-level physical dependencies and interdependencies of the Aviation Subsector. The light grey shading indicates critical infrastructure sectors that depend on Aviation Subsector resources; the dark grey shading indicates critical infrastructure sectors that are interdependent with the Aviation Subsector.

303 Instituto de Estadísticas de Puerto Rico, 2017, "Carga y pasajeros aéreos y marítimos," (in Spanish) http://www.estadisticas.gobierno.pr/iepr/Estadisticas/InventariodeEstad%C3%ADsticas/tabid/186/ctl/view_detail/mid/775/report_id/9485fbd8-efa5-4583-a8a4-a39c74eb846f/Default.aspx, accessed May 14, 2018.

Figure 2-77: Aviation Subsector Interdependencies

Table 2-45 identifies sector-level upstream dependencies for aviation infrastructure in Puerto Rico; the Aviation Subsector has downstream dependencies with all critical infrastructure sectors.

Table 2-45: Aviation Subsector Upstream Dependencies

Sector	Asset	Service/Resources Provided
Communications	Wired, wireless, satellite, and Internet	Telecommunication for daily operations; ICS and SCADA systems
Energy	Terminals, fuel storage tanks, substations	Fuels, electric power for running equipment
Financial Services	Payment systems, financial markets	Daily business operations of air terminals
IT	Security hardware, routing and switching equipment, data storage, software, electronic devices	Business management and coordination, Internet services, identity management
Water and Wastewater	Pumping stations, storage, treatment facilities, transmission and distribution mains, collection/ removal infrastructure	Temperature control (e.g., cooling of equipment), fire suppression, potable water, wastewater removal service

2.8.4.2 Concerns, Needs, and Challenges

The primary concern voiced by stakeholders consulted was the need to bolster the capabilities at smaller airport facilities to enable major air carriers to service the eastern and north-central coast. The smaller airport facilities described in Section 2.5.3.1 are capable of receiving air cargo shipments from FedEx, DHL, UPS, and other major carriers. However, stakeholders commented on a missed opportunity to expand service to these smaller airports and reduce the cargo requirements on the larger airports, which also serve passengers, and therefore decrease the travel time for truck-borne movements to and from air cargo facilities.

Considerations for Interdependent Lifeline Infrastructure in Puerto Rico

The primary consideration for interdependent lifeline infrastructure is the movement of specialty parts for maintenance in the Electricity, Water, Wastewater, and Communications Sectors and Subsectors. Air cargo capabilities enable the swift shipment of replacement parts for infrastructure assets in these sectors and subsectors. The number of airports that are able to receive these shipments by major carriers has not proven to be a significant barrier, but PREPA officials cited the number of flights operated by major carriers that are capable of delivering these parts as a potential issue.

Considerations for Dependent Industries and Community Functions in Puerto Rico

Air transportation is a significant dependency for several manufacturing facilities that DHS-IP consulted as part of this assessment. Several operations require small-quantity shipments of active pharmaceutical ingredients, which are predominately shipped to pharmaceutical manufacturing companies by air. Cold-chain management requirements also necessitate that some of these active pharmaceutical ingredients be moved as quickly as possible from U.S. and international points of production to manufacturing sites in Puerto Rico, making maritime shipments impractical. For operations that involve raw materials and finished products requiring delicate packaging (e.g., glass vials), private sector industry stakeholders favor air shipments to minimize the potential for damage during shipment.

2.9 ROAD TRANSPORTATION SYSTEM CHARACTERIZATION

2.9.1 Scope

The characterization summarizes how the infrastructure system that constitutes the Road Transportation Subsector operates, with a focus on aspects of the system that impact resilience. This section provides a baseline understanding of how the Road Transportation Subsector functions in general, how it functions in Puerto Rico, the interdependencies between the Road Transportation Subsector and other critical infrastructure systems, and the potential consequences that could result from cascading failures.

2.9.2 Sector Background: General

The Transportation Systems Sector consists of seven key subsectors, or modes, as shown in figure 2-78.

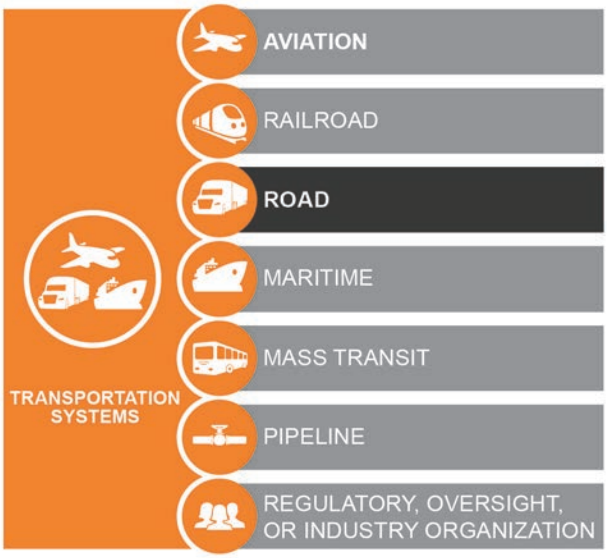

Figure 2-78: DHS Infrastructure Taxonomy–Transportation Systems Sector[304]

The Road Transportation Subsector in the United States includes roadways, road bridges, road tunnels, highway rest or service areas, and facilities that support road transportation. The highway transportation system consists of more than 4 million miles of public roads, of which more than 47,000 are interstate highways.[305] The highway system includes more than 605,100 bridges. More than 189 million light-duty automobiles, 118.5 million trucks, and approximately 700,000 buses are registered in the United States.

Across the United States, Americans traveled more than 2 trillion miles per year in light-duty vehicles (e.g., passenger cars, sport utility vehicles) between 2007 and 2015—an average of more than 39.6 billion miles per week. Trucks added to the load carried by U.S. roads, logging more than 100 billion miles per year during the same period, or more than 2 billion miles per week on average. In addition, mass transit systems and long-haul bus services also use the Nation's highway system, accounting for an additional 4 billion miles per year.[306] Figure 2-79 illustrates the flow of cargo through the road transportation system, including linkages with other transportation subsectors.

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304 DHS, 2011, *Infrastructure Data Taxonomy, Version 4*, National Protection and Programs Directorate, Office of Infrastructure Protection, Infrastructure Information Collection Division, June.

305 U.S. Department of Transportation, 2017, *National Transportation Statistics.* Bureau of Transportation Statistics. https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/national-transportation-statistics/217651/ntsentire2017q4.pdf, accessed May 15, 2018.

306 Ibid.

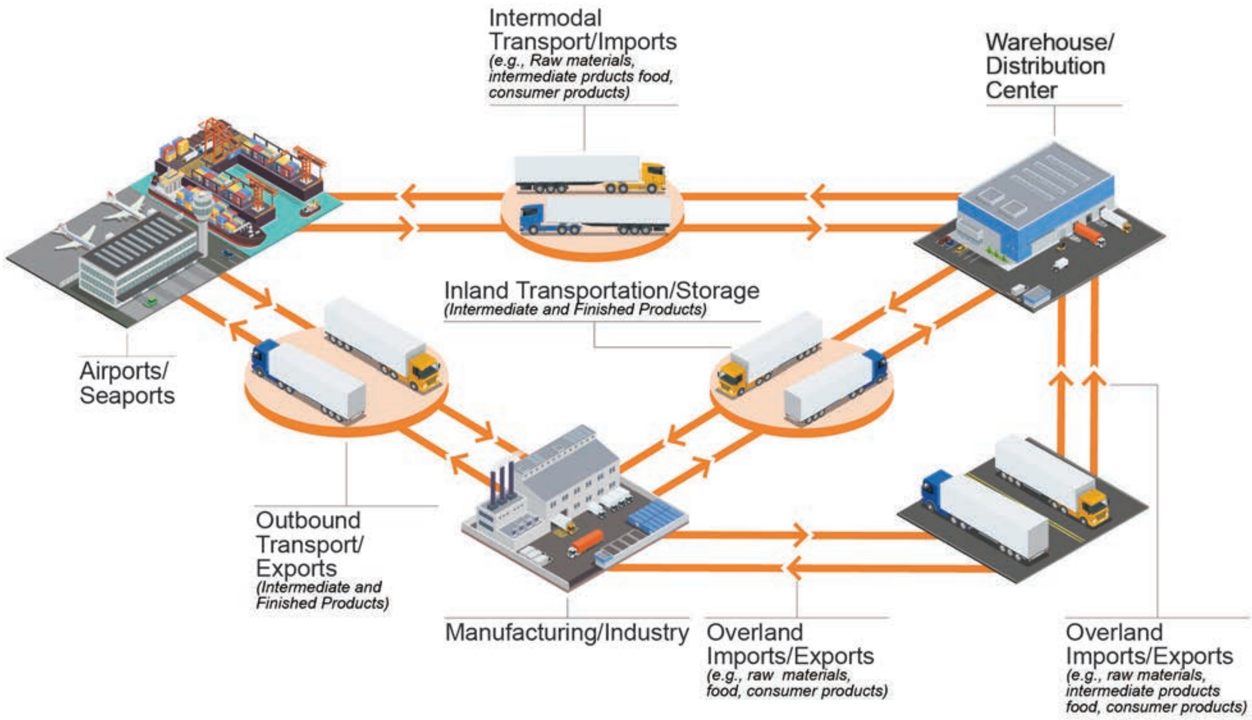

Figure 2-79: Diagram of the Road Transportation System Flow for Cargo

2.9.3 Sector Background: Puerto Rico

2.9.3.1 Physical Market in Puerto Rico

The highway system in Puerto Rico (illustrated in figure 2-80) consists of approximately 8,900 miles of roads. Roads in Puerto Rico are classified as primary highways, primary urban roads, secondary inter-municipal roads, or tertiary local roads. The classification of the highways and roads is a function of both the level of service and the volume of vehicular traffic:[307]

- Primary highways: Facilitate the movement of passengers and cargo between the principal regions of the island.
- Primary urban roads: Provide mobility for passengers and cargo within defined metropolitan areas, including San Juan, Ponce, Mayagüez, Arecibo, Aguadilla, Humacao, and Caguas.
- Secondary inter-municipal roads: Provide access to municipalities from the primary highways.
- Tertiary local roads: Provide access to the central business districts and communities of the municipalities.

Figure 2-80: National Highway System in Puerto Rico[308]

[307] PR DTWP (Puerto Rico Department of Transportation and Public Works), 2004, *Guías Para La Selección e Instalación de Rótulos de Orientación (Suplemento al MUTCD 2003)*, Estado Libre Asociado de Puerto Rico. http://www.dtop.gov.pr/act/nuevarotulación/GuíasFinalesdiciembre2004A.pdf, accessed May 15, 2018.

[308] Departamento de Transportación Y Obras Publicas, 2011, "Guía de Carreteras Principales, Expresos y Autopistas," (in Spanish), http://www.dtop.gov.pr/carretera/det_content.asp?cn_id=126, accessed May 15, 2018; ESRI, 2018; and ArcGIS.

2.9.3.2 Primary Highway System in Puerto Rico

Puerto Rico's primary highway system includes three major highways that are part of the Eisenhower Interstate System.[309] The Interstate highway system in Puerto Rico consists of approximately 250 miles of roadway, most of which (88 percent) is in areas classified as urban or suburban. The Interstate highways either follow the perimeter of the island or bisect the island, connecting the north and south coasts. Table 2-46 provides descriptions of the various highways comprising the interstate system in Puerto Rico.

Table 2-46: Puerto Rico Highway System[310]

Highway Route	Total Miles	Description
PRI-1	71.08	Bisects the island running between San Juan in the north and Ponce in the south
PRI-2	138.13	Follows the perimeter of the island beginning in San Juan and stretching to the west around to the southern coast near Ponce
PRI-3	40.56	Follows the perimeter of the island beginning in San Juan and stretching east around to the southeast corner of the island near Yabucoa
Total	249.77	–

In addition to the Interstate system routes, more than 20 other major highways serve individual or multiple municipalities around the island. These major highways range in length from 1-mile routes that connect other major highways to nearly 70-mile-long highways that serve multiple municipalities. In all, more than 350 miles of major highways exist in Puerto Rico, as described in table 2-47.

Table 2-47: Expressways and Highways of Puerto Rico[311]

Route	Origin	Destination	Municipios Traveled	Length (miles)
PR-1 Exp. Luis Muñoz Rivera	PR-26 San Juan	Pte. Martín Peña	San Juan	2.8
PR-2 Exp. John F. Kennedy	PR-1 Santurce	PR-22 San Juan	San Juan	1.9
PR-2	PR-22 Hatillo	PR-107 Entrance to the Rafael Hernández Airport in Aguadilla	Hatillo, Camuy, Quebradillas, Isabela, Aguadilla	26.5
PR-2 Exp. Rafael Hernández El Jibarito	PR-107 Entrance to the Rafael Hernández Airport in Aguadilla	North Limit of Anasco	Aguadilla, Aguada, Rincón, Añasco	9.2
PR-2 Exp. Miguel A. García Méndez	North Limit of Anasco	Municipal Limit South of Añasco (Rio Grande de Añasco)	Añasco	3.8
PR-2 Exp. Eugenio María De Hostos	Municipal Limit South of Añasco (Rio Grande de Añasco)	PR-330 San Germán	Añasco, Mayagüez, Hormigueros, San Germán	13.9
PR-2 Exp. Roberto Sánchez Vilella	PR-330 San Germán	PR-52 Ponce	San Germán, Sabana Grande, Yauco, Guayanilla, Ponce	34.5
PR-3	PR-26 San Juan	PR-53 Fajardo	San Juan, Carolina, Canóvanas, Río Grande, Luquillo, Fajardo	24.1
PR-5 Exp. Río Hondo	PR-22 Bayamón	PR-199 Bayamón Ave. Las Cumbres	Bayamón	4.0

309 U.S. Department of Transportation Federal Highway Administration, 2018, "FHWA Route Log and Finder List," https://www.fhwa.dot.gov/planning/national_highway_system/interstate_highway_system/routefinder/index.cfm, accessed May 15, 2018.

310 Ibid.

311 Ibid.

Table 2-47: (cont.)

Route	Origin	Destination	Municipios Traveled	Length (miles)
PR-10	PR-5506 Entrance to Mercedita Airport in Ponce	PR-9 Ponce	Ponce	5.1
PR-12 Ave. Santiago De Los Caballeros	Ave. Caribe, Ponce	PR-14 Ponce Ave. Tito Castro	Ponce	3.3
PR-17 Exp. Jesús T. Piñero	PR-18 San Juan	PR-26 Carolina	San Juan, Carolina	4.6
PR-18 Exp. The Americas	PR-52 int. PR-1 San Juan	PR-22 San Juan	San Juan	3.8
PR-20 Exp. Martínez Nadal	PR-2 Caparra	PR-1 La Muda in Guaynabo	San Juan, Guaynabo	6.0
PR-21 Ave. Ing. José Kiko Custodio	PR-1 San Juan	PR-18 San Juan	San Juan	0.7
PR-22 José De Diego Highway	PR-26 San Juan	PR-2 Hatillo	San Juan, Cataño, Bayamón, Toa Baja, Dorado, Vega Alta, Vega Baja, Manatí, Barceloneta, Arecibo, Hatillo	52.0
PR-26 Exp. Román Baldorioty de Castro	PR-25 Pte. San Antonio, San Juan	PR-3 Carolina	San Juan, Carolina	9.6
PR-30 Exp. Cruz Ortíz Stella	PR-1 Caguas	PR-53 Humacao	Caguas, Gurabo, Juncos, Las Piedras, Humacao	19.1
PR-52 Autopista Luis A. Ferré	PR-18 int. PR-1 San Juan	PR-2 Ponce	San Juan, Trujillo Alto, Caguas, Cayey, Salinas, Santa Isabel, Juana Díaz, Ponce	67.3
PR-53 José Celso Barbosa Highway	PR-3 Fajardo	PR-9914 Yabucoa	Fajardo, Ceiba, Naguabo, Humacao, Yabucoa	36.8
PR-53 Freeway José Dávila Monsanto	PR-54 Guayama	PR-52 Salinas	Guayama, Salinas	8.9
PR-60	PR-30 Humacao	PR-3 Humacao	Humacao	2.2
PR-66 Exp. Roberto Sánchez Vilella	PR-26 / PR-3 Carolina	PR-3 int. PR-188 Canóvanas	Carolina, Canóvanas	8.8

2.9.3.3 Bridges

With its long coastline and rugged mountainous interior, the geographic characteristics of Puerto Rico limit transportation connections between areas of the island.[312] Bridges connect the road transportation networks within and between many of the different regions of the island. These bridges allow for major highways to navigate around the perimeter of the island and for several routes to traverse the island, connecting the north and south coasts. The U.S. Department of Transportation's National Bridge Inventory lists more than 2,300 bridges in Puerto Rico, many of which are concentrated in highly populous municipalities and in municipalities where primary road routes cross through areas with major relief features (e.g., mountains, rivers). The roads with the largest number of bridges (listed in table 2-48) are the major highways that connect regions of the island. Table 2-48 also presents the maximum average daily traffic (ADT) and maximum average daily truck traffic (ADTT) for each highway listed.

[312] Puerto Rico Highway and Transportation Authority, 2010, *San Juan Urbanized Area 2030 Long Range Transportation Plan*, November, http://www.dtop.gov.pr/pdf/Nov2010_Final_SanJuanUrbanized_Area2030LRTP_JointComments_FHWA-FTA-PRHTA-NOV-22-2010.pdf, accessed May 15, 2018.

Table 2-48: Bridges Serving Major Highways[313]

Highway	Number of Bridges	Maximum ADT	Maximum ADTT (#)	Max ADTT (%)
PR-52	163	130,352	6,517	7
PR-2	105	117,238	6,890	10
PR-22	96	259,700	23,440	10
PR-53	93	45,700	2,285	7
PR-3	61	126,200	6,310	7
PR-1	49	79,000	3,950	7
PR-30	37	111,226	7,210	7
PR-181	31	102,950	1,413	5
PR-66	29	117,600	4,704	6

The most used bridges (as measured by ADT) are located in the San Juan area, where 73 bridges are in the top 10 percent of bridges by traffic volume. Other municipalities with concentrations of busy bridges include Caguas, Bayamón, Carolina, Guaynabo, Ponce, and Gurabo.[314]

2.9.4 System Interdependencies

"Interdependencies" refers to the operational relationship between two infrastructures. They include upstream dependencies, which are the effects of the use of specific resources (i.e., goods or services) on one infrastructure's operations, and downstream dependencies, which are the effects of the resources supplied by one infrastructure on other infrastructures' operations.

