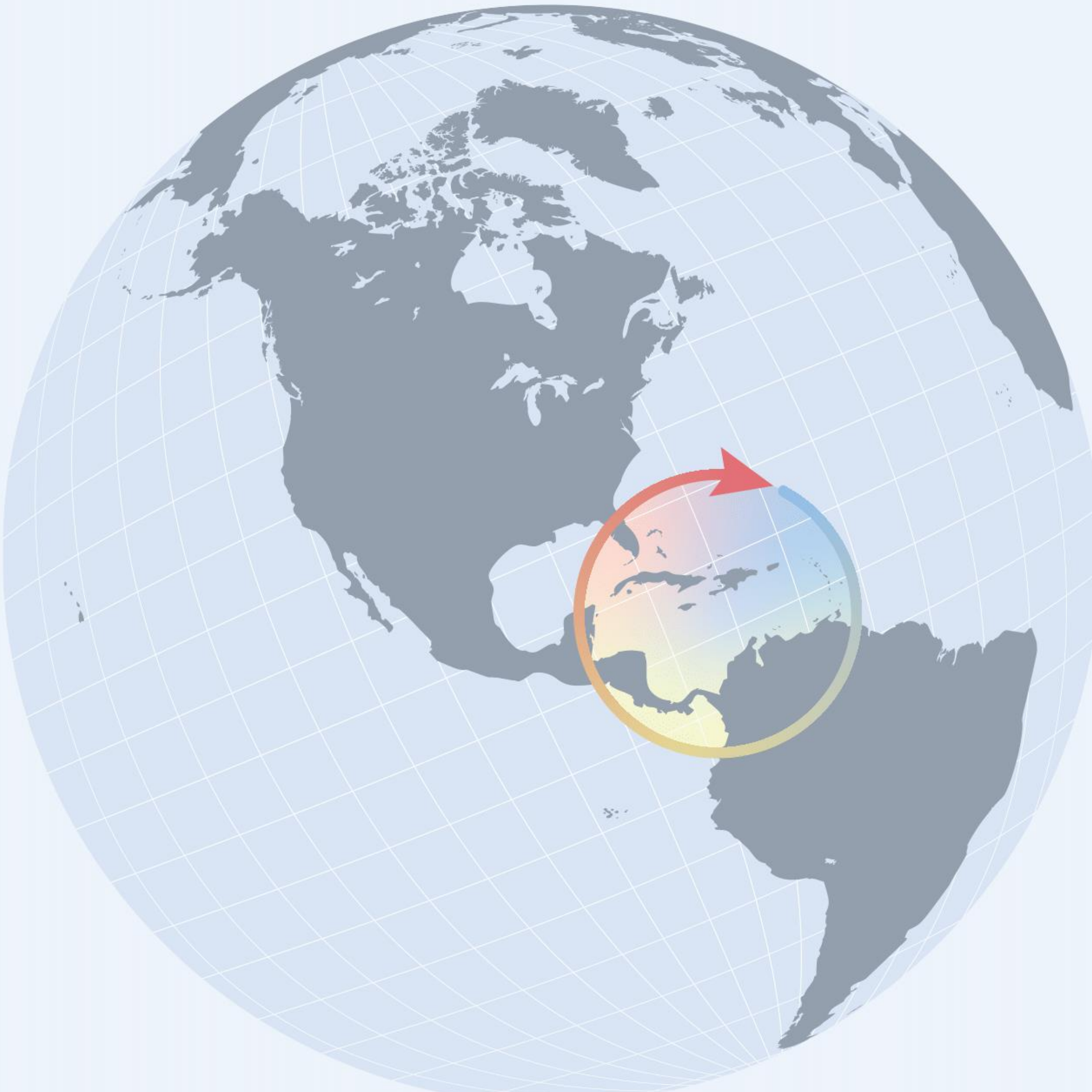
A BACKGROUND PAPER >> WATER SUPPLY AND SANITATION

360° Resilience

A Guide to Prepare the Caribbean for a New Generation of Shocks



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WORLD BANK GROUP

Revisiting Resilience in the Caribbean: Water Supply and Sanitation

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ACRONYMS

GDP	gross domestic product
lpcpd	liters per capita per day
NRW	nonrevenue water
SOE	state-owned enterprises
UNICEF	United Nations Children's Fund
WHO	World Health Organization
WSC	Water and Sewerage Corporation, The Bahamas
WSS	water supply and sanitation

$ = U.S. dollars

EXECUTIVE SUMMARY

This report provides guidance to policy and decision makers on holistic approaches to resilient services for water supply and sanitation (WSS) in the Caribbean, a high-risk region that struggles to manage natural disasters and other periodic shocks.

WSS services are critical for societies everywhere. They should be predictable, robust, and able to come back online quickly following a disaster or shock. However, WSS services in the Caribbean are particularly vulnerable to shocks. As discussed in section 2, sea-level rise, land-use changes, demographic shifts, pandemics, and other factors can hamper service delivery throughout the region. To increase resilience in the sector, a water service provider needs to identify the threats and vulnerabilities and address those posing the greatest risks.

This study concentrates on WSS services in 15 countries and 2 territories in the Caribbean. Access to basic service was found to be relatively high, with access to basic water supply at more than 90 percent for all but one of the countries—at 65.5 percent, Haiti is the exception. Access lags in basic sanitation but is accessible for more than 85 percent of the population of almost every country except Dominica (77.9 percent) and Haiti (34.7 percent).

WSS service providers in the region and the facilities they operate are identified in the table ES.1. These facilities include an array of infrastructure components, including water and wastewater treatment plants, desalination/reverse osmosis plants, aboveground and underground reservoirs, pumping stations, and wells—all of which need to be considered when assessing resilience of services. In addition, there are water distribution networks and sewage collection systems.