2.9.4.1 Overview

Puerto Rico depends heavily on its road transportation system for delivery of goods and services to the citizens and businesses that reside in Puerto Rico. No alternative ground transportation systems (e.g., railroads, pipelines) exist for moving goods from points of production to ports and airports for export, or from points of import (e.g., airports and sea ports) to points of wholesale or retail distribution. The effects of a disruption to the road transportation network can have cascading impacts on other infrastructure sectors, including Agriculture and Food, Communications, Energy, Emergency Services, Critical Manufacturing, Commercial Facilities, and Government Facilities Sectors. Ensuring the reliability of the road transportation network is essential to building a resilient Puerto Rico that meets the needs of its individual citizens, as well as the business community. Of particular interest are the major arteries in the transportation network, specifically PRI-1, PRI-2, PRI-3, and PR-22. These roads provide efficient connectivity within and between the regions of the island and the major transportation hub in San Juan.

313 "Maximum ADTT (%)" is not calculated from reported observations of ADT and ADTT. All three values are independent maximums. The bridge with the highest ADTT is not necessarily the bridge with the highest ADT. Furthermore the bridge with the highest percent ADTT is not necessarily the bridge with the highest ADTT. Source: U.S. Department of Transportation Federal Highway Administration, 2017, "National Bridge Inventory," https://www.fhwa.dot.gov/bridge/nbi/2017/delimited/PR17.txt, accessed May 15, 2018.

314 Ibid.

Using ADT on bridges as a proxy for road usage overall, the busiest roads and highways in Puerto Rico are located in the San Juan area. Looking at the busiest 100 bridges, all but one are located in a municipality in the San Juan Transportation Management Area (SJTMA). The same 100 busiest bridges have an observed ADT of between 75,000 and 266,000 vehicles per day. The busiest route appears to be PR-22, served by 30 of the 100 busiest bridges stretching from Vega Baja on the north-central coast east through Vega Alta, Dorado, Toa Baja, Cataño, Bayamón, Guaynabo, and finally San Juan municipios.[315] The busiest highways, as measured using ADT on bridges, are listed in table 2-49.

Table 2-49: Busiest Highways as Measured by ADT on Bridges[316]

Highway Route	Municipalities with Busiest Sections
PR-1	San Juan
PR-2	Guaynabo, San Juan
PR-3	Carolina, Canóvanas, Río Grande
PR-18	San Juan
PR-20	Guaynabo, San Juan
PR-22	Bayamón, Cataño, Dorado, Guaynabo, San Juan, Toa Baja, Vega Alta
PR-26	Carolina, San Juan
PR-30	Gurabo, Caguas, Juncos
PR-52	Caguas, San Juan
PR-66	Carolina, Rio Grande

The road transportation network depends on many other sectors for daily operations. Likewise, many other infrastructure assets (e.g., electric power and communication) depend on the road network for critical maintenance and repair to geographically dispersed systems. Dependencies in the road system include communications, dams, energy, financial services, IT, transportation, and water and wastewater systems, as shown in figure 2-81. The light grey shading indicates critical infrastructure sectors that depend on road transportation; the dark blue shading indicates critical infrastructure sectors that are interdependent with the Highway and Motor Carrier Subsector. Table 2-50 identifies upstream dependencies for road system infrastructure in Puerto Rico; the Highway and Motor Carrier Subsector has downstream dependencies with all critical infrastructure sectors.

315 Ibid.

316 Ibid.

Figure 2-81: Road Transportation Subsector Interdependencies

Table 2-50: Road Subsector Upstream Dependencies

Sector	Asset	Service/Resources Provided
Communications	Switching facilities, telephone/data lines	Control systems (traffic monitoring and management, toll collection systems, etc.)
Dams	Dams, levees	Roads may pass over dams, dams may control water levels of features passing under bridges
Emergency Services	Police, fire, emergency medical service	Rapid response to accidents that include physical injuries and property damage
Energy	Terminals, fuel storage tanks, substations	Electric power for traffic control signals, fuels for operating maintenance and repair equipment
Financial Services	Payment systems, financial markets	Collecting user fees, selling bonds to fund capital improvements
IT	Hardware, software	Data storage, facility security systems, control systems
Transportation Systems	Sea ports	Bringing in material for constructing new or making repairs or upgrades to existing roads

All sectors have downstream dependencies and therefore would be impacted by a loss of the road transportation system on the island. Puerto Rico's businesses and citizens rely on the road transportation system to move essential cargo to and from maritime ports, and distribute it across the island.

2.9.4.2 Concerns, Needs, and Challenges

Puerto Rico depends heavily on its highway system for transportation of goods and services. Prior to 1990, the SJTMA consisted of 13 municipalities, all along the north coast and portions of the interior to the south. The SJTMA now includes portions of 38 municipalities and stretches south and east to the municipalities of Humacao, Caguas, and Cayey.[317] With the high degree of individual dependence on an automobile to get to and from work, more than 81 percent of commuters do so alone, as shown in table 2-51. An estimated 922,000 residents drive or carpool to work on a daily basis.[318] Alternatives like public transportation are either not available or too unreliable.[319] Mean travel times to work are just under 30 minutes. Select commute characteristics for Puerto Rico's workers are reported in table 2-52.

Table 2-51: Select Commute Characteristics for Puerto Rico Workers[320]

Subject	Total	Drove Alone	Carpool	Public Transportation
Workers 16+ years	1,021,378	832,353	90,587	23,467

Table 2-52: Select Commute Characteristics for Puerto Rico Workers[321]

Travel Time to Work	Total (%)	Drove Alone (%)	Carpool (%)	Public Transportation (%)
>10 minutes	8.80	7.60	7.00	2.00
10 to 14 minutes	11.40	11.40	10.20	3.90
15 to 19 minutes	15.00	15.40	14.60	7.20
20 to 24 minutes	14.10	14.60	13.40	8.90
25 to 29 minutes	4.80	5.10	4.70	1.50
30 to 34 minutes	16.70	17.10	16.10	18.40
35 to 44 minutes	6.90	7.10	7.40	7.40
45 to 59 minutes	8.70	8.90	9.60	12.10
60 or more minutes	13.50	12.90	17.10	38.60
Mean travel time to work (minutes)	29.5	29.5	32.6	48.6

317 Puerto Rico Highway and Transportation Authority, 2010, *San Juan Urbanized Area 2030 Long Range Transportation Plan*, November, http://www.dtop.gov.pr/pdf/Nov2010_Final_SanJuanUrbanized_Area2030LRTP_JointComments_FHWA-FTA-PRHTA-NOV-22-2010.pdf, accessed May 15, 2018.

318 Levin, Jonathan, Margaret Newkirk, and Emma Ockerman, 2017, "Puerto Rico's love of cars is stalling its recovery," *Automotive News*, October 2, http://www.autonews.com/article/20171002/RETAIL/171009956/puerto-ricos-love-of-cars-is-stalling-its-recovery, accessed May 15, 2018.

319 Ibid.

320 U.S. Census Bureau, undated, "2012-2016 American Community Survey 5-Year Estimates," https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_16_5YR_S0802&prodType=table, accessed May 15, 2018.

321 Ibid.

The 2010 long-range transportation plan for San Juan reported that road infrastructure supporting the Port of San Juan and Luiz Munoz Marin International Airport was inadequate. Limits on vehicular access to these transportation hubs constrains the flow of goods during non-emergency situations, delaying shipments. Compounding the problems associated with automobile dependency is the physical condition of the roads and highways. Puerto Rico's road system is among the most deteriorated in the United States. According to a 2016 report by the oversight board within the Federal Highway Administration, the island's roads ranked 51st among the states and territories in the road roughness index, an indicator of road conditions.[322]

Considerations for Interdependent Lifeline Infrastructure in Puerto Rico

All sectors of the Puerto Rico economy rely on the highway system. It facilitates the movement of personnel from their homes to and from their workplace; the movement of raw materials and products from transportation hubs and distribution centers to points of consumption; and the movement of maintenance personnel and parts to locations to conduct work. With no alternatives for land transportation, productive industries require a robust network of roads connecting their operations both internally and to international supply chains.

Considerations for Dependent Industries and Community Functions in Puerto Rico

Highway and road connectivity to San Juan is of significant importance across industries. Most maritime cargo, including all containerized freight, arrives at the Port of San Juan. Unlike in the continental United States where ports are intermodal, incorporating rail and truck transportation capabilities, cargo in Puerto Rico is moved entirely by truck.[323] Importantly, the highway system also links food distributors to retail locations across Puerto Rico. Nearly all food imported into Puerto Rico arrives at the Port of San Juan, and the major food distributors are all located in the San Juan area in the municipalities of Bayamón and Cataño.

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322 Chico, Ricardo Cortés, 2016, "Puerto Rico's Roads Go from Bad to Worse," *El Nuevo Dia*, December 27, https://www.elnuevodia.com/english/english/nota/puertoricosroadsgofrombadtoworse-2275863/, accessed May 15, 2018.

323 Ibid.; Puerto Rico Highway and Transportation Authority, 2010, *San Juan Urbanized Area 2030 Long Range Transportation Plan,* November, http://www.dtop.gov.pr/pdf/Nov2010_Final_SanJuanUrbanized_Area2030LRTP_JointComments_FHWA-FTA-PRHTA-NOV-22-2010.pdf, accessed May 15, 2018.

Infrastructure Asset Characterization

3 INFRASTRUCTURE ASSET CHARACTERIZATION

3.1 ASSET-LEVEL ANALYSIS

3.1.1 Bottom-Up Approach

Lifeline infrastructure assets are interconnected and mutually dependent in multifaceted ways. Understanding the full extent of dependencies and interdependencies among infrastructure assets is essential to developing resilience strategies that mitigate the potential for cascading and escalating impacts to the communities and industries that depend on these assets.[324] Bottom-up analysis of infrastructure dependencies estimates the needs of both industry and infrastructure assets for specific resources. Data collection focuses on capturing the characteristics and performance of specific downstream users of infrastructure and the upstream infrastructure assets that provide critical services and resources (figure 3-1).

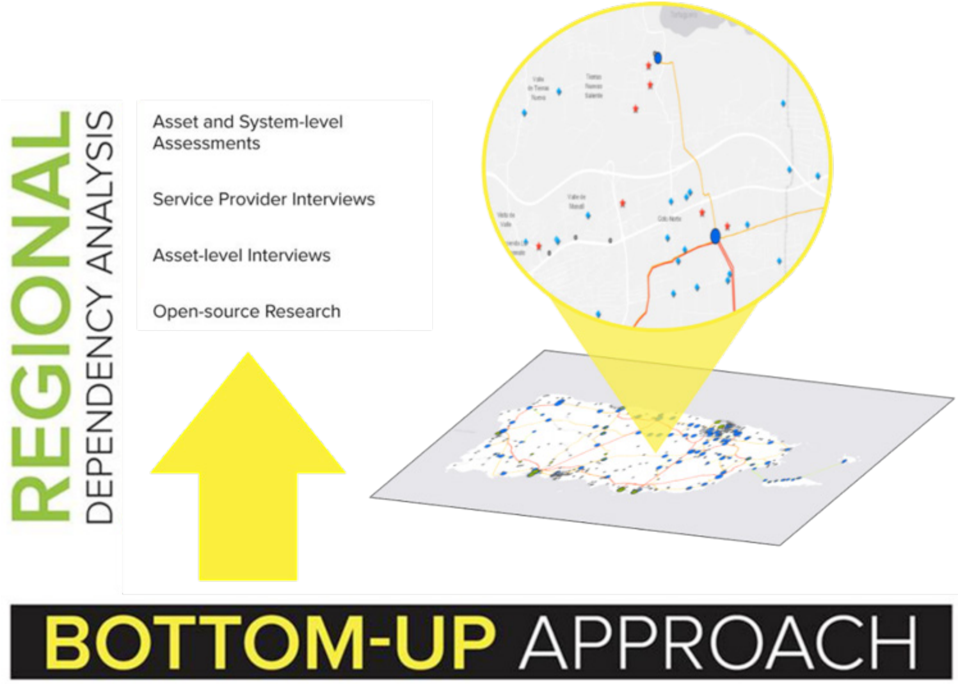

Figure 3-1: Focusing on Bottom-Up Interdependencies[325]

[324] Clifford, Megan, and Charles Macal, 2016, *Advancing Infrastructure Dependency and Interdependency Modeling: A Summary Report from the Technical Exchange,* Argonne National Laboratory.

[325] Adapted from Petit, Frederic, Duane Verner, and Leslie-Anne Levy, 2017, *Regional Resiliency Assessment Program Dependency Analysis Framework*, Argonne National Laboratory, Global Security Sciences Division, ANL/GSS-17/05, Argonne, Ill, USA.

3.1.1.1 Defining Key Terms

The focus of the bottom-up approach is on the potential downstream effects of a change in upstream operations. An infrastructure asset is considered to be "upstream" from entities to which it provides services or resources. The recipients of those services or resources are therefore "downstream," and may include both users of infrastructure such as manufacturing facilities as well as other infrastructure assets.

Connections between users of infrastructure and the infrastructure assets may also be direct or indirect. A first-order dependency describes a relationship in which an infrastructure asset provides a direct service or resource to a user. This provision could be through a specific connection, such as a distribution substation and line, by which the operation of the infrastructure asset will have an immediate impact on its user. Figure 3-2 illustrates a notional example of the first-order dependencies of a facility of interest (e.g., a pharmaceutical manufacturer) on lifeline infrastructure.

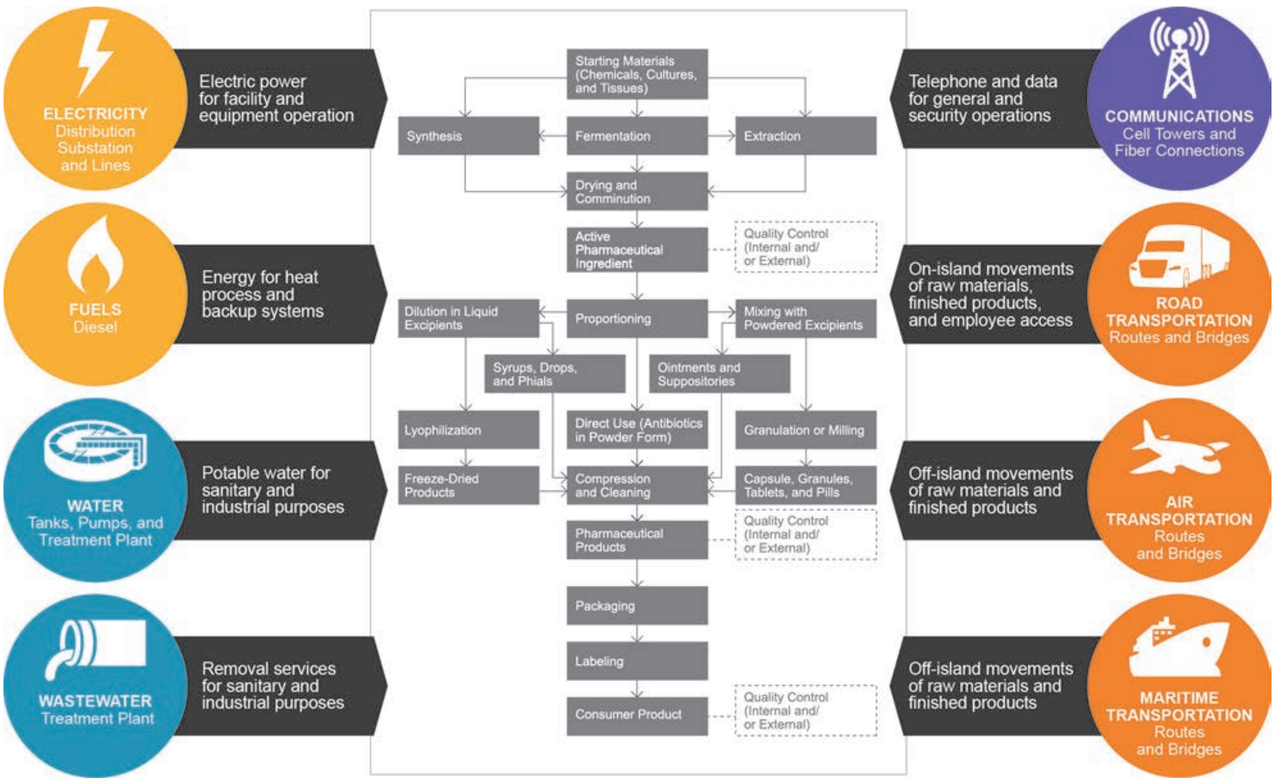

Figure 3-2: Illustration Example of First-Order Dependencies

A second-order dependency describes a relationship in which an infrastructure asset indirectly supports the operations of a downstream user. These include the upstream interactions between infrastructure assets, one or both of which provide direct services or resources to a user. The operation of the one infrastructure asset may therefore affect the operations of another, propagating an effect to all downstream users. Figure 3-3 illustrates a notional example of the second-order dependencies of a facility of interest (e.g., a pharmaceutical manufacturer) that result from the facility's first-order dependency on electric power.