Most Caribbean WSS service providers are state-owned enterprises (SOEs) whose performance was analyzed in a regional benchmarking study conducted for this report and discussed in section 3. Underperforming SOEs were not able to provide coverage, the study found, for wastewater. Inadequacies were found in quality of service, operational efficiency, and financial sustainability. Most notable are the high levels of nonrevenue water (NRW)—or water that is lost between the point of production and the consumer—common with many SOEs. The problem is critical throughout the region, but it is especially salient in water-stressed countries.

The region experiences a host of natural hazards: hurricanes, floods, drought, earthquakes, tsunamis, volcanic eruptions, and landslides. Other threats include civil unrest and political and economic instability. These hazards are summarized in section 4, along with a discussion of how they can undermine WSS infrastructure. The World Bank has developed three frameworks, described in section 5, to assess the resilience of WSS systems and infrastructure. First, a *decision tree framework* provides an approach for water resource planning under deep uncertainty. A *utilities roadmap* offers a general approach to plan for and evaluate the impact of service interruptions and failure. Finally, the *design brief* focuses on the practical tools that make WSS infrastructure more resilient—with flood, drought, and high wind foremost in mind.

It is suggested that Caribbean nations undertake efforts to strengthen the resilience of the WSS sector. The experiences of several countries are covered in the latter half of section 5, accompanied by recommendations on practical steps countries can take to achieve greater resilience. Sound policies, strong institutions, and enforceable regulations are indispensable to cope with shocks, including the COVID-19 pandemic, and require a paradigm shift that emphasizes cross-sectoral preparedness implemented systematically at the national or regional levels. This shift also requires that governments, the private sector, and multilateral institutions invest in innovative solutions, particularly in the financing required to implement governance improvements and in programs that improve resilience at the utility level as well as at the infrastructure project level.

Table ES.1. Facilities operated by the water utilities analyzed in this report

Country / territory	Utility name	Plants			Reservoirs		Pumping stations	Wells
		Water treatment	Wastewater treatment	Desalination/ reverse osmosis	Above ground	Below ground		
Antigua and Barbuda	Antigua Public Utilities Authority	2	n.a.	5 RO	27	n.a.	n.a.	1
Bahamas, The	Water and Sewerage Corporation	1	1	n.a.	n.a.	n.a.	3	n.a.
Barbados	Barbados Water Authority	0	2	1 RO	24	6	17	22
Belize	Belize Water Services Limited	1	1	1	1	0	0	0
Dominica	Dominica Water and Sewerage Company Limited	4	1	0	4	0	3	0
Dominican Republic	Instituto Nacional de Aguas Potables y Alcantarillados	13	79	0	n.a.	n.a.	34	n.a.
Grenada	National Water and Sewerage Authority	26	0	2	3	n.a.	2	7
Guyana	Guyana Water Incorporated	24	1	n.a.	n.a.	n.a.	24	137
Haiti	Direction Nationale de l'Eau Potable et de l'Assainissement	n.a.	1	0	8	n.a.	3	n.a.
Jamaica	National Water Commission	10	97	0	2	1	3	307
St. Kitts and Nevis	St. Kitts Water Services Department	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	26
St. Lucia	Water and Sewerage Company	2	1	n.a.	n.a.	n.a.	3	n.a.
St. Vincent and the Grenadines	Central Water and Sewerage Authority	3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sint Maarten (Netherlands)	N.V. Gemeenschappelijk Elektriciteitsbedrijf Bovenwindse Eilanden	0	1	1 RO	3	n.a.	n.a.	n.a.
Suriname	N.V. Surinaamsche Waterleiding Maatschappij	1	0	n.a.	n.a.	0	11 production stations	n.a.
Trinidad and Tobago	Water and Sewerage Authority	1	2	0	4	0	n.a.	n.a.
Turks and Caicos Islands (U.K.)	Provo Water Company (distributor) Turks & Caicos Water Company Ltd. (producer)	1	n.a.	1 RO	0	2	2	n.a.

Source: Original compilation.

Note: The Turks & Caicos Water Company Ltd is owned and operated by the HAB Group.

n.a.= data not available.

1. INTRODUCTION

This report provides guidance to policy and decision makers on holistic approaches to resilient services for water supply and sanitation (WSS) in the Caribbean, a high-risk region that struggles to manage natural disasters and other periodic shocks.

The World Bank's Water Global Practice defines *resilience* as the ability of individuals, communities, institutions, businesses, and systems to survive, adapt, and thrive in the face of stress and shocks, and even to transform when conditions require it. Adaptability and robustness are two components of resilience. *Adaptability* is the capacity of a system to adjust in response to shocks and stress. *Robustness* is the capacity to withstand and recover without significant negative consequences.

Seventeen island countries and territories fall under the scope of this report (table 1.1). Except for the larger countries of Suriname, Guyana, the Dominican Republic, and Haiti, the sample is made up of small island states with average areas of 4,400 km^2.

When a shock hits a small island or coastal state, large segments of the population, businesses, and infrastructure are affected. Hurricanes, floods, and droughts mean that water infrastructure, owing to its proximity to rivers and coastlines, is especially vulnerable.

Table 1.1. GDP, population, and land area for selected countries and territories in the Caribbean

Countries	GDP per capita	Area (km^2)	Population (thousands)
Antigua and Barbuda	$16,900	440	96
Bahamas, The	$31,900	13880	386
Belize	$5,000	22970	383
Barbados	$16,300	430	287
Dominica	$7,000	750	72
Dominican Republic	$7,700	48670	10,627
Grenada	$11,900	340	111
Guyana	$4,600	214970	779
Haiti	$870	27750	11,123
Jamaica	$5,400	10990	2,935
St. Kitts and Nevis	$19,900	260	52
St. Lucia	$10,400	620	182
Suriname	$6,000	16820	576
Sint Marteen (Netherlands)	$15,400	34	41
Turks and Caicos Islands (UK)	$27,100	950	38
Trinidad and Tobago	$16,800	5130	1,390
St. Vincent and the Grenadines	$7,400	390	110

Source: WDI database.

The small populations of Caribbean countries limit their ability to handle shocks efficiently. Management of the multiple complex tasks involved in disaster response and recovery is challenging, and the region's emergency management and preparedness field is made up of only a small pool of professionals. In addition, Caribbean countries have small domestic markets and significant debt, which limit their borrowing capacity.

This report builds on knowledge and resilience frameworks developed by the World Bank and other organizations so WSS services can be accessed in low- and medium-income countries. As discussed later, developing a system-level *resilience plan* is to be differentiated from *resilient design* for an infrastructure component. This report draws on deep knowledge of these frameworks, highlighting those factors affecting the Caribbean region and how they can be addressed through resilient design.

2. WATER RESOURCE MANAGEMENT CHALLENGES IN THE CARIBBEAN

Countries in the Caribbean face several water-sector challenges (GWP 2014; CEPAL 2015). Small island developing states are vulnerable in this regard. They have limited land, extreme inflows (and outflows) of residents and tourists, expensive energy sources, limited skills, fragile economies, vulnerability to climate change, and constrained development opportunities. The region has a large geographical footprint—a body of water dotted with small and dispersed land masses—subject to climatic and demographic conditions that affect the water resources people depend on. Therefore, for small island developing states it would make sense to strengthen regional collaboration in ways that encourage countries to identify common threats and engage in more intraregional collaboration on knowledge exchanges and integrated water-management solutions. The region's larger islands (e.g., Jamaica and Hispaniola) and some continental countries (e.g., Belize, Guyana, and Suriname) face similar stresses and hazards, but their water resources are more plentiful.

Table 2.1 shows the annual availability of water per capita for the 15 countries in the sample. The range of total renewable water resources varies, with Guyana boasting almost 350,000 m^3/capita/year, to Barbados, which has faced water scarcity for decades.

The U.N. Food and Agriculture Organization defines (i) *water scarcity* as less than 1,000 m^3 of total renewable water resources per capita per year, and (ii) *water stress* as below 1,700 m^3 of total renewable water resources per capita per year.

Table 2.1. Availability of water resources for 15 Caribbean countries in m^3/capita/year

Country	1998–2002	2003–2007	2008–2012	2013–2017	Water stress/ scarcity?
Guyana	360,420	362,348	359,846	348,374	n/a
Suriname	204,969	194,232	184,323	175,719	n/a
Belize	82,876	72,822	64,538	57,993	n/a
Jamaica	4,015	3,899	3,809	3,744	n/a
Trinidad and Tobago	3,005	2,934	2,861	2,805	n/a
Dominica	2,865	2,819	2,776	2,706	n/a
Dominican Republic	2,661	2,473	2,314	2,183	n/a
Grenada	1,959	1,931	1,896	1,855	n/a
Bahamas	2,264	2,045	1,882	1,770	near water stressed
St. Lucia	1,877	1,793	1,716	1,678	water stressed
Haiti	1,588	1,468	1,364	1,278	water stressed
St. Vincent and the Grenadines	925	917	915	910	water scarce
Antigua and Barbuda	603	569	537	510	water scarce
St. Kitts and Nevis	515	482	456	434	water scarce
Barbados	295	290	284	280	water scarce

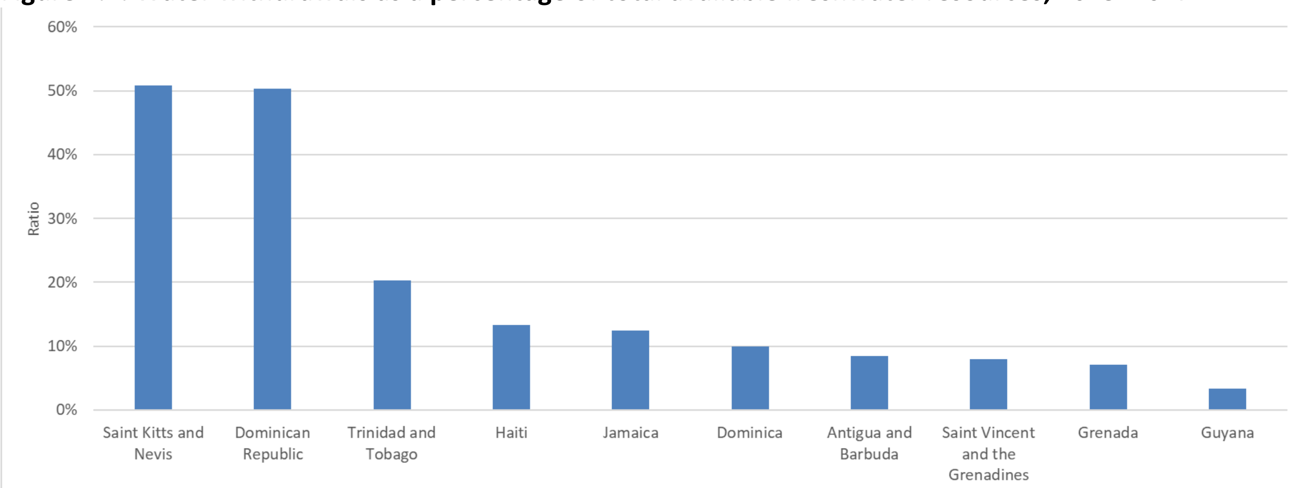
Source: AQUASTAT (FAO 2016).

n/a = not applicable.

Countries that have reached or exceeded the threshold of 1,700 m^3/capita/year include Haiti, Saint Vincent and the Grenadines, Antigua and Barbuda, Saint Kitts and Nevis, and Barbados. Jamaica, Trinidad and Tobago, Dominica, Dominican Republic, and Grenada are all nearing this threshold.

When water stress is measured by the ratio of freshwater withdrawal to available freshwater resources, some countries are using their water resources less sustainably than others (Figure 2.1). Notable is St. Kitts and Nevis, which at less than 500 m^3/capita/year faces absolute water scarcity. The country withdraws 50 percent of its freshwater resources, while Antigua and Barbuda takes out just 8 percent. Another country using water resources unsustainably is the Dominican Republic, which is just above 1,700 m^3/capita/year; like St. Kitts and Nevis, it extracts half of its freshwater.