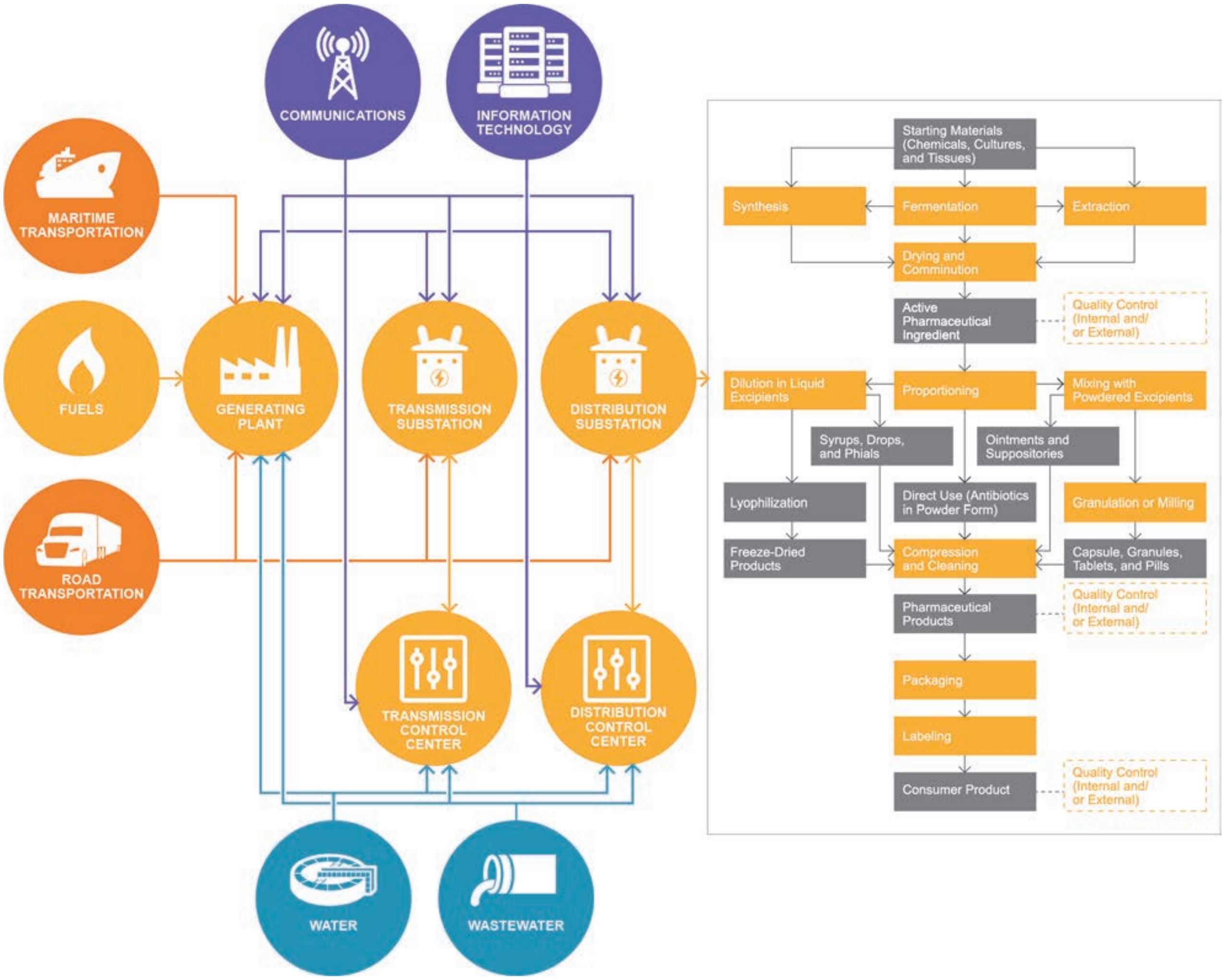

Figure 3-3: Illustration of Second-Order Dependencies

3.1.2 Applying a Bottom-Up Approach in Puerto Rico

To facilitate the analysis of the materials that follow, infrastructure analysts developed a web-based GIS environment to assess and visualize dependencies and interdependencies between lifeline infrastructure sectors and a selection of economically significant regions throughout the commonwealth of Puerto Rico. PRIIA consists of three primary components that analysts incorporated into an interactive Esri ArcGIS web application.

3.1.2.1 Geodatabases

Geodatabases of manufacturing facilities and infrastructure assets have been assembled to house data collected through structured interviews with the private sector, infrastructure operators, and commonwealth and federal partners. These databases include searchable characterizations of the operations and dependencies for both manufacturing facilities and infrastructure assets. Data points of interest include the following:

- Business offerings, including a general industry perspective, description of the final products, position on the supply chain, and market share of the facility in relation to its parent company and the global market;
- Production processes, including the raw materials required, equipment used for production, and timing of production lines;
- Impacts resulting from Hurricane Maria, including the disruptions to production, mitigation policies in place, and total economic impact; and
- Infrastructure dependencies, including the specific connections that each facility has with external providers, alternative sources utilized, and criticality of services and resources.

3.1.2.2 Relational Tables

Relational tables help establish the network of connections between facilities and infrastructure assets, as well as among the infrastructure assets themselves. These tables record the criticality of the connections to manufacturing facility and infrastructure asset operations, which are also included for each facility and asset in the geodatabase entries. Figure 3-4 provides a notional example of the relational tables.

User	Type	Description	Criticality	Comments
Manufacturing Plant 1	Electricity	Distribution Substation		Onsite generators can sustain operations as long as they have fuel
Manufacturing Plant 1	Electricity	Distribution Line		Connects A001 to F007
Manufacturing Plant 1	Water	Pump Station		Onsite deep water can sustain operations as long as they have electricity
Manufacturing Plant 1	Water	Water Pipe		Connects A005 to F007
Manufacturing Plant 1	Water	Deep Well		Connection to PRASA can sustain operations as long as A005/A029 are operating
Manufacturing Plant 1	Water	Water Pipe		Connects A006 to F007
Manufacturing Plant 1	Wastewater	Treatment Plant		Onsite wastewater treatment can sustain operations as long as they have electricity
Manufacturing Plant 1	Wastewater	Sewer Line	0/1	Critical to operations with no alternatives, even if treated onsite
Manufacturing Plant 1	Communications	PSTN		Service through cell and Internet can sustain operations
Manufacturing Plant 1	Communications	Wired		Connects A012 to F007
Manufacturing Plant 1	Communications	Cell Tower		Service through wired and Internet can sustain operations

Figure 3-4: Notional Example of a Related Table

3.1.2.3 Analysis and Visualization

Analytical tools leverage these components to perform the assessment and visualization of dependencies and interdependencies. These visualizations highlight the first-order and second-order dependencies and interdependencies of manufacturing facilities and infrastructure assets; the results of each run of the tool can be exported to multiple data formats. Figure 3-5 provides a notional example of the results of the analytical tool in identifying first- and second-order dependencies of a facility of interest.

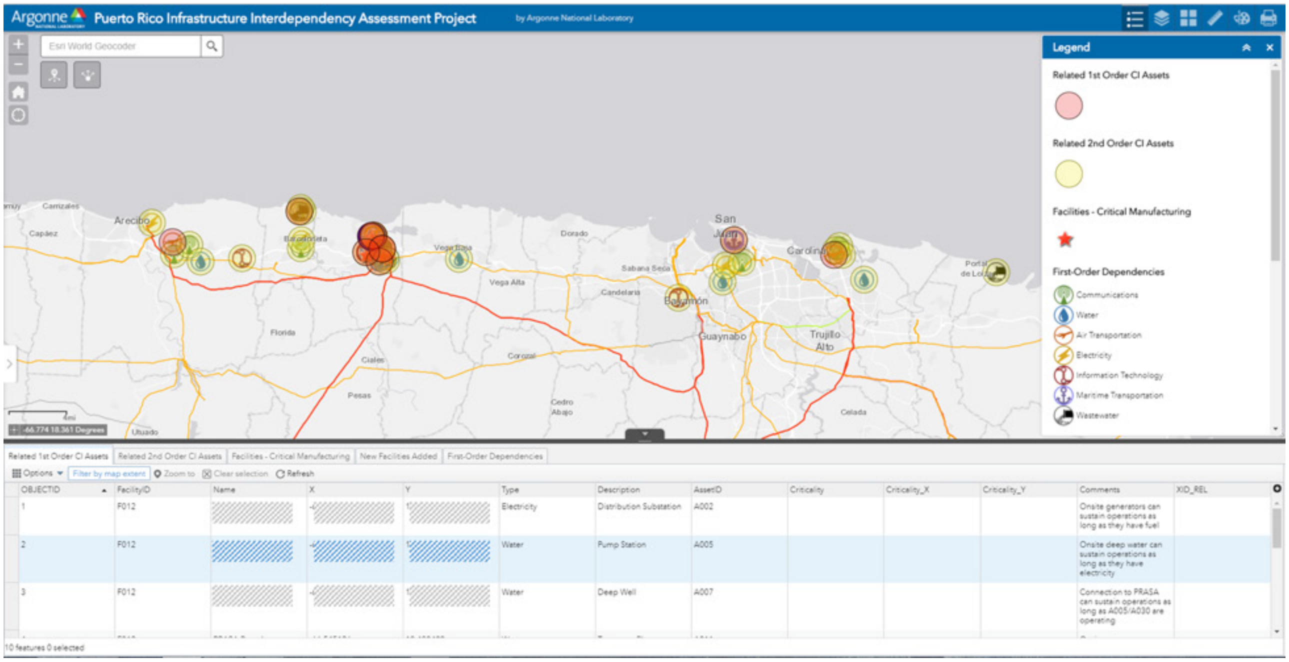

Figure 3-5: Notional Example of Analytical Tool Results

3.1.2.4 Case Study Overview

The remainder of Section 3 provides case studies of four subjects that were addressed through the bottom-up interdependency analysis in Puerto Rico:

- Assessing Infrastructure Resilience in Support of the Manatí Critical Manufacturing Cluster
- Impact of Hurricane Maria on Critical Healthcare Supply Chains
- Impact of Hurricane Maria on the Agricultural Biotechnology Industry in Puerto Rico
- Impact of Hurricane Maria on Food Supply and Distribution in Puerto Rico

Each of the case studies provides a description of significant economic and community challenges that resulted from Hurricane Maria's impacts, how infrastructure asset operations affected these challenges, and how communities and industries were affected.

The perspectives described in the case studies highlight several important themes related to infrastructure resilience:

- **Redundancy** – Facilities and service areas pursue multiple connections to lifeline infrastructure in order to offset the potential consequences of losing service through a single connection.
- **Alternatives** – A lack of diversity in available options results in critical dependencies on infrastructure assets that are potential single points of failure during emergencies.
- **Independence** – Inadequate reliability in infrastructure services and resources has led many entities to consider options that would provide local autonomy over infrastructure management.
- **Coordination** – Communities and industries have been unsuccessful in their attempts to collaborate with utilities on proposed changes that would better meet needs.
- **Confidence** – The reliability and costs associated with lifeline infrastructure operation have a direct effect on business confidence, which will be crucial to the economic recovery.

3.2 CASE STUDY: ASSESSING INFRASTRUCTURE RESILIENCE IN SUPPORT OF THE MANATÍ CRITICAL MANUFACTURING CLUSTER

3.2.1 Introduction

The Manatí critical manufacturing cluster is a model of the economic development that Puerto Rico has endeavored to foster and sustain over the past 40 years. Leveraging federal tax incentives designed to promote the commonwealth as an attractive business environment between the 1970s and early 2000s, Manatí has grown from a small agricultural basin into a significant center for the pharmaceutical, medical device, and agrochemical manufacturing industries.[326] Manatí is frequently cited as a successful example of the commonwealth's ability to draw large-scale industrial investments that offer significant returns to Puerto Rico's economy.[327]

However, chronic, island-wide deficiencies in planning for, maintaining, and investing in infrastructure improvements have eroded the confidence of industries that depend on these services and resources. Manufacturing facilities in Puerto Rico already face challenges to their market competitiveness because of the risks and corresponding costs associated with unreliable infrastructure services.[328] The impacts of Hurricane Maria severely exacerbated these pre-existing difficulties, increasing uncertainty over the long-term viability of Puerto Rico as a base for major manufacturing operations.

Examples from Manatí highlight the persisting need to better understand and manage the infrastructure dependencies of private industry to enhance critical infrastructure resilience, rally economic recovery, and support broader community development and resilience across Puerto Rico.

3.2.2 Community Profile

The Municipio of Manatí forms part of the western-most expanse of the San Juan-Carolina-Caguas Metropolitan Statistical Area.[329] The municipio is centrally located within a corridor of critical manufacturing activity that stretches across the northern coast of Puerto Rico. Although Manatí is relatively mid-sized in terms of its population, the density of large industrial operations places it in the top 15 municipios in terms of manufacturing sector economic output.[330] The presence of this critical manufacturing cluster in Manatí has also had abundant influence on its community profile.

3.2.2.1 Employment Data

With approximately 41,500 residents, Manatí ranks as the 24th-largest municipio in terms of population.[331] The population has decreased by an average of 2.2 percent every year since 2010; however, this downward trend follows a 12.5 percent increase in total households between 2000 and 2010, corresponding to new job opportunities in

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326 26 U.S.C. § 936 (1976); *see also* U.S. Government Accountability Office, 1993, *Tax Policy: Puerto Rico and the Section 936 Tax Credit*, Report to the Chairman, Committee on Finance, U.S. Senate, GGD-93-109, Washington, D.C., June, https://www.gao.gov/assets/220/218131.pdf, accessed May 16, 2018.

327 Vélez, Eva Lloréns, 2017, "Manufacturing in the Post-Growth Era: Road Paved with Much Uncertainty," *Caribbean Business*, July 6, http://www.piapr.org/clientuploads/Published%20News/2017.07.06-CB-Manufacturing%20in%20the%20Post-Growth%20Era.pdf, accessed May 16, 2018.

328 Ibid.

329 U.S. Census Bureau, 2018, "Cumulative Estimates of Resident Population Change and Rankings: April 1, 2010 to July 1, 2017 - United States — Metropolitan Statistical Area; and for Puerto Rico," https://factfinder.census.gov/, accessed May 16, 2018.

330 U.S. Census Bureau, undated, "American Community Survey," https://www.census.gov/programs-surveys/acs/, accessed May 16, 2018.

331 Ibid.

manufacturing and homebuilding during the same period.[332] Approximately 11,000 Manatí residents participate in the labor force. Table 3-1 provides a breakdown of industry employment statistics.

Table 3-1: Employment by Industry in Manatí (2016)[333]

Industries	Total Number Employed	Percentage of Labor Force
Manufacturing	1639	14.3
Healthcare and Social Assistance	1620	14.2
Retail Trade	1618	14.2
Accommodation and Food Service	1018	8.9
Educational Services	949	8.3
Public Administration	871	7.6
Other Services, except Public Administration	572	5.0
Construction	521	4.5
Administration, Support, Waste Management Services	478	4.2
Professional, Scientific, Technical Services	346	3.0
Finance and Insurance	284	2.5
Wholesale Trade	256	2.2
Transportation and Warehousing	216	1.9
Real Estate, Rental and Leasing	204	1.8
Arts, Entertainment, and Recreation	180	1.6
Agriculture, Forestry, Fishing, Hunting, and Mining	134	1.2
Information	59	0.5
Utilities	56	0.5

Manufacturing, healthcare, and retail have topped Manatí's industry employment statistics since the 1980s; approximately 43 percent of Manatí's labor force is employed in one of these three economic industry categories.[334] Manatí is in the top quarter of muncipios in terms of median average wages, with an average household income of $18,543. Average salaries in the manufacturing industry, however, range from $40,000 to $75,000. Although the manufacturing industry accounts for only 14.3 percent of direct employment in Manatí, it accounts for 38 percent of all wages.[335]

3.2.2.2 Commercial Activities

There are 672 registered businesses operating in Manatí.[336] A portion of these are retail storefronts located within Manatí's three shopping districts. Many local businesses also offer support services to the critical manufacturing cluster, including professional, scientific, and technical services that independent contractors provide; financial and insurance advising by accountants and consultants; and transportation and warehousing by logistics companies, which fulfill a crucial need for the critical manufacturing cluster.[337] Industry representatives noted that these

332 Ibid.

333 Ibid.

334 Ibid.

335 Ibid.

336 U.S. Census Bureau, undated, "Quick Facts: Manatí Municipio, Puerto Rico," https://www.census.gov/quickfacts/fact/table/manatmunicipiopuertorico/PST045216, accessed May 16, 2018.

337 Data USA, undated, "Manatí Municipio, PR," https://datausa.io/profile/geo/manat%C3%AD-municipio-pr/#economy, accessed May 16, 2018.

"satellite" companies have flourished because of the immediate requirements of critical manufacturing operations for subject matter expertise, surge capacity, and additional capabilities.[338] According to representatives from the Pharmaceutical Industry Association of Puerto Rico, which serves as a chamber of commerce for the biotechnology and pharmaceutical industries, its membership supports an additional one out of every ten jobs in Puerto Rico and nearly two out of every ten jobs in Manatí through indirect employment.[339]

3.2.2.3 Other Community Resources

Manatí is also the location of two large hospital complexes that serve communities throughout the central-northern coast of Puerto Rico. Manatí Medical Center is a 235-bed general practice and surgical hospital. The hospital supports several specialty areas of medicine, including cardiovascular procedures, which are not widely available elsewhere in Puerto Rico.[340] Doctors' Center Hospital is a 255-bed acute care facility. The hospital provides emergency medical care to Manatí and four of its neighboring municipios.[341] Industry stakeholders noted that the development of these healthcare systems coincided with the growth of pharmaceutical manufacturing in Manatí. Corporate partnerships, educational opportunities, and the proximity to biomedical research have induced benefits for the healthcare industry in Manatí.[342]

In effect, modern Manatí has grown around this critical manufacturing cluster. Its direct, indirect, and induced economic effects have influenced the development of community life. The survival of these facilities and the infrastructure that support it through the recovery from Hurricane Maria will ultimately determine Manatí's prospects for long-term community resilience.

3.2.3 Critical Manufacturing Cluster

The six facilities that make up the Manatí critical manufacturing cluster study group include primary source manufacturers of pharmaceutical, medical device, and agrochemical products for global distribution.[343] These sites are essential contributors to national and international healthcare industries, as well as worldwide industrial supply chains. Figure 3-6 illustrates a notional example of the types of pharmaceutical manufacturing processes in particular that occur in this cluster. For certain commodities produced in Manatí, few alternative production lines exist that could readily satisfy the total demand from the industries and markets in which these facilities operate. The facilities' economic footprint is massive; a total of $1.3 billion in annual economic activity can be attributed to the cluster.[344]

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338 Interviews and site visits by DHS-IP, November 16–20, 2017.