Figure 2.1. Water withdrawals as a percentage of total available freshwater resources, 2013–2017



Source: https://www.sdg6data.org.

Note: Some countries are not included in the graph for lack of data.

These metrics highlight the urgent need for the region to adopt strong water policies to balance water demands and gain resilience to climate change under conditions of dwindling freshwater resources. Policies, interventions, and investments that promote efficiency, valuation, and reuse should be a priority.

Several obstacles hinder the management of water resources in the region. To begin with, governments lack formal mechanisms for the cross-sector collaboration needed to address water scarcity and resilience. Drinking water, irrigation, drainage, sewerage, emergency management, and urban development cannot be coordinated without such mechanisms. In addition, water utilities tend to be state-owned enterprises for which managing water resources may take a back seat to their utility functions. Lax management can lead to deteriorating streams and rivers exhibiting higher peak flows during storms and poorer water quality as land use changes from natural cover to built-up urban areas and land cultivated for food production (GWP 2014).

While access to potable water has improved through network expansion, the networks need upgrades, maintenance, and rehabilitation. Inattention to infrastructure results in significant water losses known as “nonrevenue water.” Between 24 and 63 percent of potable water never reaches the customer after leaving the point of production (Burdescu et al., 2020). These losses also lead to inefficient energy consumption for transporting water that is ultimately lost to leakage, metering lapses, or theft. The wasted energy has been estimated to be as much as 30 percent of the operational budget of water utilities. This inefficiency is critical, considering the region’s debt levels and dependence on imported fossil fuels. Nonrevenue water and energy inefficiencies, combined with tariffs that are below cost recovery, cut into the funds needed for investment as well as for operation and maintenance (CEPAL

2015). Even when water availability is sufficient, many countries face deficits owing more to infrastructural and governance shortcomings than to scarce water resources.

Wastewater management is also a major problem, caused by growing populations, poor or nonexistent urban planning, and weak governance. Many countries experience seasonal influxes of tourists, making the task of managing the additional volume of wastewater more difficult. By some estimates, 85 percent of the region's wastewater is discharged, untreated, into the Caribbean Sea—a practice that threatens not only public health and the marine environment but also the region's long-term economic prosperity (CEPAL 2015).

Other factors also come into play. Storm surges, for example, overtop coastal barriers. The ever-more-frequent tropical cyclones threaten to inundate coastal freshwater aquifers and increase salinization in them. In addition, aging water infrastructure is becoming more vulnerable to damage from floods and high winds.

3. WATER SUPPLY AND SANITATION SERVICES IN THE CARIBBEAN

Every component of the water sector—irrigation, agriculture, water resources management, rural water supply and sanitation, and urban utilities—is being affected by the challenges described in the previous section. This report focuses, however, on water supply and sanitation (WSS) services, critical lifelines for society. WSS services must be predictable, robust, and able to bounce back quickly after a failure. Furthermore, WSS provision is vital during shocks—both the response and recovery stages. Vulnerable to climate change, especially compared with other sectors, WSS services are now subject to droughts that come more often and last longer than they did in the past. In addition, floods are more frequent, and significant shifts are expected in precipitation patterns, sea levels, and other climate-related phenomena. All these affect the region's resilience—especially sequential and protracted disasters.

The COVID-19 pandemic has underscored that WSS services are crucial in multipronged responses to slow the spread of the virus, from behaviors to infrastructure—behaviors like handwashing to infrastructure that supplies clean water to hospitals, frontline workers, and the general population. Moreover, public health workers can now test sewage for the presence of COVID-19 and other communicable diseases in the population. This public health surveillance and early-warning tool highlights yet another valuable function of a robust water infrastructure. The World Bank has identified activities that can mitigate the impacts of COVID-19, better preparing countries in the likely event of future pandemics. Behavior-change communications regarding hygiene and water saving would be one alteration. Also important is information on (i) emergency water provision; (ii) water, sanitation, and hygiene in school strategies; (iii) better continuity of services; and (iv) operational and financial sustainability, among others.

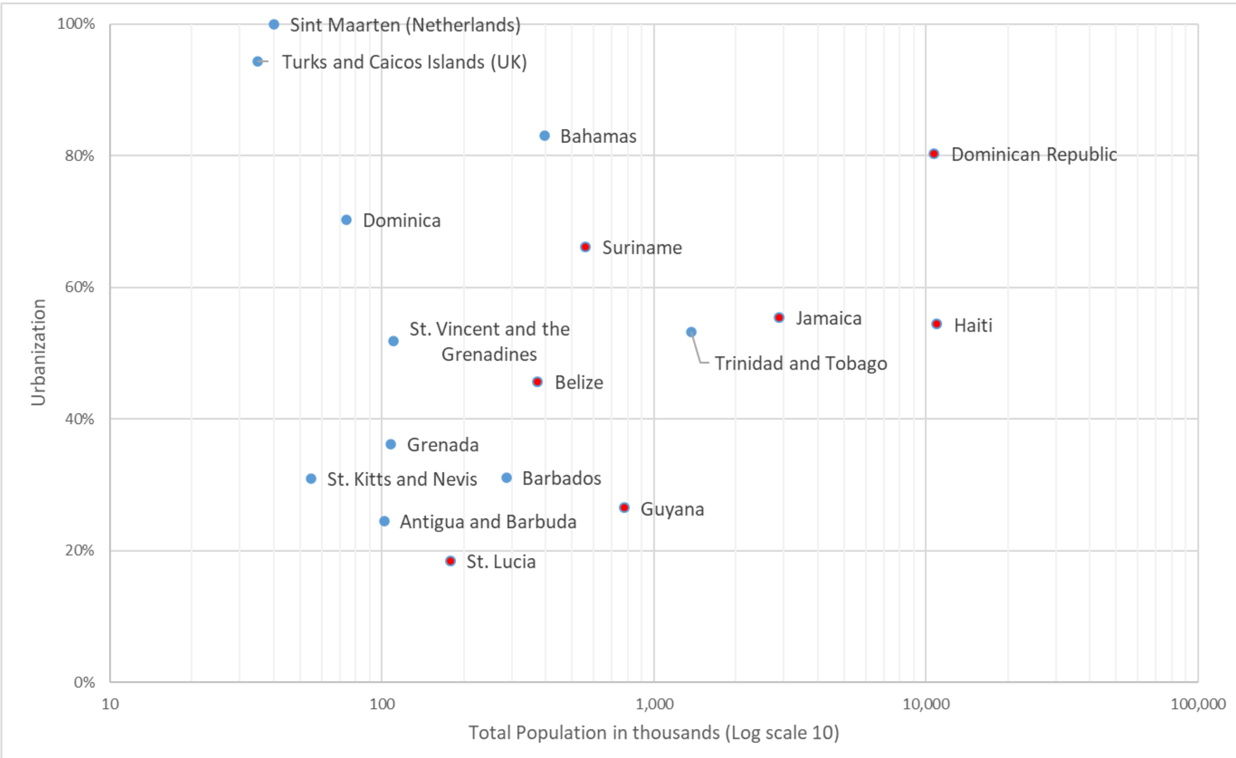
Because WSS services are so critical, they need to be resilient to natural hazards and shocks, which, as the report emphasizes, will intensify with climate change. To improve resilience, water providers must first attain a stable baseline and improve existing services (Hallegatte, Rentschler, and Rozenberg 2019). Providers need to identify threats and vulnerabilities and address those that create the most significant risk, which in many cases can be done simply by expanding to underserved areas or improving the provider's financial situation.

The financial health of a water service provider is as fragile as the system is vulnerable to external factors because any interruption in service, and the associated costly repairs, reduce revenue to the provider. Events like natural disasters, large population shifts to cities, pandemics, land-use changes that degrade the quality and quantity of surface waters (e.g., forest clearing, mining, poor agricultural practices), and similar shocks all have a direct impact on the income of the water service provider.

3.1. DEMOGRAPHICS

Urban-rural population breakdowns for the Caribbean region vary widely by country. Service provision for largely urbanized Caribbean nations is different from service in countries characterized by rural settlements. Service provision reflects the region's uneven population patterns—from sparsely populated countryside to densely populated cities. Infrastructure that is cost-effective in a populous and largely urbanized country is not cost-effective in less-populous countries dotted with homesteads, farms, and villages. On average, the Caribbean is 54 percent urban. In St. Lucia, 82 percent of the population lives in rural areas. In contrast, the two territories with the highest proportion of urban residents are Sint Maarten (100 percent) and Turks and Caicos (94 percent). Additionally, total populations vary greatly. The Dominican Republic and Haiti, on the island of Hispaniola, are each home to more than 10 million people. As shown in Table 1.1, most of the countries and territories have populations under 1 million—with Turks and Caicos Islands, Sint Maarten, St. Kitts and Nevis, and Dominica all hosting fewer than 100,000. Figure 3.1 shows the total population of each country or territory, as well as the extent of urbanization. Keep in mind that, as shown in Figure 2.1 and table 2.1, total renewable water resources per capita are declining with population growth across the Caribbean.

Figure 3.1. Total population vs. urbanization in countries and territories analyzed in this report



Source: Original compilation.

3.2. ACCESS TO WSS SERVICES

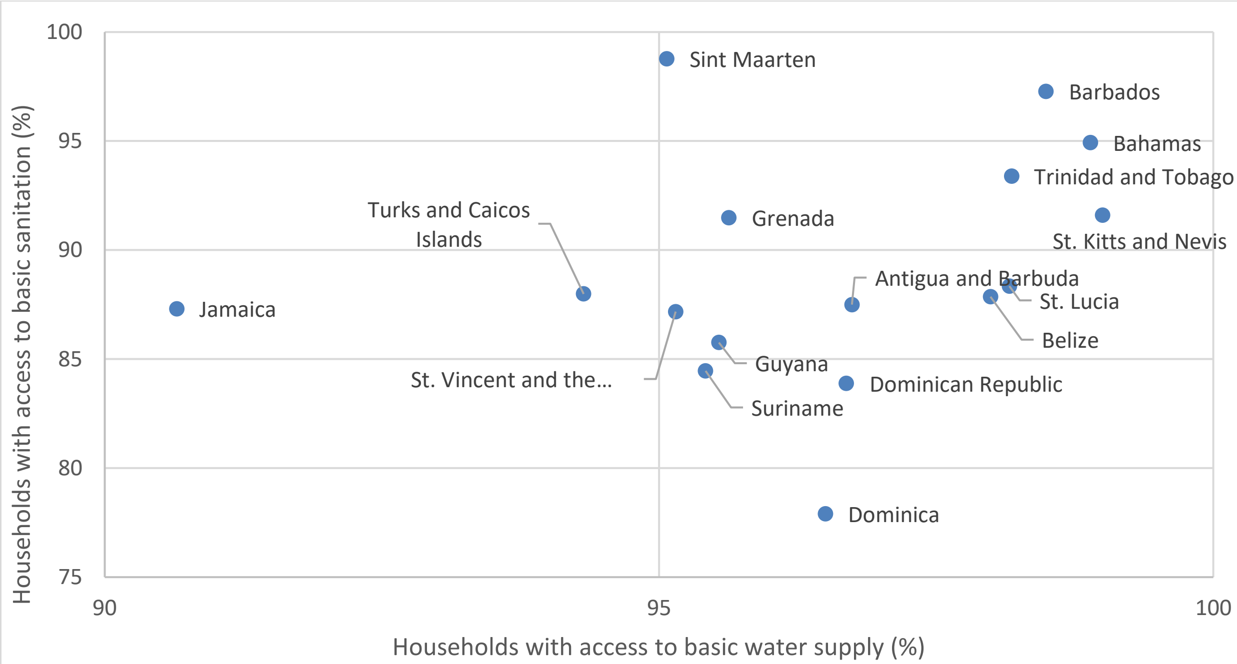
This report draws on publicly available data from the UNICEF/WHO Joint Monitoring Programme on the region's rates of access to WSS services. Local service providers have more detailed information, and utilities should use the best and most appropriate local data to develop their own resilience plans.

Access in the Caribbean to basic WSS services is relatively high, with most countries ranking above 80 percent for both water supply and sanitation.[1] Basic water supply has access rates of over 90 percent for all countries, except for Haiti, which stands at 65.5 percent (Figure 3.). Access to sanitation is lower, but, still, it is more than 85 percent for almost all countries except Dominica, at 77.9 percent, and Haiti, at just 34.7 percent. These Caribbean countries are on par with Latin America, whose regional average for basic sanitation is 91.7 percent, and 97.7 percent for basic water supply. Data that capture the quality of services (measured as "safely managed" by the SDG guidelines) are not available for the Caribbean

1 This means access to drinking water from an "improved source," provided access requires no more than 30 minutes of travel time, to and from, including time waiting in line (https://washdata.org/monitoring/drinking-water).

nations studied here—except for Grenada, which reports 87 percent for "safely managed" water supply.[2]

Figure 3.2. Fraction of households with access to basic water supply (2017)



Source: UNICEF/WHO Joint Monitoring Programme.

Note: Haiti is not shown. Its rate of access is 65.5 percent.

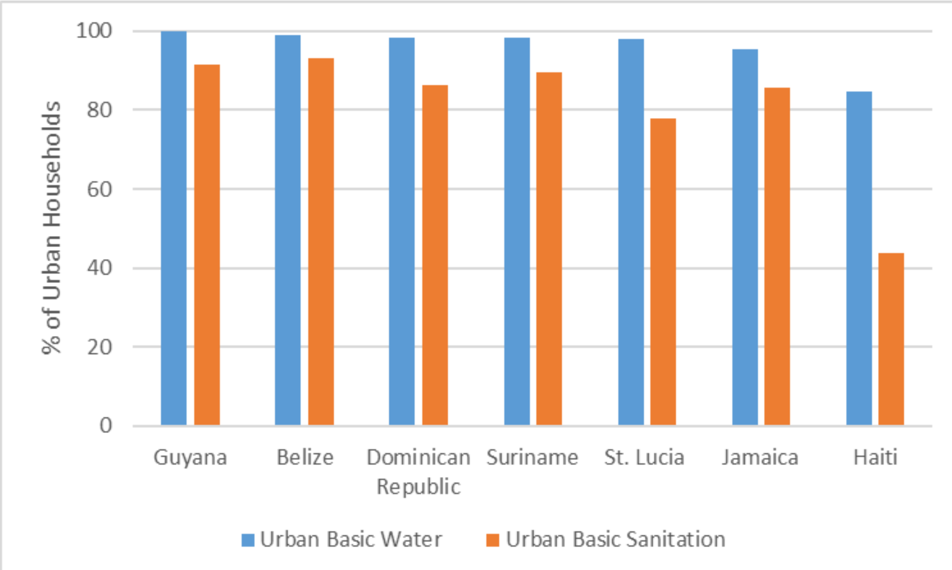
The delivery mechanisms for WSS services vary between urban and rural areas. Statistics are available only for the countries shown in figures 3.3 and 3.4, not for the complete set of countries and territories analyzed in this report. Urban services are mostly centralized and traditionally provided by utilities; rural areas tend to be decentralized and often managed at the community or household level. The different delivery mechanisms result in different needs when the goal is improving resilience. While it is important to provide resilient WSS services to rural communities, each community may need to be analyzed separately. Nevertheless, the installation of basic infrastructure is the first step toward providing resilient WSS services. For example, piped water supply, where feasible, along with rainwater harvesting and well-constructed onsite sanitation facilities, produce vast quality-of-life improvements for beneficiaries. Urban WSS services are provided by centralized utilities and should be evaluated and improved as a system.

Data on rural and urban access to basic water and sanitation are scarce in the Caribbean, especially in comparison with national averages. Where subnational data do exist, however, they demonstrate that residents in rural areas have higher rates of access to basic water services than to sanitation. Even in Haiti, where the national average is 65.5 percent for basic water supply, more than 80 percent of urban households report access to basic water supply, compared with just over 40 percent in rural areas. More surprising is the Dominican Republic, where just over 70 percent of rural households have access to basic sanitation.

2 Drinking water from an improved water source located on premises, available when needed, and free from contamination by fecal matter and priority chemicals (https://washdata.org/monitoring/drinking-water).

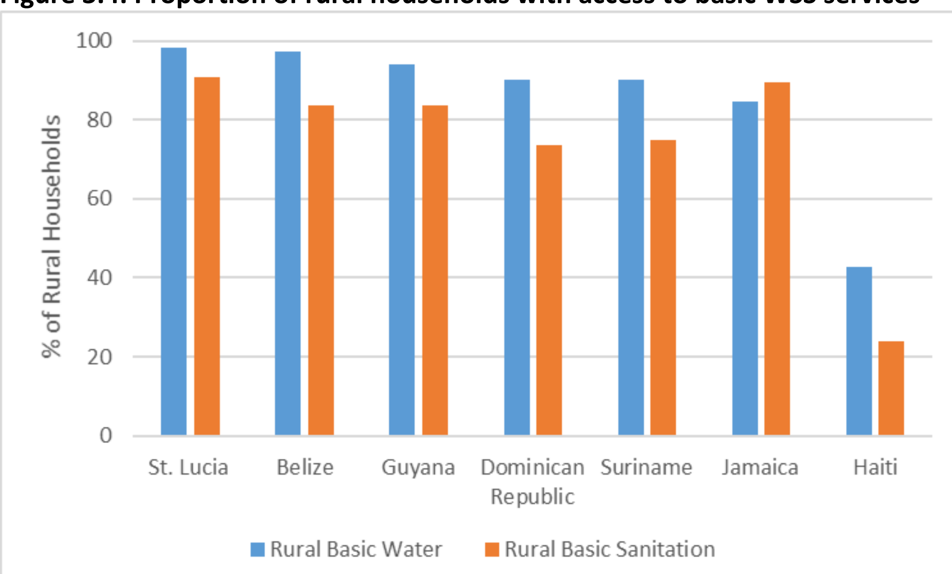
Continued urbanization is likely in the region, and urban WSS services must plan to reach more of the population with resilient services; therefore, the strain of urbanization on service providers must be taken into consideration early.