339 Interviews and site visits by DHS-IP, January 24, 2018.

340 Manatí Medical Center, 2018, Home page, http://www.Manatímedical.com, accessed May 16, 2018.

341 Doctors' Center Hospital, 2018, https://www.tuhospitalfamiliar.com, accessed May 16, 2018.

342 Interviews and site visits by DHS-IP, November 16–20, 2017.

343 "Primary source" in this context refers to a manufacturer that produces the majority of a commodity for an industry or market. This can be distinguished from a "sole producer," which refers to manufacturers that produce all of a commodity for an industry or market. Source: Interviews and site visits by DHS-IP, January 24, 2018.

344 U.S. Census Bureau, undated, "Quick Facts: Manatí Municipio, Puerto Rico," https://www.census.gov/quickfacts/fact/table/manatmunicipiopuertorico/PST045216, accessed May 16, 2018.

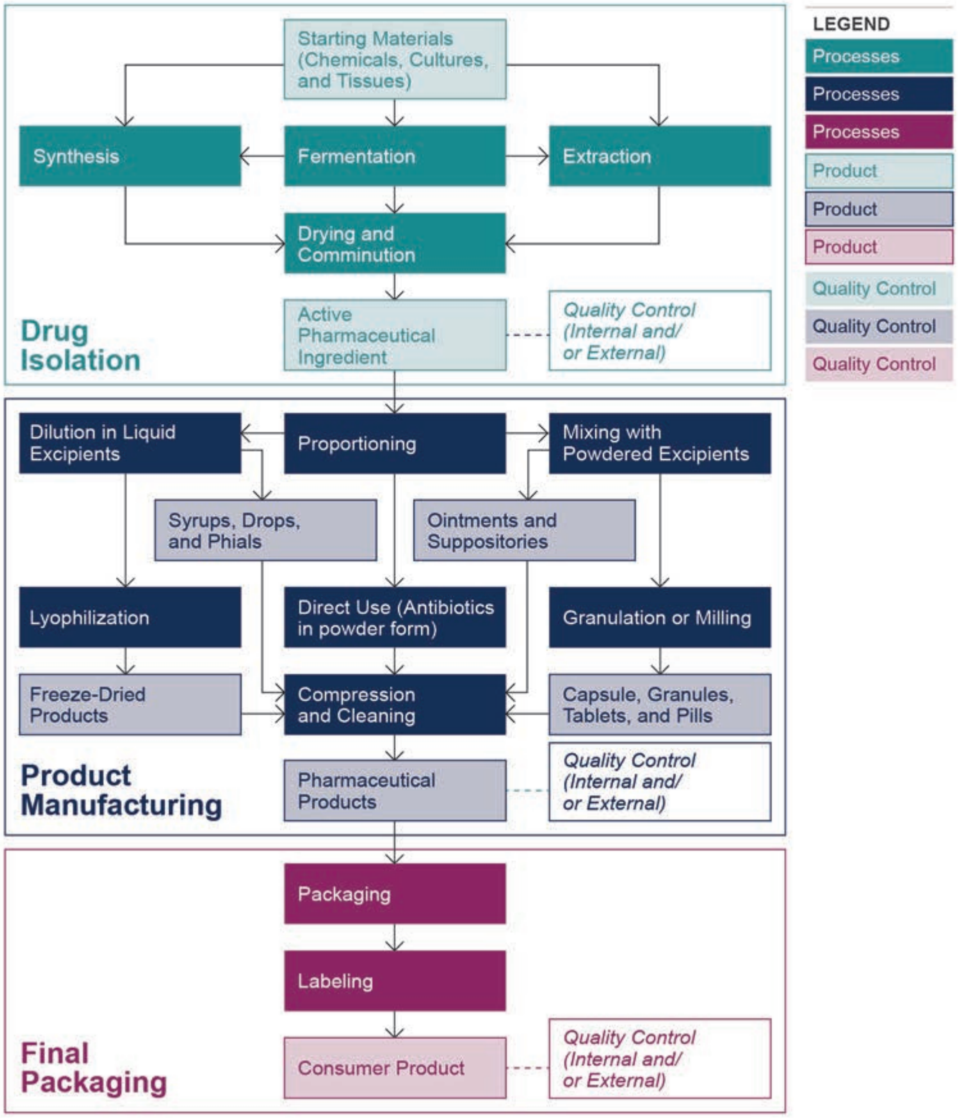

Figure 3-6: Notional Example of Pharmaceutical Manufacturing Processes[345]

[345] Adapted from Tait, Keith D., 1996, "Chapter 79: Pharmaceutical Industry," Figure 79.2, *The Encyclopedia of Occupational Health and Safety*, Fourth Edition, http://www.ilocis.org/documents/chpt79e.htm, accessed May 16, 2018.

3.2.3.1 BASF Agricultural Products de Puerto Rico

BASF Corporation is the second-largest global producer of industrial chemicals and related products.[346] The subsidiary BASF Agricultural Products de Puerto Rico facility in Manatí produces liquid and solid herbicides for consumer distribution in the national and international markets.[347] The facility employs approximately 200 people in a 24-hour operation. Because of minor damage and the simultaneous loss of electricity and communications services, the facility was forced to shut down for 30 days following Hurricane Maria.[348]

3.2.3.2 Bristol-Myers Squibb

The Bristol-Myers Squibb Company is one of the largest biopharmaceutical companies in the world, with both a prescription pharmaceutical production line and a broad research and development portfolio.[349] The Bristol-Myers Squibb facility in Manatí employs approximately 600 people in aseptic processing, isolation technology, terminal sterilization, oral solid dosing, inspection, and packaging.[350] The company manufactures several of its brand-name pharmaceutical products at the Manatí plant, including Opdivo®, a cancer treatment; Coumadin®, an anticoagulant; Empliciti®, a myeloma treatment; and Nulojix®, a kidney transplant medication.[351] Approximately 99 percent of the products manufactured at the Manatí facility are injectable; they are packaged onsite in bottles, vials, and syringes. The facility produces more than 12 million vial units every year. The remaining 1 percent of the facility's total manufacturing operation is in bulk tablet pressing; 150 million tablets are produced every year[352]

3.2.3.3 DowDuPont

DowDuPont Inc. is the largest chemical company in the world.[353] Its facility in Manatí produces thick-film paste material used in various electronic medical devices, automotive parts, and commercial electronic products.[354] The material is a critical component in each of these downstream manufacturing processes. The intermediates used in the final paste are produced at the facility and shipped to other DowDuPont facilities around the world, where they are mixed to produce the finished paste.. The facility employs approximately 260 full-time employees and contractors. An average of 80 product shipments are made from the facility through the Port of San Juan each day, with daily revenues of over $300,000.[355] The facility was shut down for 2 weeks following Hurricane Maria, after which one of its lines (which produces a product with few alternatives in the market) was reestablished.[356]

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346 BASF Corp., 2018, "Agriculture," https://agriculture.basf.com/us/en.html, accessed May 16, 2018.

347 Interviews and site visits by DHS-IP, November 16–20, 2017.

348 Ibid.

349 Bristol-Myers Squibb Co., 2018, "Our Research and Development Facilities," https://www.bms.com/about-us/our-company/worldwide-facilities/our-research-facilities.html, accessed May 16, 2018.

350 Bristol-Myers Squibb Co., 2018, "Manatí, Puerto Rico," https://www.bms.com/about-us/our-company/worldwide-facilities/manati-puerto-rico.html, accessed May 16, 2018.

351 Interviews and site visits by DHS-IP, November 16–20, 2017; Bristol-Myers Squibb Co., 2018 "Patients and Caregivers: Our Medicines," https://www.bms.com/patient-and-caregivers/our-medicines.html, accessed May 16, 2018.

352 Interviews and site visits by DHS-IP, November 16–20, 2017.

353 DowDuPont Inc., 2018, "Materials Science Division," http://www.dow-dupont.com/about-dow-dupont/materials-science/default.aspx, accessed May 16, 2018.

354 Interviews and site visits by DHS-IP, November 16–20, 2017.

355 Ibid.

356 Ibid.

3.2.3.4 FMC Technologies

FMC Technologies, a subsidiary of TechnipFMC PLC, produces active herbicide ingredients for both the global TechnipFMC and DowDuPont agrochemical manufacturing complexes.[357] The facility produces 20–30 tons of the herbicide ingredients per month in campaigns and is therefore able to plan production over a month in advance. This arrangement reduces the facility's vulnerability to acute disruptions in the supply chain. However, several ingredients require refrigeration, and the facility has climate-controlled warehousing onsite to accommodate this need. Before Hurricane Maria made landfall on Puerto Rico, the facility opted to lease refrigerated containers to store these ingredients; the facility does not have generators capable of sustaining operations during a loss of electric power.[358]

3.2.3.5 Janssen Ortho Pharmaceuticals

The Janssen Ortho Pharmaceuticals facility in Manatí is one of six manufacturing facilities operating under the Janssen Pharmaceutica subsidiary of Johnson & Johnson in Puerto Rico.[359] Production processes at this facility include ingredient proportioning, granulation, milling, compressing, coating, and packaging onsite. The facility produces 9 billion tablets of over-the-counter pain reliever medications annually.[360]

3.2.3.6 Teva Pharmaceutical Industries

Teva Pharmaceutical Industries Ltd. is the largest global pharmaceutical producer of controlled substances in the world.[361] The Teva facility in Manatí was the primary source producer of generic controlled substances, specifically hydrocodone and oxycodone tablets, for the United States and some European markets.[362] The facility employed more than 200 people; the Fajardo plant employed approximately the same before its reduction in operations. Facility operations included ingredient mixing, tablet pressing, coating, and packaging onsite. The facility produced approximately 1.7 billion tablets annually.[363] The operational costs resulting from Hurricane Maria was $83,000 per day. The facility managers consulted during the site visit remarked that they would likely lose market share of their distributors because of the lapse in production.[364] As of December 2017, Teva operated two plants in Puerto Rico. Since then, the Teva facility in Manatí closed, and operations at the Teva facility in Fajardo have been reduced. Although these decisions are connected to a broader corporate restructuring plan and not the impacts of Hurricane Maria, the consolidation is an example of the pace at which critical manufacturing industries move to reduce costs, avoid risks, and remain competitive.[365]

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357 Interviews and site visits by DHS-IP, November 16–20, 2017; TechnipFMC PLC, 2018, "What we do: Onshore," https://www.technipfmc.com/en/what-we-do/onshore, accessed May 16, 2018.

358 Interviews and site visits by DHS-IP, November 16–20, 2017.

359 Janssen Pharmaceutica, 2018, "Home Page," http://www.janssen.com/us/; Pharmaceutical Industry Association of Puerto Rico, 2018, "Manufacturing Operations," http://www.piapr.org/index.php?src=directory&view=Suppliers&category=Manufacturing%20Operations, both accessed May 16, 2018.

360 Interviews and site visits by DHS-IP, November 16–20, 2017.

361 Teva Pharmaceutical Industries Ltd., 2018, "Home Page," http://www.tevapharm.com/, accessed May 16, 2018.

362 Interviews and site visits by DHS-IP, November 16–20, 2017.

363 Ibid.

364 Ibid.

365 Rosario, Frances, and Joanisabel González, 2018, "Closing of Teva pharmaceutical leaves hundreds of people unemployed: the Manatí plant will stop operating, while Fajardo will continue to work with fewer staff," *El Nuevo Dia*, January 25 (in Spanish), https://www.elnuevodia.com/negocios/empresas/nota/cierredelafarmaceuticatevadejasinempleoacientosdepersonas-2392932/, accessed May 16, 2018.

3.2.3.7 Business Outlook

Throughout development of this case study, several industry stakeholders noted that growth in these critical manufacturing industries has plateaued in Manatí over the last decade.[366] A similar trend is apparent in these industries across the commonwealth.[367] As new markets across the developing world become increasingly attractive to industries searching for lower-cost production, industry leaders in Puerto Rico have had to expend greater time and money in order to preserve business confidence in the commonwealth.[368] Much of this energy has been devoted to addressing the operational instabilities that result from recurrent lapses in infrastructure service.

Figure 3-7 illustrates the areas and points of community and industrial activities described above.

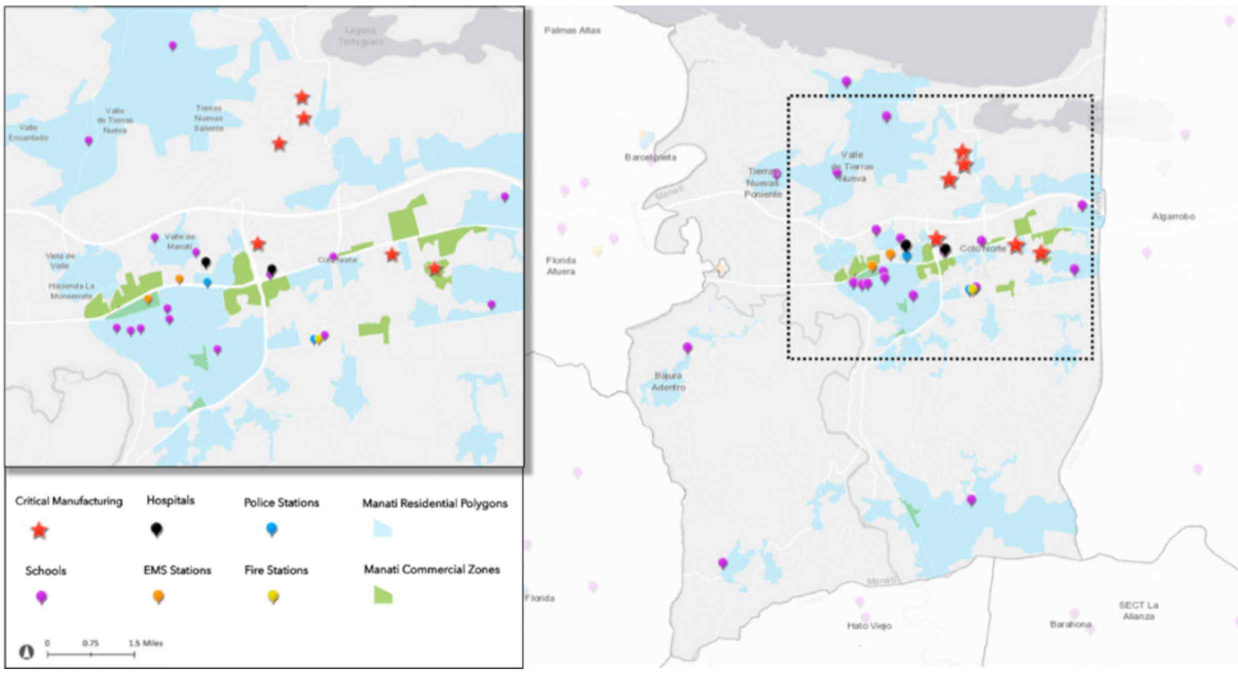

Figure 3-7: Centers of Community and Industrial Activity in Manatí[369]

Despite investments that major industrial players have made, infrastructure improvements have not kept up with the pace of business development in Manatí. Industry representatives reported that critical dependencies on lifeline infrastructure frequently fell short of demand.[370] The impact of Hurricane Maria on lifeline infrastructure sectors tested (and in some cases overwhelmed) the business continuity planning of industry representatives; their challenge was to mitigate disruptions to infrastructure that had long-standing reliability issues even under normal operating conditions.

366 Interviews and site visits by DHS-IP, November 16–20, 2017.

367 Vélez, Eva Lloréns, 2017, "Manufacturing in the Post-Growth Era: Road Paved with Much Uncertainty," *Caribbean Business,* July 6, http://www.piapr.org/clientuploads/Published%20News/2017.07.06-CB-Manufacturing%20in%20the%20Post-Growth%20Era.pdf, accessed May 16, 2018.

368 Interviews and site visits by DHS-IP, November 16–20, 2017.

369 U.S. Census Bureau, undated, "Quick Facts: Manatí Municipio, Puerto Rico," https://www.census.gov/quickfacts/fact/table/manatmunicipiopuertorico/PST045216, accessed May 16, 2018; ArcGIS, 2018, *Geographic Mapping and Information System Version 10.4.1*, developed by ESRI.

370 Interviews and site visits by DHS-IP, November 16–20, 2017.

3.2.4 Regional Lifeline Infrastructure

The critical manufacturing cluster accounts for the overwhelming majority of demands placed on lifeline infrastructure in Manatí, including electricity, communications, water, wastewater, and transportation. The infrastructure dependencies of these six facilities may vary given their differing industries and production cycles, but the common characteristics of 24-hour industrial operations, as well as the quantities of materials and products handled, necessitate large and reliable volumes of services and resources.

Similarly, dependencies and interdependencies among infrastructure assets themselves add to the reliability demands on certain critical assets. The current capacities and stability of Manatí regional lifeline infrastructure are frequently challenged by these cumulative regional infrastructure dependencies and interdependencies.[371] Several of these dependencies and interdependencies are discussed in the key findings in Section 3.2.6. The following is a brief summary of available data on the configurations and resilience characteristics of local lifeline infrastructure assets in Manatí that impacted the critical manufacturing cluster in the aftermath of Hurricane Maria.

3.2.4.1 Electricity

More than 9 million KWh of electricity are used in Manatí every year. This rate of municipal energy consumption places it among the top 16 municipios for electricity demand across the island.[372] The municipio is served by two transmission substations and four distribution substations that PREPA owns and operates, as well as one distribution substation that is owned and operated by the private sector, as listed in table 3-2.

Table 3-2: Electricity Infrastructure Assets in Manatí[373]

Infrastructure Asset Name	Owner/Operator	Max Voltage Rating (kV)
Transmission Substation Manatí 404	PREPA	230
Transmission Substation Manatí 468	PREPA	115
Distribution Substation Manatí 405	PREPA	115
Distribution Substation Private	Private Sector	115
Distribution Substation Manatí 401	PREPA	<100
Distribution Substation Manatí Urbano	PREPA	<100
Distribution Substation Manatí American	PREPA	<100

All of the critical manufacturing facilities share connections with one of two of the distribution substations listed above: the privately-owned substation or the PREPA-owned 405.[374] Additional characteristics of note in the local electricity distribution configuration include the following:[375]

- Both of the transmission substations within the municipio are co-located with distribution substations that then provide electric power to the facilities.
- These distribution substations are connected to the transmission substations by 115-kV lines. Each facility is, in turn, fed by one 38-kV line from one of the distribution substations. None of the facilities has connections to more than one distribution substation.

371 Ibid.

372 PREPA, 2015, "Municipal Energy Consumption (2004-2014)," July 21, http://energia.pr.gov/en/datos/municipal-energy-consumption-2004-2014/, accessed May 2015.

373 Ibid.; interviews and site visits by DHS-IP, November 16–20, 2017.

374 Interviews and site visits by DHS-IP, November 16–20, 2017.

375 Ibid.

- All but one of the facilities can operate without electric power from the grid. They have installed backup and prime power generators for critical processes and emergency management, resulting in large diesel fuel requirements; data on this dependency are unavailable.
- Industry stakeholders reported few workarounds when distribution lines are damaged. Few options exist for rerouting power after minor damages to the lines (e.g., a fallen tree branch).

3.2.4.2 Communications

AT&T, Claro, and Liberty provide communication services throughout Manatí. Claro's fiber network is buried throughout the municipio, whereas AT&T's was largely aerial and co-located with PREPA electricity distribution lines. Local fiber optic cable for AT&T and Claro have a geographic dependency due to the co-location at the fiber optic junction. When this junction was damaged and lost electric power service, communications infrastructure throughout Manatí was interrupted. The critical interdependency between electricity and communications, and its impacts following Hurricane Maria, are covered further in the key findings (Section 3.2.6). Table 3-3 provides a list of the communications infrastructure assets in Manatí.

Table 3-3: Communications Infrastructure Assets in Manatí[376]

Infrastructure Asset Name	Total Number	Owners/Operators
Transmission Cell Tower	1	AT&T
Local Antennae	12	Municipio
Junction	1	AT&T and Claro
Public Switch Telephone Network	1	Claro

3.2.4.3 Water and Wastewater

The largest WTP that PRASA operates, the Santiago Vazquez WTP in the nearby Municipio of Arecibo, serves Manatí. The plant has the capacity to treat 100 million gallons of water per day and feeds sanitary water to the Puerto Rico Superaqueduct, which provides treated water to municipios across the island's northern coast between Arecibo and San Juan.[377]

PRASA's Barceloneta WWTP is the sole service provider for wastewater services in the municipios of Manatí, Barceloneta, and Florida. The plant treats 1,769 million gallons of wastewater per year.[378] Hurricane Maria disrupted electric power service to the plant, which remained out of service into early 2018.[379] PRASA was able to facilitate a workaround from the plant and a temporary allowance from Federal partners to flush untreated wastewater through the system while they completed repairs. Although the Barceloneta plant is the sole provider of wastewater treatment services to the area, facilities in the Manatí critical manufacturing cluster were able to leverage internal capabilities to treat water onsite, as described in the key findings in Section 3.2.6.

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376 Government of Puerto Rico, undated, "Portal Datos Geograficos Gubernamentales, Catalog of Geodata," (in Spanish), http://www.agencias.pr.gov/agencias/gis/catalogogeodatos/Pages/default.aspx, accessed May 16, 2018; Interviews and site visits by DHS-IP, November 16–20, 2017.

377 Water Technology, 2018, "North Coast Transmission and," http://www.water-technology.net/projects/northcoast/, accessed May 16, 2018.

378 Government of Puerto Rico, undated, "Portal Datos Geograficos Gubernamentales, Catalog of Geodata," (in Spanish), http://www.agencias.pr.gov/agencias/gis/catalogogeodatos/Pages/default.aspx, accessed May 16, 2018.

379 Interviews and site visits by DHS-IP, January 24, 2018.

Table 3-4 lists the water and wastewater infrastructure assets that Manatí industrial facilities use in their processes.

Table 3-4: Water and Wastewater Infrastructure Assets Serving Manatí[380]

Infrastructure Asset Name	Total Number	Owners/Operators
Private Deep Well	12	Industry and municipio
Public Deep Well	24	PRASA and municipio
Water Pumps	14	PRASA
Water Tanks	19	PRASA and municipio
WTP	1 (Santiago Vazquez)	PRASA
WWTP	1 (Barceloneta)	PRASA

The region has rich groundwater resources that some industrial facilities have accessed through onsite deep wells and treatment operations. In this unique hydrological environment, these facilities use groundwater as their primary source of potable and process water, with PRASA services being secondary. Although some facilities possess onsite capabilities that reduce their dependencies on external water and wastewater services, certain industrial regulations may still require that PRASA service be available. For example, the BASF facility has two deep wells and onsite chlorination processes enabling it to draw water that may be used for production. However, BASF still needs sanitary water service from PRASA for domestic and eye-washing stations. Industrial policies require that these stations be fed from sources that conduct physical, chemical, and biological treatment before they can be used in emergency processes such as eye-washing stations.[381]

3.2.4.4 Transportation

As crucial nodes in the global pharmaceutical, medical device, and agrochemical supply chains, transportation is critical to the manufacturing cluster in Manatí. Table 3-5 describes the transportation infrastructure assets that support facility operations.[382]

Table 3-5: First-Order Infrastructure Dependencies of Manatí Manufacturing Facilities

Subsector	Infrastructure Asset Name	Notes
Air	Luis Munoz Marin Airport (SJU) – San Juan	Accounts for 25-75% of inbound raw material deliveries and up to 50% of outbound final product shipments
Air	Antonio Juarbe Pol Airport (ABO) – Arecibo	Accounts for up to 25% of inbound raw material deliveries, and serves as an alternative to other airports
Air	Rafael Hernandez Airport (BQN) – Aguadilla	Accounts for 25-75% of inbound raw material deliveries and up to 50% of outbound final product shipments
Maritime	Port of San Juan	Critical to most operations with no alternatives; accounts for up to 100% of some inbound and outbound shipments
Road	Puerto Rico Highway 2	Critical for access to Aguadilla; parallel route provides alternative between Arecibo and San Juan.
Road	Puerto Rico Highway 22	Parallel route provides alternative between Arecibo and San Juan

380 Government of Puerto Rico, undated, "Portal Datos Geograficos Gubernamentales, Catalog of Geodata," (in Spanish), http://www.agencias.pr.gov/agencias/gis/catalogogeodatos/Pages/default.aspx, accessed May 16, 2018; ArcGIS, 2018, *Geographic Mapping and Information System Version 10.4.1*, developed by ESRI.

381 Interviews and site visits by DHS-IP, November 16–20, 2017.

382 Ibid.

As noted earlier, the Port of San Juan is the single most important infrastructure asset on the island. Each of the facilities in Manatí depends on the port for the receipt of bulk raw materials and, in several instances, the shipment of large-volume final products.[383] Air transportation is also critical for receipt and delivery of active pharmaceutical ingredients and other sensitive materials that require cold-chain transportation management. Air transportation is also the preferred method for the shipment of delicately packaged final products, such as glass bottles, vials, and syringes.[384] Although the parallel routes of Puerto Rico Highway 2 (PR-2) and 22 (PR-22) serves Manatí, PR-2 is critical for those facilities that use air transportation at Rafael Hernandez Airport in Aguadilla.[385]

3.2.5 Analysis Summary

In this case study, DHS-IP leveraged the infrastructure interdependency assessment methodology described earlier to assess and visualize the first- and second-order dependencies of the Manatí critical manufacturing cluster.

3.2.5.1 Data Collection

Data from these interviews and site visits were incorporated into geodatabases that establish connections with the infrastructure described by industry representatives, as well as the nature of the connections (e.g., criticality). Table 3-6 provides an example of the resulting relational tables produced for each facility.

Table 3-6: First-Order Infrastructure Dependencies of a Critical Manufacturing Facility

Facility	Sector/ Subsector	Infrastructure Asset Name	Critical	Notes
Facility 1	Electricity	PREPA Distribution Substation 405	●	Facility is equipped with backup generation that could sustain operations for 72 hours
Facility 1	Water	PRASA Manatí Water Tank Stations 1–7		Onsite deep well could sustain operations
Facility 1	Water	PRASA Santiago Vazquez WTP		Onsite deep well could sustain operations
Facility 1	Water	F001 Deep Well		Utility connection could sustain operations
Facility 1	Wastewater	PRASA Barceloneta WWTP	●	Facility is not equipped with any alternatives that could sustain operations
Facility 1	Communications	Manatí Cellular Tower 1	●	Facility is not equipped with any alternatives that could sustain operations
Facility 1	Communications	Fiber/DSL Junction 1	●	Facility is not equipped with any alternatives that could sustain operations
Facility 1	Air Transportation	Rafael Hernandez Airport (BQN)		
Facility 1	Maritime Transportation	Port of San Juan	●	
Facility 1	Road Transportation	Puerto Rico Highway 2 (PR-2)		

383 Ibid.

384 Ibid.

385 Ibid.

DHS-IP developed a parallel series of geodatabase entries and relational tables for the infrastructure assets identified as first-order dependencies by the manufacturing facilities. Data collection for these entries included geographic information system and database resources that FEMA, PREPA, PRASA, the U.S. Army Corps of Engineers, and the Government of Puerto Rico provided. Table 3-7 provides an example of the resulting relational tables produced for each infrastructure asset.

Table 3-7: First-Order Infrastructure Dependencies of an Electricity Infrastructure Asset

Asset	Sector/Subsector	Infrastructure Asset Name	Critical	Notes
Asset 1	Electricity	Transmission Substation Manatí 404	•	Connection to 230-kV connection is critical
Asset 1	Electricity	Transmission Substation Manatí 468		Connection to 115-kV connection will require customer prioritization
Asset 1	Communications	AT&T Junction	•	Critical for control systems
Asset 1	Road Transportation	Puerto Rico Highway 22 (PR-22)	•	Critical for road access to facilitate repair or maintenance

3.2.5.2 Analysis

The relational tables for manufacturing facilities and infrastructure assets were incorporated into the PRIIA toolkit. The assessment team used the toolkit to conduct iterative identifications and assessments of connections between manufacturing facilities and infrastructure assets. Figure 3-8 illustrates an example of a single identification and assessment result from the PRIIA toolset.

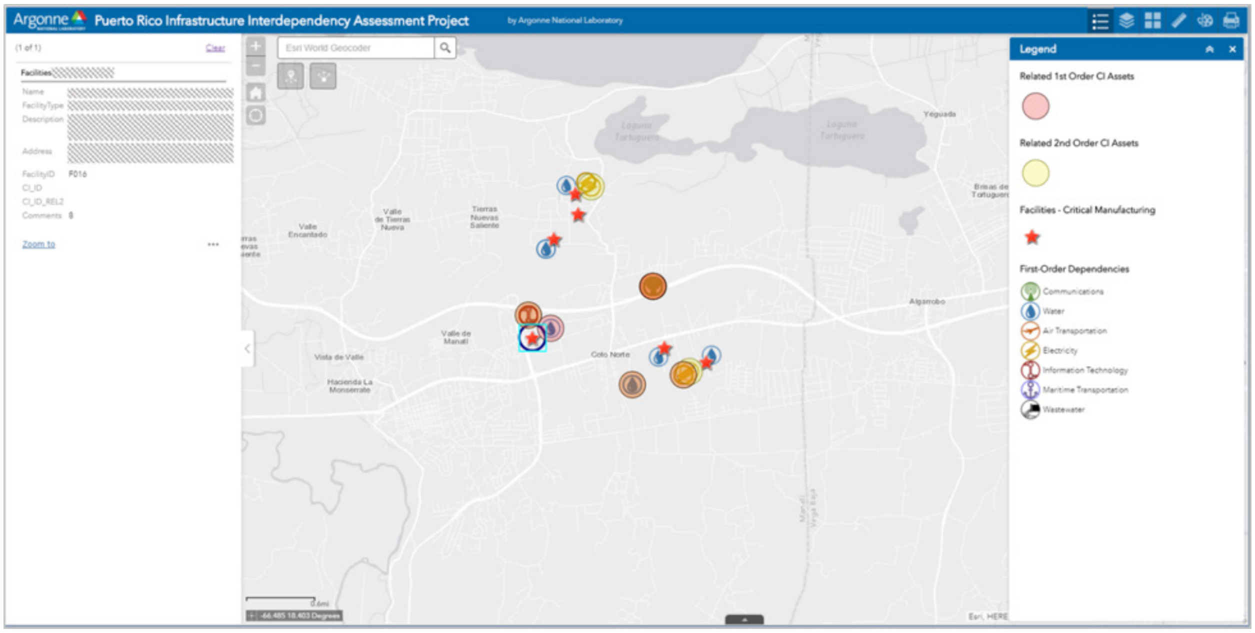

Figure 3-8: Local First- and Second-Order Dependency Visualization of a Facility

The facilities that make up the manufacturing cluster and infrastructure assets across the region were characterized in the geodatabase and mapped in the PRIIA map environment. In the example above, a single manufacturing facility was selected and the PRIIA toolset returned three possible results. The infrastructure assets identified as first-order dependencies are highlighted with a red-shaded circle, and second-order dependencies are highlighted with a yellow-shaded circle. This provides an initial identification of the upstream infrastructure assets that are critical to manufacturing facility operations.

Some infrastructure assets appear to be highlighted with orange-shaded circles. This is the result of both a red-shaded circle and a yellow-shaded circle being used to highlight the same infrastructure asset. These infrastructure assets are therefore both first- and second-order dependencies of the chosen manufacturing facility. For example, a distribution substation that provides a direct connection for electric power to the manufacturing facility as well as a direct connection to a cellular communications tower that is also a first-order communications dependency of that manufacturing facility is providing both a direct and indirect service to the manufacturing facility. An interruption in the service of the distribution substation may be mitigated by the manufacturing facilities backup generators, but the parallel loss of communications service may, nonetheless, result in an impact to manufacturing operations.

The output of this iterative process is a list of the connections between manufacturing facilities and infrastructure assets that constitute the first-order dependencies shared by all facilities. Table 3-8 provides the tally of infrastructure assets that provide services and resources to the critical manufacturing cluster. The assessment team then combined this list with a similar list of individual infrastructure asset assessments to tally the total first- and second-order dependencies of the critical manufacturing cluster.

Table 3-8: First-Order Infrastructure Dependencies of Manatí Manufacturing Facilities

Sector/ Subsector	Infrastructure Asset Name	Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6
Electricity	PREPA Distribution Substation 405	●	●				●
Electricity	Distribution Substation P			●	●	●	
Water	PRASA Manatí Water Tank Stations 1–7	●	●	●		●	●
Water	PRASA Manatí Water Tank Stations 8–14		●			●	●
Water	PRASA Santiago Vazquez WTP	●	●	●		●	●
Water	F001 Onsite Deep Well	●					
Water	F002 Onsite Deep Well		●				
Water	F003 Onsite Deep Well			●			
Water	F004 Onsite Deep Well				●	●	
Water	F006 Onsite Deep Well						●
Water	F006 Onsite Deep Well		●				●
Wastewater	PRASA Barceloneta WWTP	●	●	●	●	●	●
Communications	Public Switched Telephone Network		●	●		●	●
Communications	Manatí Cellular Tower 1	●	●	●	●	●	●

Table 3-8: (cont.)

Sector/ Subsector	Infrastructure Asset Name	Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6
Communications	Fiber/DSL Junction 1	●	●	●	●	●	●
Air Transportation	Luis Munoz Marin Airport (SJU)		●	●	●		
Air Transportation	Antonio Juarbe Pol Airport (ABO)			●			
Air Transportation	Rafael Hernandez Airport (BQN)		●		●		
Maritime Transportation	Port of San Juan	●	●	●	●	●	●
Road Transportation	Puerto Rico Highway 2 (PR-2)		●	●	●		
Road Transportation	Puerto Rico Highway 22 (PR-22)	●	●	●	●	●	●

3.2.6 Key Findings

DHS-IP compiled and interpreted the results of this analysis to formulate a series of key findings intended to (1) highlight some of the infrastructure dependencies and interdependencies that were most difficult to manage during Hurricane Maria and to (2) describe the efforts taken by industry stakeholders to mitigate the potential consequences of disruptions to critical infrastructure dependencies.

External electric power service is important, but service from communications infrastructure is the most critical dependency for manufacturing operations in Manatí.

The island-wide loss of electricity following Hurricane Maria resulted in escalating infrastructure failures across the island. As noted in the Electricity Subsector Characterization (Section 2.2), every critical infrastructure sector includes assets that require electric power for certain operations. Despite the severity of a total loss of utility-provided electricity to dependent infrastructure sectors and communities, most of the manufacturing facilities in the Manatí cluster were able to avoid a prolonged shutdown due to the electric power outage. Each of the facilities had installed considerable backup electric power generation capacity that was capable of supporting most operations; only one facility depends completely on electric power from the grid, as its power demand is so large that backup generation is impractical.[386] In some cases, facilities have even invested in prime power generators that are capable of satisfying the facility's full electric power load requirement. For instance, the Bristol-Myers Squibb facility is equipped with a 1MW prime power generator that enabled it to restart some operations within 5 days of the storm and return to full operations within 30 days.[387] The manufacturing cluster facilities' first-order dependency on electricity is critical, but most of the facilities have alternative sources that may satisfy this dependency, given stable supply of fuel needed for onsite generation.

Consequences of disruptions to the communications infrastructure (a first-order dependency), however, proved to be more difficult for the facilities in the cluster to overcome following the storm. Every industrial operation in Manatí involves data-driven processes, requiring a consistent connection to off-island enterprise business management systems, manufacturing equipment systems, or crucial data centers. As described in the Communications Sector Characterization (Section 2.4), these systems depend on the network of control centers, fiber optic cable, and cellular

386 Ibid.

387 Ibid.

towers to transmit and receive data from across the world. For those communications infrastructure assets that require electricity to operate but are not equipped with backup generators or alternative sources of electricity, the island-wide loss of electricity stymied the flow of data.[388]

Few of the facilities were equipped with alternatives to these externally provided communications infrastructure services. Some facilities believed they had redundant communication systems in place, only to discover that the alternatives relied on the same communications network backbone as their primary system, and were thus equally degraded. Although some facilities acquired satellite phones and microwave antennae, this equipment proved to be insufficient to receive the bandwidth of data required to sustain operations.[389] Industry representatives in Manatí cited the disruption in electricity flow to and lack of sufficient backup generator capabilities at local communications infrastructure assets (second-order dependency) as the most critical point of failure.