Figure 3.3. Proportion of urban households with access to basic WSS services



Source: UNICEF/WHO Joint Monitoring Programme.

Figure 3.4. Proportion of rural households with access to basic WSS services



Source: UNICEF/WHO Joint Monitoring Programme.

3.3. TYPES AND LEVELS OF INFRASTRUCTURE

The WSS service providers in the countries and territories surveyed in this report own and operate an array of infrastructure components, including water and wastewater treatment plants, desalination/reverse osmosis plants, aboveground and underground reservoirs, pumping stations, and wells, all of which need to be considered in assessing the resilience of services (table 3.1). Water distribution networks and sewage collection systems must also be assessed.

Table 3.1. Facilities operated by the water utilities analyzed in this report

Country / territory	Utility name	Plants			Reservoirs		Pumping stations	Wells
		Water treatment	Wastewater treatment	Desalination/ reverse osmosis	Above ground	Below ground		
Antigua and Barbuda	Antigua Public Utilities Authority	2	n.a.	5 RO	27	n.a.	n.a.	1
Bahamas, The	Water and Sewerage Corporation	1	1	n.a.	n.a.	n.a.	3	n.a.
Barbados	Barbados Water Authority	0	2	1 RO	24	6	17	22
Belize	Belize Water Services Limited	1	1	1	1	0	0	0
Dominica	Dominica Water and Sewerage Company Limited	4	1	0	4	0	3	0
Dominican Republic	Instituto Nacional de Aguas Potables y Alcantarillados	13	79	0	n.a.	n.a.	34	n.a.
Grenada	National Water and Sewerage Authority	26	0	2	3	n.a.	2	7
Guyana	Guyana Water Incorporated	24	1	n.a.	n.a.	n.a.	24	137
Haiti	Direction Nationale de l'Eau Potable et de l'Assainissement	n.a.	1	0	8	n.a.	3	n.a.
Jamaica	National Water Commission	10	97	0	2	1	3	307
St. Kitts and Nevis	St. Kitts Water Services Department	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	26
St. Lucia	Water and Sewerage Company	2	1	n.a.	n.a.	n.a.	3	n.a.
St. Vincent and the Grenadines	Central Water and Sewerage Authority	3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sint Maarten (Netherlands)	N.V. Gemeenschappelijk Elektriciteitsbedrijf Bovenwindse Eilanden	0	1	1 RO	3	n.a.	n.a.	n.a.
Suriname	N.V. Surinaamsche Waterleiding Maatschappij	1	0	n.a.	n.a.	0	11 production stations	n.a.
Trinidad and Tobago	Water and Sewerage Authority	1	2	0	4	0	n.a.	n.a.
Turks and Caicos Islands (U.K.)	Provo Water Company (distributor) Turks & Caicos Water Company Ltd. (producer)	1	n.a.	1 RO	0	2	2	n.a.

Source: Original compilation.

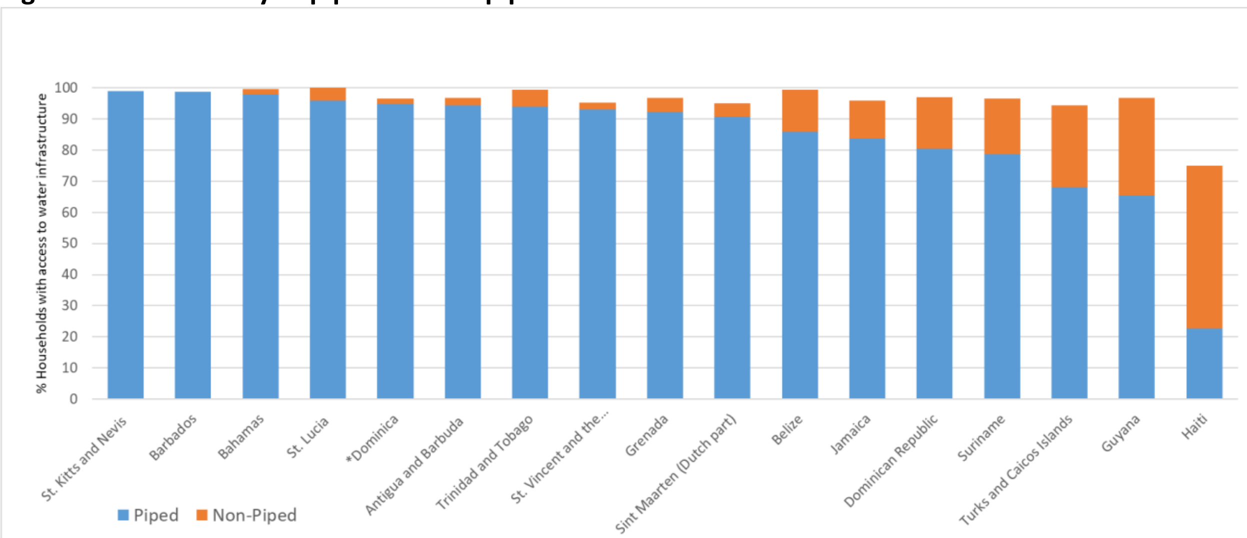
Note: The Turks & Caicos Water Company Ltd is owned and operated by the HAB Group.

n.a.= data not available.

Although basic WSS services reach most of the region's population, services are provided in several different ways and with different levels of quality. The great majority of the urban population enjoys basic services, but those without access to piped water and sanitation are receiving lower-quality services. This deficiency underscores the need to develop specific service improvements in a resilience plan that carefully considers the local context. Furthermore, while a few broad conclusions can be gleaned from these data, it is not advisable to compare the resilience of specific countries or utilities.