Investments in local electricity infrastructure assets will require corresponding system-level investments.

Several of these industrial facilities use highly sensitive instruments that require consistent electric voltage throughout the manufacturing cycle. The consistent flow of power is especially crucial for processes at pharmaceutical manufacturing facilities which, as illustrated in figure 3-6, involve the fermentation of perishable, active pharmaceutical ingredients. Fluctuations in voltage during the fermentation process have tainted entire product batches, resulting in the loss of millions of dollars in revenue and delays in the supply of life-sustaining pharmaceuticals to domestic and international markets. These processes generally require that voltage remain within 2 percent variability. Industry representatives reported that PREPA has struggled to accommodate voltage within 10 percent variability during peak demand periods with its current system.[390]

The desire for greater autonomy over the management of critical services and resources motivated several facility managers to agree to a joint investment in shared distributed electricity infrastructure independent of PREPA. Two PREPA-owned transmission substations and four PREPA-owned distribution substations service the manufacturing cluster. Local industry financed the fifth distribution substation, which provides electricity on a loop circuit to three facilities that share an industrial campus. Although this investment enabled industry partners to exercise control over distribution, service quality from the transmission substation remains an issue. Industry representatives found that the voltage instability challenges they have long experienced result from issues further upstream in the Electricity Subsector.[391] Their investment reduced voltage instability, but the risk of fluctuations remains. Further private sector investments in local electric power infrastructure assets will require corresponding system-level investments by the commonwealth.

Unique onsite water treatment capabilities at manufacturing facilities may reduce the demands on infrastructure and offset the consequences of its disruption.

Industry representatives have made a number of investments intended to reduce both the demands on local infrastructure and the impacts of service interruptions. Investments in onsite water and wastewater treatment capabilities, in particular, have enhanced the resilience of these facilities. Pharmaceutical and agrochemical companies settled in Manatí in part to take advantage of the region's rich groundwater resources.[392] Industrial facilities in Manatí use onsite deep wells and treatment operations as a primary source of potable and process water, with service from the

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388 Ibid.

389 Ibid.

390 Ibid.

391 Ibid.

392 Miller, James A., R.L. Whitehead, Stephen B. Gingerich, Delwyn S. Oki, and Perry G. Olcott, 1999, *Ground Water Atlas of the United States,* U.S. Geological Survey, https://pubs.usgs.gov/ha/730n/report.pdf, accessed May 16, 2018; Interviews and site visits by DHS-IP, November 16–20, 2017.

PRASA serving as a secondary source.[393] This arrangement has offset the high cost of water on the island, which is especially attractive for pharmaceutical manufacturing processes, some of which require more than 100,000 gallons of treated water per day.[394]

Bristol-Myers Squibb, FMC Technologies, and Johnson & Johnson facilities in Manatí have dedicated onsite wastewater treatment operations, providing primary physical and chemical treatment of industrial wastewater before it is transported to PRASA's wastewater treatment system. The FMC Technologies site also has bioreactor treatment that enables the facility to recycle water sufficiently for immediate reuse for industrial purposes.[395] Although the loss of electricity at PRASA's Barceloneta WWTP interrupted the sole treatment service for the region, these onsite physical and chemical treatment capabilities have enabled the facilities to continue operating even without biological treatment services from PRASA.[396]

This unique onsite water treatment capability provided greater resilience not only for the businesses, but for their employees and other members of the community. While FMC Technologies' production line remained idle during the power outage (operating on backup generation is not feasible given its high electricity requirements), it was still able to operate its onsite well and water treatment using backup power. FMC Technologies also provides treated process water to the neighboring DowDuPont facility, but without need for water to operate its own production process, it possessed excess treated water capacity. This excess capacity was redirected to provide potable water to employees of the facilities and other citizens from the Manatí community.[397] As PRASA worked to restore water service, Manatí businesses were able to provide some measure of life-sustaining assistance to residents in need.

Improving the resilience of infrastructure assets and systems serving manufacturing facilities benefits entire communities.

Industry served as a valuable focal point for this case study in light of the massive requirements that the critical manufacturing cluster places on lifeline infrastructure in Manatí. The number of jobs, local developments, and overall economic impacts that are connected to these facilities illustrates the importance of incorporating industry needs as one of the central considerations for long-term infrastructure investment. The benefits that could be derived would be shared across the communities where these and other manufacturing clusters are located.

Improvements in infrastructure resilience translate into improved service reliability across the geographic service areas of assets and systems. These improvements would be enjoyed by all customers that depend on these systems, including manufacturers, businesses, hospitals, community institutions, and individual households. The positive cascading effects that would result from comprehensive infrastructure improvements, driven by the largest users and economic engines within the community, may also increase the efficiency of the infrastructure and reduce service rates for all customers.

Identifying and assessing the cumulative supplies and demands of critical resources and services to inform long-term planning will ultimately support infrastructure resilience, economic recovery, and the revitalization of communities across Puerto Rico.

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393 Interviews and site visits by DHS-IP, November 16–20, 2017.

394 Ibid.

395 Ibid.

396 U.S. Environmental Protection Agency, 2018, "Progress Reports: December 2017 – January 2018," https://www.epa.gov/newsreleases/search/field_geographic_locations/puerto-rico, accessed May 16, 2018; Interviews and site visits by DHS-IP, November 16–20, 2017.

397 Interviews and site visits by DHS-IP, November 16–20, 2017.

3.3 CASE STUDY: IMPACT OF HURRICANE MARIA ON CRITICAL HEALTHCARE SUPPLY CHAINS

3.3.1 Introduction

The concentration of pharmaceutical and medical device manufacturing facilities in Puerto Rico places the island at the center of several critical healthcare supply chains. Primary-source manufacturers like the ones in Manatí (described in Section 3.2) operate throughout the commonwealth. From a business perspective, decisions by primary-source manufacturers related to the consolidation of production lines in their facilities may be based on a number of considerations, including specialized processes or costs involved in producing a particular product.[398] From an infrastructure resilience perspective, these operations require special planning to ensure that critical dependencies on lifeline infrastructure are assured through the implementation of redundant and alternative services and resources. Of the many pharmaceutical and medical device products manufactured in Puerto Rico, perhaps none received as much national attention as the Baxter Healthcare Corp. facility in Jayuya.

3.3.2 Facility Profile

Baxter Healthcare Corp. operates three pharmaceutical and medical device manufacturing facilities in Puerto Rico, one of which is located in Jayuya.[399] The Baxter Jayuya facility manufactures small-volume parenteral (SVP) products, which are primarily used in pharmacy settings to compound or aid in the delivery of a medication, as well as amino acids and certain premixed products. Baxter also produces the saline solution that is used in hospitals for intravenous (IV) treatments.[400] According to the Puerto Rico Industrial Development Corporation, the Baxter Jayuya facility accounts for 10 percent of the entire supply of saline solution used in the United States; other sources reported that the total production at this plant is over 40 percent of SVP products for the domestic market.[401] Baxter Jayuya employs approximately 700 of the city's 16,000 residents.[402]

3.3.3 Impacts from Hurricane Maria

Although Hurricane Maria resulted in widespread, severe damage to infrastructure across the island, remote areas of Puerto Rico such as Jayuya felt the impacts more acutely. Jayuya was without grid power until mid-February; even after transmission lines were energized, unfinished repairs to distribution lines throughout the rural community left half of the residents without power.[403] Roads to Jayuya were damaged by flood washouts or blocked by fallen trees and debris. Without power to manufacture and means to transport its product, the isolated Baxter Jayuya facility was unable to operate. Its power demands are substantial; onsite emergency generators were not sufficient to sustain operations or to restart the plant after it went offline.

3.3.3.1 Federal Response

398 Interviews and site visits by DHS-IP, November 16–20, 2017.

399 Baxter, 2018, "About Baxter Puerto Rico," http://www.baxter.com.pr/about_baxter/about_baxter_pr.html, accessed May 17, 2018.

400 Luce, Scott P., 2018, "IV Solutions Supply Update Letter," Baxter, January 24, http://baxterivsolutions.com/sites/default/files/documents/IV%20Solutions%20Supply%20Update%20Letter%20January%202018%20FINAL.pdf, accessed May 17, 2018.

401 Saker, Anne, and Shari Rudavsky, 2018, "Hospitals find other ways to deliver medicine amid IV bag shortage," *USA Today*, January 14, https://www.usatoday.com/story/money/nation-now/2018/01/14/iv-bag-shortage-puerto-rico/1032369001/, accessed May 17, 2018.

402 Baxter, 2017, "Baxter Provides Update on Puerto Rico Recovery Status Post Hurricane Maria," October 12, https://www.baxter.com/baxter-newsroom/baxter-provides-update-puerto-rico-recovery-status-post-hurricane-maria, accessed May 17, 2018.

403 Thomsen, Jacqueline, 2018, "Power companies pull workers from Puerto Rico as many remain without power," *The Hill,* February 27, https://www.positivechangepc.com/2018/02/, accessed May 17, 2018.

In early December 2017, FEMA delivered five 1megawatt (MW) diesel generators to restart the facility to avert the possible public health concern that could result from a shortage of saline solution. Grid power was restored to the facility two weeks later. However, the facility continued to operate on diesel generators because the restored grid power was still prone to both outages and fluctuations in quality that could have disrupted sensitive production processes. To avoid similar extended power outages affecting this facility, the government of Puerto Rico and the U.S. Department of Energy assessed the site and surrounding community's power needs to evaluate their suitability for microgrid deployment.

3.3.4 Long-Term Infrastructure Concerns

The deployment of a microgrid providing local generation to serve Jayuya's residents, businesses, and this critical manufacturing site is a positive development. However, to achieve the intended outcome—ensuring continued production of saline solution at the Baxter facility—additional infrastructure issues are relevant.

3.3.4.1 Distributed Electricity Generation

Microgrids rely on local power generation, which requires fuel. In this case, local generation is expected to be a natural-gas-fired turbine plant capable of producing approximately 7 MW. Puerto Rico has no natural gas pipelines; fuel delivery would likely then be via tanker truck. Given Jayuya's remoteness, and the damage the roads into Jayuya experienced during Hurricane Maria, truck delivery may be problematic without new investment in road infrastructure capable of withstanding future damage. The only existing natural gas terminal is 20 miles away in Guayanilla, which requires a driving distance of 40 miles for trucks through Ponce.[404] The main roadways connecting the Guayanilla fuel terminal to Jayuya are Puerto Rico Highway (PR) 140, PR-10, and PR-2. For power generation in Jayuya to be reliable, roads serving the area must be capable of withstanding future storm damage and designed to support the high truck traffic associated with fuel deliveries.

3.3.4.2 Natural Gas

Delivery of natural gas into Puerto Rico is presently limited to a single terminal/storage facility, which represents a single point of failure. Its disruption could lead to natural gas supply shortages and lengthy delays in the delivery of natural gas to Jayuya. To maintain energy production in Jayuya to support saline solution manufacture at Baxter, the EcoEléctrica natural gas terminal and storage area in Guayanilla must become more resilient to damage or disruption. Alternatively, additional points of entry for natural gas could be established to provide diversity of sources and thus redundancy in fuel supply if EcoEléctrica experiences disruptions.

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[404] ESRI, 2018, ArcGIS Geographic Information System Software Version 10.4.1.

3.3.4.3 Maritime Transportation

For saline solution to reach healthcare facilities in the United States, the Port of San Juan must remain operational and capable of sending and receiving maritime cargo shipments. The Port of San Juan depends on reliable road transportation, electric power, and communications service to support its operation. Without these, operations are significantly slowed or halted. In addition, the single channel serving the port must remain clear, and aides to navigation must remain in place, for marine vessels to access the port area. The Port of San Juan is a single point of failure for the delivery of saline solution (and nearly every other product sent or received by Puerto Rico). The following actions are needed to ensure resilient provision of saline solution manufactured at the Baxter Jayuya facility to healthcare facilities in the United States:

- Electric power, transportation, and communications systems serving the Port of San Juan must be made resilient/more reliable;
- Port facilities (e.g., terminals, cranes) must be hardened to prevent damage from future storms; and
- The channel and other navigation assets must be maintained and hardened.

3.3.5 Considerations for Recovery Planning

In addition to design and deployment of a microgrid to address Baxter and Jayuya's power needs, recovery planners should also consider the following actions to improve the resilience of production operations for saline solution at the Baxter Jayuya facility:

- Develop robust engineering designs for roadways connecting Jayuya with the Port of San Juan and the Port of Guayanilla; the roadways should be capable of handling heavy freight and fuel truck traffic. Engineering plans should include rerouting of roads to avoid areas subject to landslides and washouts, or feature designs to mitigate their impact.
- Develop robust design of the 32 bridges along those roadways that are capable of withstanding flood and scour damage, or consider implementing flood control measures that will prevent such flood conditions and impacts.
- Implement solutions to improve power supply to the Ports of Guayanilla fuel terminal and Port of San Juan container terminals. Evaluate redundant power feeds and alternate power source strategies.

3.4 CASE STUDY: IMPACT OF HURRICANE MARIA ON THE AGRICULTURAL BIOTECHNOLOGY INDUSTRY IN PUERTO RICO

3.4.1 Introduction

Agricultural biotechnology is a growth industry in Puerto Rico, particularly on the south side of the island. The sector employs more than 5,000 workers and injects more than $125 million into Puerto Rico's economy each year.[405] For more than 30 years, global seed businesses have operated in Puerto Rico, attracted by a warm climate that can sustain four growing seasons. Puerto Rico's fields have hosted the research and development for up to 85 percent of the commercial corn, soybean, and other hybrid seeds that U.S. farmers use.[406] Figure 3-9 shows a growth operation in Juana Diaz on the southern side of the island.

Figure 3-9: Agricultural Biotechnology Grow-out in Juana Diaz, February 2018 (Photo by Matthew Berry/Argonne)

Hurricane Maria struck just before the first planting of the winter season; few crop experiments were in the ground at that point and operations managers were planning for the new season. However, the storm hit far enough in advance of the winter planting that research teams were able to relocate operations to alternative winter farms for the 2017–2018 season.

As news of post-storm damage spread, researchers at agricultural biotechnology firms made quick decisions about business operations. Some firms quickly diverted planned work to alternative locations in Mexico, Chile, and New Zealand out of concern that the infrastructure in Puerto Rico could not support their operations.[407] Some firms reduced their operations to as low as 30 percent of normal capacity, while others continued normal operations. The degree to which winter farms were impacted varied based on their level of preparedness before the storm and their ability to obtain support from their parent companies. Sites that invested in mitigation strategies (e.g., installed generators to support critical components of their operation) were able to return to normal operations more quickly than those that had not.

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405 Puerto Rico Agricultural Biotechnology Industry Association, undated, "Agricultural Biotechnology in Puerto Rico," https://www.prabia.org/agbio-puerto-rico, accessed May 16, 2018.

406 Mayer, Amy, 2017, "Puerto Rico's Hurricane Recovery Hinders Farm Businesses' Seed Research," *National Public Radio,* November 29, https://www.npr.org/sections/thesalt/2017/11/29/567254037/puerto-ricos-hurricane-recovery-complicates-ag-businesses-seed-research, accessed May 16, 2018.

407 Interviews and site visits by DHS-IP, February 21–22, 2018; Mayer, Amy, 2017, "Puerto Rico's Hurricane Recovery Hinders Farm Businesses' Seed Research," *National Public Radio*, November 29, https://www.npr.org/sections/thesalt/2017/11/29/567254037/puerto-ricos-hurricane-recovery-complicates-ag-businesses-seed-research, accessed May 16, 2018.

3.4.2 Industry Structure

The agricultural biotechnology industry in Puerto Rico consists of major global players. Dow, DuPont, Bayer, and Monsanto all have winter farm operations scattered across the southern coastal plain of the island; independent seed farms such as 3rd Millennium Genetics and the Illinois Crop Improvement Association also have facilities in the region. The winter farms for large seed firms are internal cost centers for the companies. Corporate and academic researchers working on new seed products send their seed experiments to Puerto Rico for a number of purposes:

- **Trait integration** occurs in the early stages of seed production research and development. Plants with desirable traits are cross-bred to create hybrids.
- **Generation advance** is the continuation of the trait integration process in which hybrids that were initially successful are planted in successive generations to ensure that the desired traits remain.
- **Planting for increase** is planting new hybrid seeds to generate more hybrid seeds. The "increase" production seeds are typically sent to test plots in the United States, Canada, and Europe to ensure that they will perform as desired.
- **Planting for certification** is when a third-party farm plants hybrid seeds and confirms that the traits purported to be in the plant actually are. Seeds produced at the winter farms are then returned to researchers for further study or shipped to test plots in the United States, Canada, and Europe for planting.

3.4.3 Infrastructure Requirements

Operating a winter farm requires more than fertile soil, sunlight, rainfall, and farm equipment. In fact, numerous critical infrastructure dependencies exist at agricultural biotechnology operations. For example, electric power is necessary for access to and diversion of water and for equipment used in seed conditioning. Communications infrastructure allows researchers located remotely to oversee their experiments in near-real time. Air cargo operations link the winter farms to the overall supply chain. Fuel supplies of diesel and gasoline keep farm equipment operating. Disruptions in any of these upstream infrastructure dependencies can have significant impacts on the agricultural biotechnology industry, potentially risking an entire season's worth of work.

3.4.3.1 Electricity

The primary concern that agricultural biotechnology industry representatives following Hurricane Maria cite is the fragility of the electric power system in Puerto Rico. Electric power at winter farms supports the following critical functions:

- Energizing pumps that bring ground water to the surface and charge irrigation systems;
- Pumping surface water to charge irrigation systems;
- Powering seed conditioning equipment (including dryers, thrashers, and shellers) and climate-controlled seed storage equipment; and
- Powering communications and information technology equipment that allows investigators located around the world to oversee their experiments between visits to the farms.

Winter farms commonly maintain multiple connections to the power grid. Many operations are dispersed across two or three non-contiguous locations that may be separated by tens of miles. Common electric power infrastructure at primary sites (e.g., administrative and headquarters buildings) includes site-owned and -maintained substations connected to PREPA's 38-kV transmission grid, connections to the PREPA distribution grid, and backup generators. Figure 3-10 shows utility poles in Juana Diaz. None of the locations visited had installed renewable generation capacity such as solar or wind.

Winter farm operations in Puerto Rico had to act following the storm to make up for the loss of electric power. Some sites brought in generators from the continental United States; others circulated generators around their sites as needed to meet their functional requirements; and others simply curtailed operations. As grid power returned, the facilities with onsite substations connected to the transmission grid resumed operations before those connected to the distribution grid.

Figure 3-10: Utility Poles at a Winter Farm in Juana Diaz, February 2018 (Photo by Matthew Berry/Argonne)

3.4.3.2 Fuel

Farm operations rely on fuel deliveries to power farming and transportation equipment, including tractors, planters, combines, pickup trucks, and buses. Discussions with farm operators confirmed that they maintained onsite diesel fuel tanks and, in some cases, gasoline tanks. Demand for fuel service to refill tanks under normal operations typically fluctuates based on the time of year, ranging from once a week during peak operations to once a month during non-peak times. Reliance on generators for electric power at the facilities following the storm increased the demand for diesel fuel, requiring fuel deliveries to double to twice a week. Two of the farms' representatives reported disruptions in their fuel supply chain during hurricane response. Both had primary fuel service contracts with the same provider. In the immediate response period, the primary provider was unable to meet delivery requirements. As a result, the farms contracted with an alternative provider. For one operation, the fuel disruption caused the firm to curtail operations to half days in order to conserve fuel.

3.4.3.3 Communications

Communications link the winter farms in Puerto Rico to researchers from around the globe who are working on seed projects there. Farm personnel send updates to the researchers throughout the season, sometimes daily. Updates may include structured quantitative data or large data files such as photographs. Observations about crop performance can force researchers to make time-sensitive decisions about their experiments. All of the farm operations interviewed reported surprise at their degree of reliance on telecommunications for normal operations and the impact of the disruption.[408]

Immediately following Hurricane Maria, winter farm operators struggled to contact their parent companies to report on local conditions. The disruption of the telecommunications system may have contributed to reduced operations during the 2017–2018 winter season; farm operators were unable to confirm with off-island partners that physical damage to their facilities in Puerto Rico was minimal.[409] Also, operators experienced challenges in contacting employees to perform personnel accountability checks and get them to return to work.

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408 Interviews and site visits by DHS-IP, February 21–22, 2018.

409 Mayer, Amy, 2017, "Puerto Rico's Hurricane Recovery Hinders Farm Businesses' Seed Research," *National Public Radio*, November 29, https://www.npr.org/sections/thesalt/2017/11/29/567254037/puerto-ricos-hurricane-recovery-complicates-ag-businesses-seed-research, accessed May 16, 2018.

In response to the failure of wired telecommunications infrastructure, winter farm operators used a variety of strategies to reach out to parent companies, employees, and service providers. For example, personnel reported using their personal devices and data plans, often having to travel to other places on the island where service was still available. In addition, many attempted to use satellite phones. However, reports indicated that these connections experienced poor voice quality. One company went so far as to fly in a satellite communications tower to improve satellite phone performance. In terms of data, service was slow to return, with some reporting no wired data connection into January, four months after the storms struck. As an alternative, many contracted with a wireless data provider for a data hotspot that allowed for a limited number of wired as well as wireless, connections.

3.4.3.4 Water

Access to water is a necessity on farms in southern Puerto Rico. The winter farms are primarily located in the south coastal plain, which the U.S. Geological Society characterizes as semi-arid. Annual rainfall totals in the area range from 30 to 64 inches.[410] Depending on location, farming operations receive water for irrigation through either an aqueduct system that delivers surface water from Lago Patillas or the Guamani Canals or from groundwater.[411] Groundwater is pumped to the surface from the South Coast Aquifer, which extends westward along the southern coast from Patillas to Ponce.[412]

The pumps that support irrigation at winter farms operate on electricity delivered from the PREPA distribution grid. Not all of the winter farms had installed backup generation dedicated to well pumps; many relied on mobile generators to operate them. Interviews with farm operators revealed that some backup generators originally thought to be sufficient to operate the pumps were not. This development required the farm operators to revise their response strategy in real time, relocating generators to operate pumps and using the smaller generators to power administrative or maintenance facilities. Figure 3-11 shows water wells supported by backup electricity generation.


Figure 3-11: Water Wells at Agricultural Biotechnology Farm Operations in Juana Diaz, February 2018. Left, Permanently Installed Backup Generation; Right, Temporary Generator Operating Well at an Agricultural Biotechnology Farm Operation (Photos by Matthew Berry/Argonne)

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410 U.S. Geological Survey, 2014, *Hydrogeology of Puerto Rico and the Outlying Islands of Vieques, Culebra, and Mona*, https://pubs.usgs.gov/sim/3296/pdf/sim3296.pdf, accessed May 16, 2018.

411 Interviews and site visits by DHS-IP, February 21–22, 2018, February 22; Mayer, Amy, 2017, "Puerto Rico's Hurricane Recovery Hinders Farm Businesses' Seed Research," *National Public Radio*, November 29, https://www.npr.org/sections/thesalt/2017/11/29/567254037/puerto-ricos-hurricane-recovery-complicates-ag-businesses-seed-research, accessed May 16, 2018.

412 U.S. Geological Survey, 2016, "South Coast aquifer (Puerto Rico)," December 8, https://water.usgs.gov/ogw/aquiferbasics/ext_scaq.html, accessed May 16, 2018.

All of the facilities surveyed receive domestic water for sanitation from the aquifer. Water is treated onsite and pumped into storage tanks for sanitary and fire suppression purposes. Wastewater at all of the sites surveyed is handled using septic systems, either in-ground septic tanks or leaching fields. Electric power is not necessary for the septic systems, as all are gravity-fed.

3.4.4 Other Considerations

Each facility is unique in its dependence on local infrastructure, as illustrated through their experience following Hurricane Maria. The uniqueness stems from each site's age and design, its level of preparedness for crises, and the degree to which mitigation measures were in place prior to the storm. Facilities with more mitigation measures and plans for responding to catastrophic incidents generally fared better immediately following the storm. The sections below explore additional infrastructure dependencies that agricultural biotechnology firms reported experiencing in the wake of the 2017 hurricane season.

3.4.4.1 Hospitality Industry

Multiple sources indicated a dependency on the hospitality industry, which is largely represented by the Commercial Facilities Sector (including lodging, retail, and public assembly facilities). Researchers from universities and seed manufacturers around the world send their seeds to winter farms in Puerto Rico. Farm operators provide frequent updates and data via data and telecommunications. However, researchers like to inspect their experiments in person as well. The hospitality presence on the south side of the island is far less-developed than that of San Juan. The agricultural biotechnology industry would welcome an increase in the number of hotels and restaurants in the area.

3.4.4.2 Stormwater Management

Stormwater from the mountains in the center of the island is channeled to the island's south side. However, the culverts that manage the stormwater do not carry it all the way to the coast, but release it 2–3 miles inland. This inland release leads to flooding in the area where the farms operate, eroding topsoil and sending it into homes downstream.

3.4.4.3 Human Capital

The agricultural biotechnology industry employs thousands of temporary workers during the growing season. Following Hurricane Maria, the industry experienced significant challenges in retaining temporary employees during the 2017–2018 growing season. Companies that typically hire seasonal staff directly worked with employment agencies to fill positions. The temporary employees identified through the employment agencies did not have experience in the industry and require greater supervision than their normal temporary personnel. A combination of factors led to these challenges. For example, some of the temporary labor force left Puerto Rico for destinations in the continental United States and were no longer available to work. Others who may have wanted to work could not reach the farms due to of lack of transportation options, either personal or public.

3.5 CASE STUDY: IMPACT OF HURRICANE MARIA ON FOOD SUPPLY AND DISTRIBUTION IN PUERTO RICO

3.5.1 Introduction

Like most islands, Puerto Rico confronts major challenges and vulnerabilities regarding the supply and distribution of food products, especially during disasters that disrupt normal business operations and supply chains. Hurricane Maria demonstrated how a large-scale disaster can impact the supply and distribution of food products in Puerto Rico. While most of the underlying food "system" remained intact and adapted, post-storm experiences suggest a need to more closely examine the island's preparedness and resilience to future events that could significantly obstruct the ability to receive and distribute food products.

Many factors influence improved food system preparedness and resilience in Puerto Rico, but a leading consideration is the physical infrastructure that underpins all aspects of how food is received, staged, handled, transported, and sold to customers. At issue is not just the immediate facilities and capabilities for handling and shipping food around the island, but also the supporting infrastructure that is often essential for the operation of the overall food system, such as power, communications, transportation, and water.

3.5.2 Overview of Food Supply and Distribution in Puerto Rico

Puerto Rico imports the vast majority of food products consumed on the island. Some items such as chicken, dairy products, certain fruits, and coffee are produced on the island, but these products represent a very small portion of the total food supply.[413] Puerto Rico imports food of every type from dozens of countries, with the United States serving as a leading supplier. The majority of U.S.-sourced food is shipped from the Port of Jacksonville in Florida. Other U.S. ports of origin include Houston and Philadelphia. Puerto Rico also imports significant amounts of food from South America and Asia.

With the exception of a miniscule amount of specialty food items that are flown into Puerto Rico, nearly all imported food arrives by ocean vessel at the Port of San Juan. While there are many variations in the on-island food supply chain, Figure 3-12 depicts the basic movement of most foods.[414]

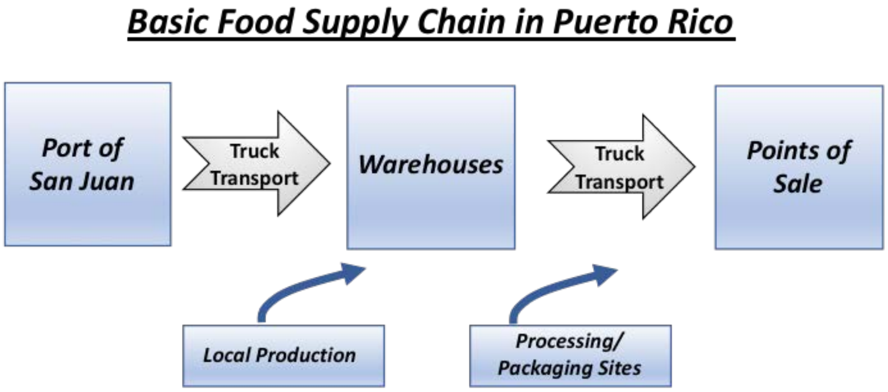

Figure 3-12: Basic Food Supply Chain in Puerto Rico

As the figure shows, the food supply chain in Puerto Rico has a few critical elements:

413 While estimates vary, it is generally understood that 80–90 percent of all food consumed in Puerto Rico is imported.

414 The precise supply chain in Puerto Rico for a given food product can depend on factors such as the nature of the product (e.g., need for interim processing/packaging), terms of sale and differing business models, and final destination (e.g., temporary storage at a second, more distant warehouse).

- The Port of San Juan, which receives most food consumed on the island;
- A network of warehouses that serve as the main staging points for most food products and that orchestrate the truck movement of products to customers; and
- Final points of sale, including supermarkets, convenience stores, restaurants, hotels, hospitals, nursing homes, and other locations.

In addition, numerous organizations and facilities around the island serve food-related purposes, such as agricultural production and food processing and packaging (e.g., water bottling sites, meat processing).[415] However, given the overwhelming reliance on imported food products, these types of facilities and operations are responsible for a limited portion of total food demands in Puerto Rico. The Port of San Juan, large food distribution warehouses, and final points of sale are the predominant elements that underpin Puerto Rico's food supply chain and provide residents and visitors a safe and predictable supply of food each day.

Figure 3-13 highlights several of the leading companies involved in each of these three elements of the food supply chain.

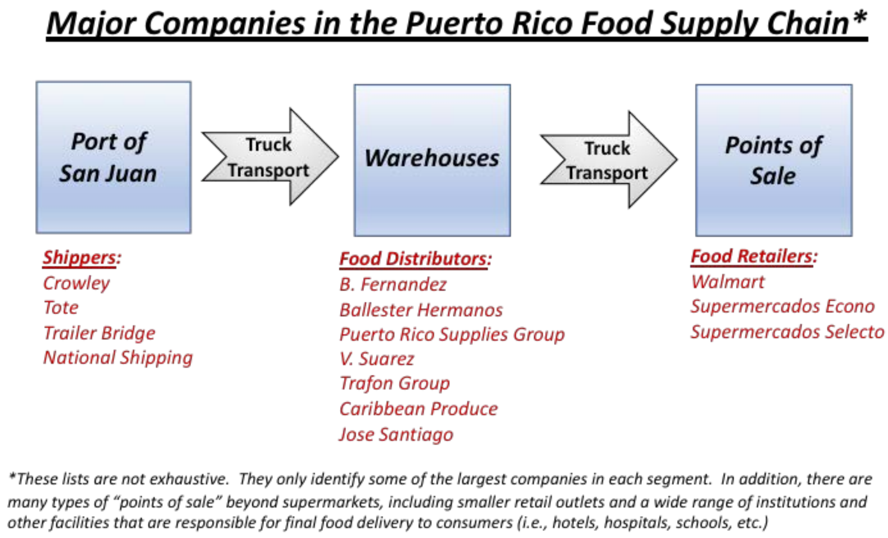

Figure 3-13: Major Companies in the Puerto Rico Food Supply Chain

415 Food warehouses often also conduct various types of food processing and packaging.

3.5.3 Food Warehouses in Puerto Rico

Officials in Puerto Rico recognize the criticality of the Port of San Juan in receiving the vast array of products imported to Puerto Rico. Likewise, residents and visitors to Puerto Rico, who visit supermarkets and other points of sale daily, appreciate the importance of food retailers. Figure 3-14 shows the locations of supermarkets operated by several of the largest retailers on the island.

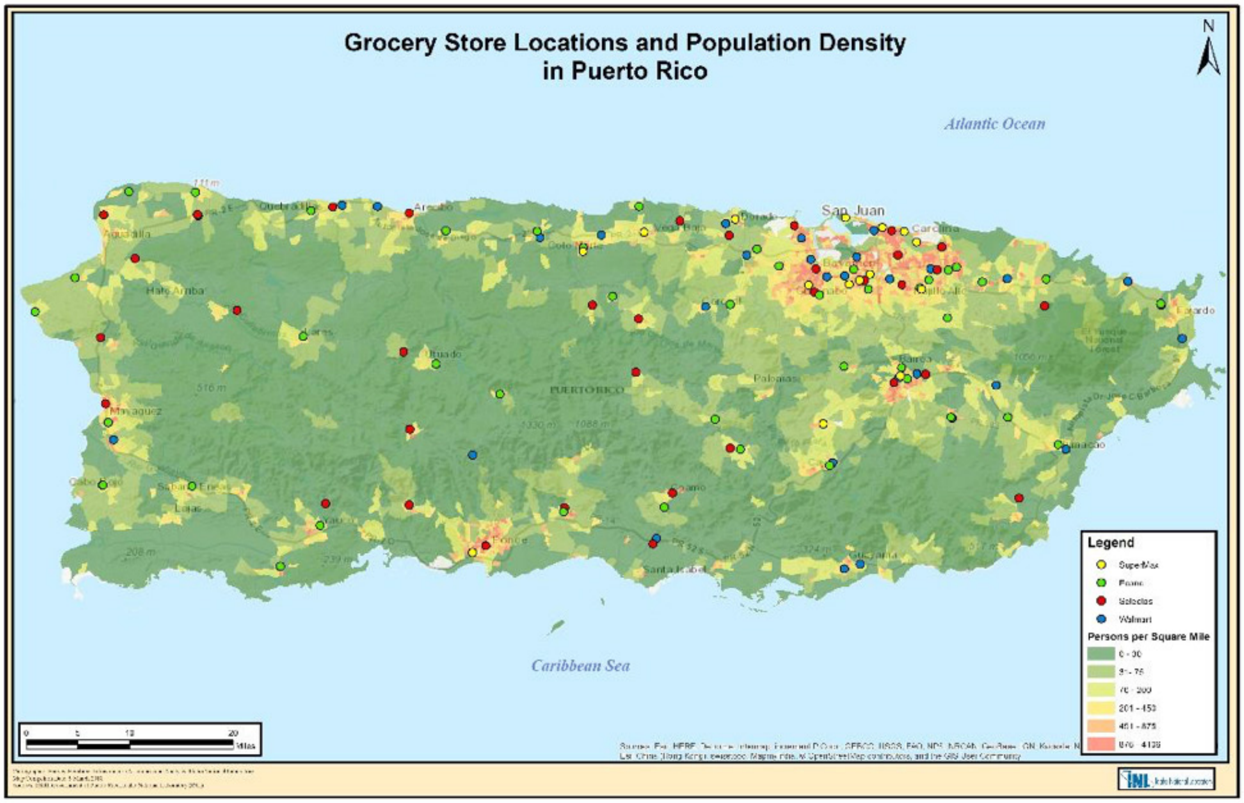

Figure 3-14: Grocery Store Locations and Population Density in Puerto Rico

The role, ownership, and locations of the large food warehouses at the center of the food supply chain in Puerto Rico are less understood and appreciated.[416] These warehouses are typically owned and operated either by food distributors that are responsible for receiving bulk shipments and delivering products to end customers (e.g., supermarkets, restaurants), or the large retailers themselves. In either case, these warehouses have several primary purposes:

- Staging and breakdown of incoming bulk shipments from the port;
- Performing interim processing and/or packaging for certain products;
- Regulating the outbound flow of products based on current supply and demand; and
- Providing refrigeration and other required handling and treatment until final shipment to customers.

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416 Puerto Rico has a wide range of facilities that may be considered "food warehouses." However, many of these are small facilities with a limited purpose or customer base. This discussion focuses on high-volume food warehouses that the largest wholesalers and retailers on the island operate.

Figure 3-15 shows the locations of most of the large food warehouses that form the midstream segment of Puerto Rico's food supply chain. The majority of these facilities are located in the immediate San Juan metropolitan area to enable convenient access to the Port of San Juan's container terminals, with several located very near one another. The inability of these warehouses to operate would present profound obstacles to delivery and distribution of food to island residents.