Resilience plans must be based on appropriate, site-specific analysis. Piped water can be accessed in more than 80 percent of urban households in most countries and territories (figure 3.5), with notable shortfalls in Haiti, Guyana, and Turks and Caicos Islands, where lack of access to piped water for segments of the population may make them less resilient to shocks.

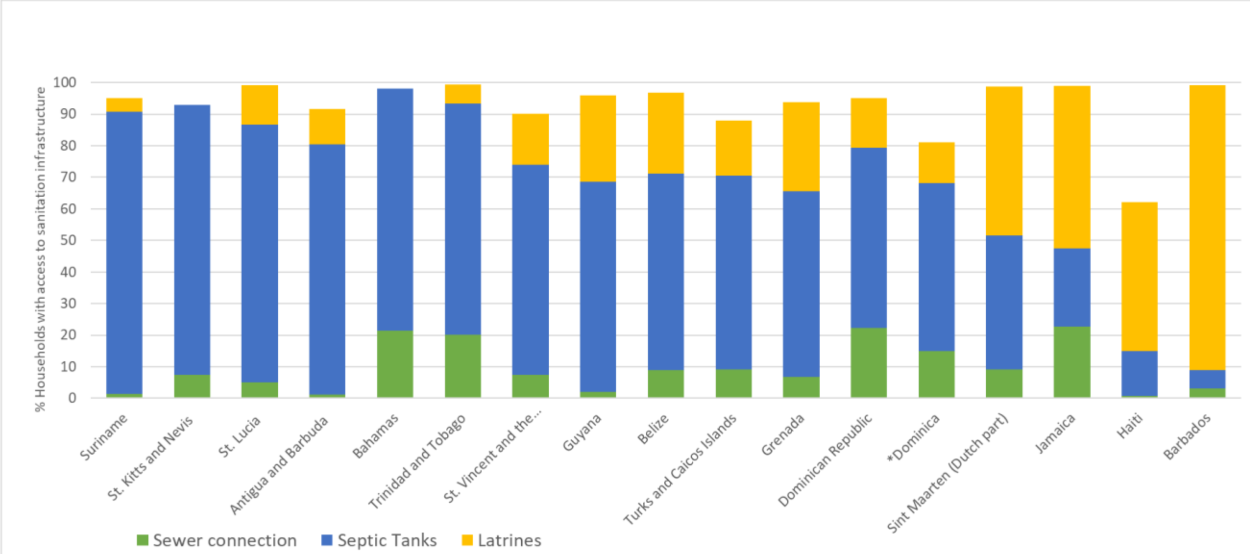
Figure 3.5. Availability of piped and nonpiped water service to urban households in 2017



Source: UNICEF/WHO Joint Monitoring Programme.

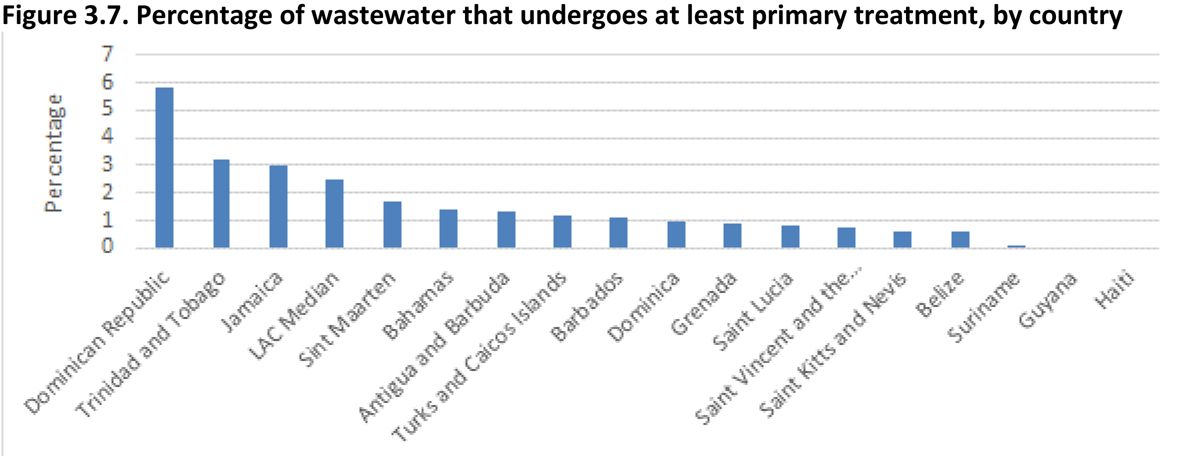
Sanitation services exhibit a similar pattern, with piped sewerage services generally providing higher-quality service than pit latrines or septic tanks. Again, service varies significantly from one country to the next, and indeed from one utility to the next. The breakdown of the types of infrastructure that give residents access to those services provides insight into the resilience of existing infrastructure. For example, while on-site sanitation is a vast improvement over open defecation, pit latrines and septic tanks pose contamination issues during floods and heavy rain, not to mention groundwater and surface water contamination during normal periods. A much lower proportion of residents have access to sanitation services through sewerage connections than by other means (figure 3.6). Even in the countries with the largest fraction of sewer connections—Jamaica, the Dominican Republic, The Bahamas, and Trinidad and Tobago—those connections still make up less than 25 percent of the total sanitation service in urban areas. Only a tiny fraction of wastewater in the region undergoes primary treatment (figure 3.7). These inequities in access to sewerage and wastewater treatment highlight the expansion opportunities for sewerage services. But as they take the preliminary steps toward a resilience plan, policy makers must strike a balance between achieving full access and expanding resilient sewerage services.

Figure 3.6. Availability of piped sewerage to urban households in 2017



Source: UNICEF/WHO Joint Monitoring Programme.

Figure 3.7. Percentage of wastewater that undergoes at least primary treatment, by country



Source: Environmental Performance Index, https://epi.yale.edu/downloads.

LAC = Latin America and Caribbean.

4. HAZARDS AND VULNERABILITIES THREATENING WATER SUPPLY AND SANITATION SERVICES