Figure 3-15: Food Distribution Centers in Puerto Rico

3.5.4 Impacts from Hurricane Maria on Food Supply and Distribution

Hurricane Maria disrupted the normal distribution of food products in various ways. Some of the more prominent include the following:

- Loss of normal power, water, and communications/Internet capabilities at most of the facilities that comprise the food supply chain, including warehouses and points of sale.
- Significant congestion at the Port of San Juan, due in part to the accumulation of thousands of containers that were not being delivered to their customers for various reasons.
- Shortage of trucks and drivers due, in large part, to their diversion to other hurricane response tasks.
- Transportation challenges, especially in more rural areas, caused by blocked and damaged roadways.

An additional factor in some of these disruptions was the effort by FEMA and other response agencies to supply food directly to consumers, bypassing the normal private sector supply chain to ensure that adequate supplies were reaching those in need. FEMA plays a unique and critical role in food assistance following any major disaster. However, some officials expressed concern that its processes following Hurricane Maria were not as coordinated with the normal food supply chain actors in Puerto Rico as they could have been, leading to unnecessary diversion of critical resources, delays in reconstituting the normal food supply chain, and other related outcomes.

Despite these and other complicating factors, food industry organizations made significant efforts to minimize the impacts and continue food distribution to the greatest extent possible following the hurricane. These efforts included use of generator power at warehouses and other facilities, communication workarounds (e.g., person-to-person orders in lieu of normal Internet processes), and use of onsite water tanks.

3.5.5 Recognition of Other Hazards Facing the Food System in Puerto Rico

Hurricane Maria presented significant challenges to the normal functioning of the food supply and distribution process in Puerto Rico. Fortunately, Puerto Rico avoided a critical island-wide food crisis that could have left hundreds of thousands without replenished food supplies for weeks or longer. The Port of San Juan rapidly re-established grid power, and its operations were not otherwise significantly affected. The large food warehouses responsible for orchestrating the flow of food products throughout the island resumed operations very soon after the hurricane and were able to rely on backup generators.[417] In many cases, supermarkets and other points of sale suffered prolonged power and communications outages, preventing various functions, including refrigeration, credit card transactions, and verification of government food assistance eligibility. However, these retail sites were mostly intact and able to restart full operations as these elements came back on line. Compared to other sectors, these food retail sites and restaurants are not frequently considered to be a priority for restoration. In short, although all of the major elements of the food supply chain were impacted to varying degrees, they were able—in conjunction with FEMA and other related food assistance programs—to reconstitute rapidly enough to avoid prolonged, severe food supply shortages in most parts of the island.

Although every disaster is unique, Puerto Rico, the Federal Government, private industry, and other stakeholders can use the lessons learned following Hurricane Maria as an opportunity to consider how the island's food system could be disrupted in even more profound ways in the future. The scenarios listed below are not exhaustive, but they offer a starting point for such examinations of Puerto Rico's food supply chains.

- **Significant or complete shutdown of operations at the Port of San Juan**—This would be one of the most serious events that Puerto Rico could face from the standpoint of normal business operations and supply

[417] It is important to note that these and other businesses in Puerto Rico are increasingly turning to alternative power generation as a normal course of business operations given the unreliability of grid power even during normal times.

chain continuity. Daily food shipments would cease, and extraordinary work-around measures would be needed that take into account the multitude of products that normally enter the port.[418]

- **Simultaneous failure of many of the large food warehouses that underpin Puerto Rico's food system**—Significant lost warehouse capacity resulting from a major disaster such as storm surge, flooding, or earthquake would cripple the normal food supply system on the island. This risk is magnified given the tight clustering of many of these large facilities in the same areas (figure 3-18). Potential workarounds for a major loss of warehouse capacity are possible, but would entail unusual and very difficult short-term solutions.
- **Massive and prolonged disruptions to last-mile delivery of food products and/or points of sale**—Even if the port and large warehouses are operational, suppliers must be able to transport food products to final points of sale, and those receiving point of sale facilities must be operational. Natural disasters that impede this final leg of the food supply chain for an extended period would create fundamental challenges to feeding the island's citizens.

3.5.6 Hurricane Maria Recovery: Infrastructure Considerations for Puerto Rico's Food System

The multi-year effort to recover from Hurricane Maria and create more resilient infrastructure systems in Puerto Rico should take into account food supply and distribution, and how this critical need is intertwined with other infrastructure on the island, including power, transportation, fuel, communications, water, and wastewater. While predicting future disruptions to the food system in Puerto Rico is not possible, contemplating the impacts of potential disasters of varying severity is worthwhile. As stakeholders identify and implement upgrades to Puerto Rico's infrastructure, they should carefully consider how these improvements contribute to a more resilient food system in Puerto Rico. A more resilient food system—or at least an improved understanding of its operations and dependencies—should help to lessen the amount of feeding operations undertaken during emergencies by FEMA and other food assistance programs and hasten the restoration of this important system; both would contribute to a faster return to normalcy post-disaster. Below are several topics that could inform these cross-sector considerations.

3.5.6.1 Port of San Juan

Future investments and upgrades to the port are likely to benefit numerous industries given their shared reliance on this critical infrastructure. However, to the extent that elements of the port are particularly relevant to the food industry, these should be highlighted for consideration. Such elements may include shore-side facilities and/or capabilities that enable refrigeration and other special handling needs, as well as specific outbound surface transportation routes that food transporters predominantly use.

As alternative marine ports around the island are considered for development or expansion, these plans should fully consider the capabilities and business factors that would relate to the import and distribution of food products. For example, some proposed locations may not make logistical and/or business sense (e.g., lack of collocated warehouse space, distance to warehouses and population centers, expense and nature of transportation).

3.5.6.2 Food Warehouse Clusters

The clustering of large food warehouses in the greater San Juan metropolitan area (and, in particular, within tightly coupled warehouse "districts") presents a shared vulnerability that Puerto Rico should consider as the Hurricane Maria recovery effort examines mitigation measures against storm surge, flooding, and other risks. If officials pursue investments in this area, they should account for the criticality and potential exposure of these important facilities.

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418 Other ports in Puerto Rico, in lieu of San Juan, could receive ships and unload food products. However, this strategy would involve unusual operations and face major limitations, including lack of proper food storage, handling, and refrigeration at the alternative port; lack of nearby food warehouses to receive the products; and major alterations to normal trucking operations that would involve significantly longer and potentially cost-prohibitive routing.

As Puerto Rico undertakes efforts to modernize important infrastructure such as electricity, water, wastewater, communications, and transportation, officials should also focus on mitigating risks to the large food warehouses that are critical to the island's food supply. While many of these facilities experienced significant disruptions to utility service after Hurricane Maria and managed to continue many of their operations, future disruptions to power, communications, and other critical resources could be more severe if improvements do not extend to these facilities.

3.5.6.3 Retail Sales

Similar to food warehouses, points of sale for food can benefit from improved infrastructure services. However, hundreds of supermarkets, convenience stores, and other food outlets are spread throughout the island, creating a more diffused challenge. Puerto Rico should examine how these facilities, which are the final food distribution point for most Puerto Ricans, can better withstand future disruptions to operations. Power is always a major concern, but communication is also crucial, including the ability to process non-cash payments. Transportation is another key need, especially in more rural locations. As Hurricane Maria recovery officials examine proposed upgrades to transportation routes around the island, including rural regions, they should consider the need to move food products by truck to final retail locations. In general, improving the resilience of essential services (e.g., electricity, communications, and transportation) in specific areas of the island will result in corresponding improvements in the resilience of food retail locations in those locales.

3.5.6.4 Coordination on FEMA Food Assistance

The quickest possible return to normal supply chain operations for every type of product following a disaster is in the best interest of all stakeholders. For the food supply chain, the more rapidly service providers and infrastructure supporting the steady-state food supply chain are restored, the sooner FEMA can begin to reduce its food assistance operations.

FEMA's immediate response role in ensuring that food is delivered to affected and vulnerable populations after emergencies is a life-sustaining function. However, the manner in which FEMA delivers food assistance, with what resources, and for how long are questions that deserve review with local public and private sector organizations. These processes bear on how infrastructure is used, what infrastructure is available, who may use it, in what order it is restored, and other key questions. FEMA's ability to coordinate emergency food distribution with, rather than in place of, the steady-state food supply chain on the island will create a more effective and resilient food system that can return to normal more quickly following future disruptions.

3.5.6.5 Local Food Production

Many of the food-related challenges described in this section relate directly to the fact that Puerto Rico must import the vast majority of its food. However, Puerto Rico has the ability to reduce—though not eliminate—this reliance by producing a larger share of food locally. Many raw ingredients would still need to be imported, many items cannot be produced economically in Puerto Rico, the island has arable acreage limitations, and supply chains can still be disrupted, even for locally produced food. Nevertheless, those involved in hurricane recovery efforts may consider this option to help mitigate the effects of disruptions to the island's food supply. Such discussions should include associated infrastructure considerations. For example, food production facilities can have large electricity, water, and communications needs. Similarly, agricultural operations have distinct needs, including irrigation, inbound transportation of inputs, outbound transportation of products, and electricity. As power, water, wastewater, communications, transportation, and potentially other infrastructure upgrades and investments are considered during the recovery effort, their relation to potential future expansions in food production in Puerto Rico should be taken into account.

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Path Forward

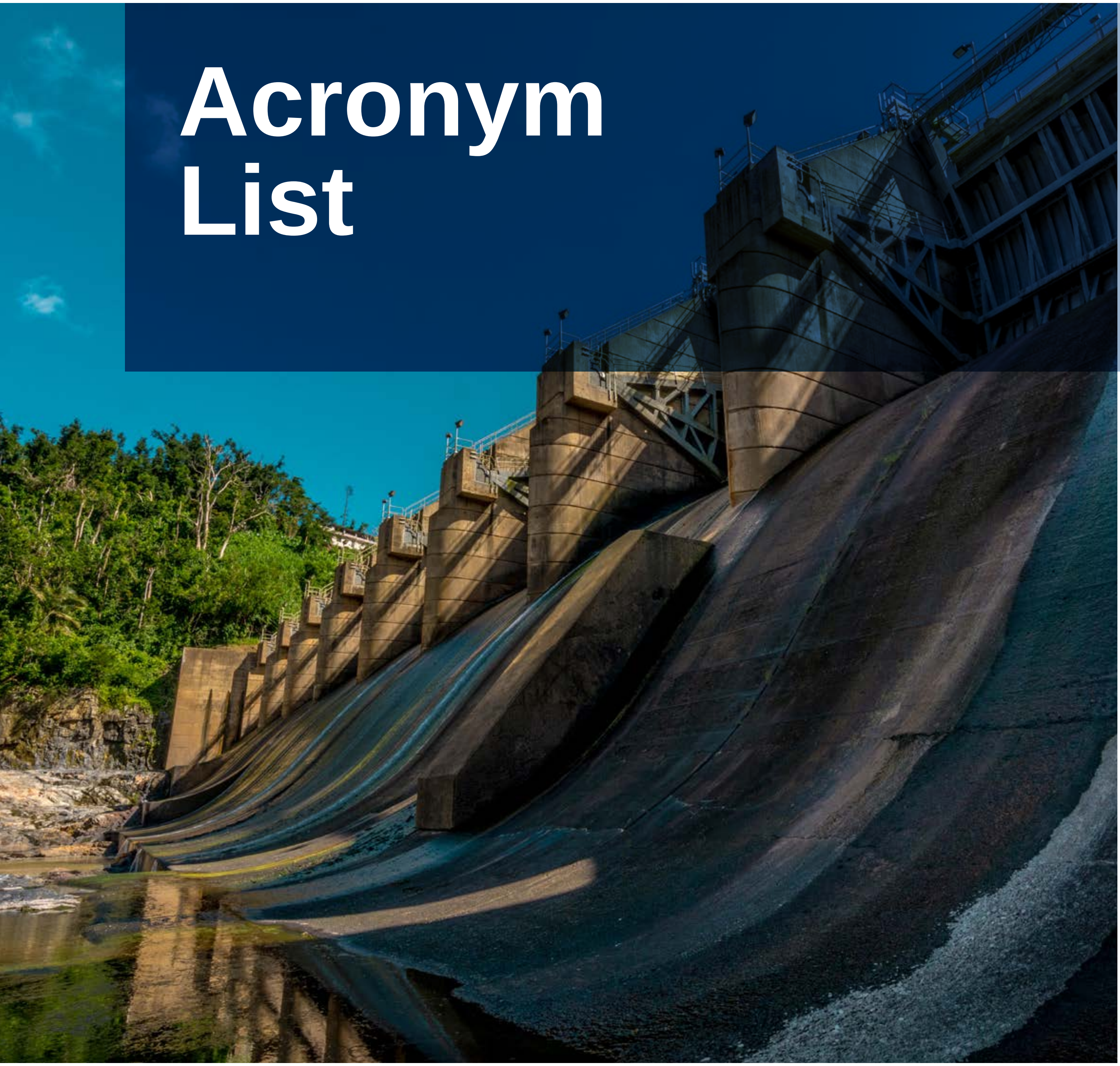
4 PATH FORWARD

DHS-IP and its National Laboratory partners leveraged more than a decade of experience conducting infrastructure assessments across the United States to implement this infrastructure interdependency methodology and develop this preliminary analysis for Puerto Rico. The infrastructure sector characterizations provide a high-level summary of system-level dynamics that affect infrastructure resilience across the island. The case studies provide a series of specific examples of how lifeline infrastructure asset operation affects critical manufacturing industries, food distribution networks, and broader community resilience. This material is intended to provide recovery planners with a foundational understanding of infrastructure interdependencies and how these could inform the development of unified solutions for long-term recovery planning.

With the extension to its mission assignment, DHS-IP will be able to continue its support to the IS-RSF and to perform additional interdependency analysis in support of the Infrastructure Sector Solutions Teams. This continuing support aligns with other assessments and planning that might support or benefit from collaboration. As an initial proposal, the following projects could commence immediately:

- **Analyzing additional geographic clusters:** Similar to the Manatí case study, additional geographic cluster analyses could be conducted in other areas where a density of industrial manufacturers are located. These geographic cluster analyses could also offer a deeper understanding of cumulative regional infrastructure requirements and capacities, and how industry-driven change could benefit broader community resilience.
- **Evaluating critical supply chains:** Previous sections highlighted several critical supplies that have been subject to interruptions due to infrastructure service reliability issues. An analysis focusing on port terminal capacities and supporting road transportation assets, for example, could alleviate the stress that high-demand infrastructure assets are place under and where additional capacities would benefit the greatest number of users.
- **Conducting sector-specific dependency and interdependency analyses:** Uunderstanding system-level dynamics involves complex modeling of individual systems and how these interact with other systems. Conducting system modeling would provide a deeper understanding of the behavior of the infrastructure, how these behaviors affect other systems, and how these behaviors affect infrastructure asset resilience.
- **Supporting essential services:** Beyond the private industry stakeholders that were the focus of this preliminary analysis, the same infrastructure interdependency assessment methodology could also be applied to other downstream users of focus. The infrastructure dependencies of hospitals, first responder facilities, or government facilities could be also analyzed to support long-term planning related to the essential services that these partners provide to communities.
- **Contributing to ongoing recovery planning efforts:** Multiple planning and analysis efforts are underway in Puerto Rico currently to inform federal investments in rebuilding infrastructure in Puerto Rico and ensure the future health of Puerto Rico’s economy. Significant activities include the long-term recovery planning process being led by HSOAC for FEMA; analysis by the U.S. Department of Energy to improve the resilience of the electric grid; collaboration with the National Institute of Standards and Technology on infrastructure planning for community resilience; and interagency coordination on investing FEMA public assistance resources and redevelopment funding from the U.S. Department of Housing and Urban Development. Additional interdependency analysis can inform these longer-term activities to help Puerto Rico build back better from the historic 2017 hurricane season.

Acronym List



ACRONYM LIST

ADT	Average Daily Traffic
ADTT	Average Daily Truck Traffic
BPD	Barrels per Day
BTU	British Thermal Units
CLEC	Competitive Local Exchange Carrier
CO	Central Office
CPE	Customer Premise Equipment
DHS-IP	U.S. Department of Homeland Security Office of Infrastructure Protection
DSL	Digital Subscriber Line
EEI	Electronic Export Information
EIA	Energy Information Administration
EMS	Emergency Medical Services
EPA	U.S. Environmental Protection Agency
FCC	Federal Communication Commission
FCO	Federal Coordinating Office
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
GDAC	Geospatial Data and Analysis Cell
GIS	Geographic Information Systems
HAZMAT	Hazardous Material
HSOAC	Homeland Security Operational Analysis Center
ICS	Industrial Control System
ILEC	Incumbent Local Exchange Carrier
IMPLAN	Impact analysis for PLANning
IS-RSF	Infrastructure Systems Recovery Support Function
IT	Information Technology
IV	Intravenous
IXP	Internet Exchange Point

JFO	Joint Field Office
kV	Kilovolts
kWh	Kilowatt-hours
LNG	Liquefied Natural Gas
MBGC	Motor Gas Blending Components
MGD	Million Gallons per Day
MHz	Megahertz
MTS	Maritime Transportation System
MW	Megawatts
NAICS	North American Industry Classification System
NDRF	National Disaster Recovery Framework
NEC	Not Elsewhere Classified
NERC	North American Electric Reliability Council
NGL	Natural Gas Liquid
OCIA	DHS Office of Cyber and Infrastructure Analysis
POP	Point of Presence
POTS	Plain Old Telephone Service
PPM	Parts per Million
PR	Puerto Rico (Highway)
PRASA	Puerto Rico Aqueduct and Sewer Authority
PRBI	Puerto Rico Bridge Initiative
PREC	Puerto Rico Energy Commission
PREPA	Puerto Rico Electric Power Authority
PRIIA	Puerto Rico Infrastructure Interdependency Assessment
PRPA	Puerto Rico Ports Authority
PSTN	Public Switched Telephone Network
PWS	Potable Water Service
RRAP	Regional Resiliency Assessment Program
RSF	Recovery Support Function

SCADA	Supervisory Control and Data Acquisition
SJTMA	San Juan Transportation Management Area
SMS	Short Message Service
SVP	Small Volume Parenteral
TEU	Twenty-foot Equivalent Unit
UE	End-user
USD	U.S. Dollars
VoIP	Voice over Internet Protocol
WMR	Water Management Region
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant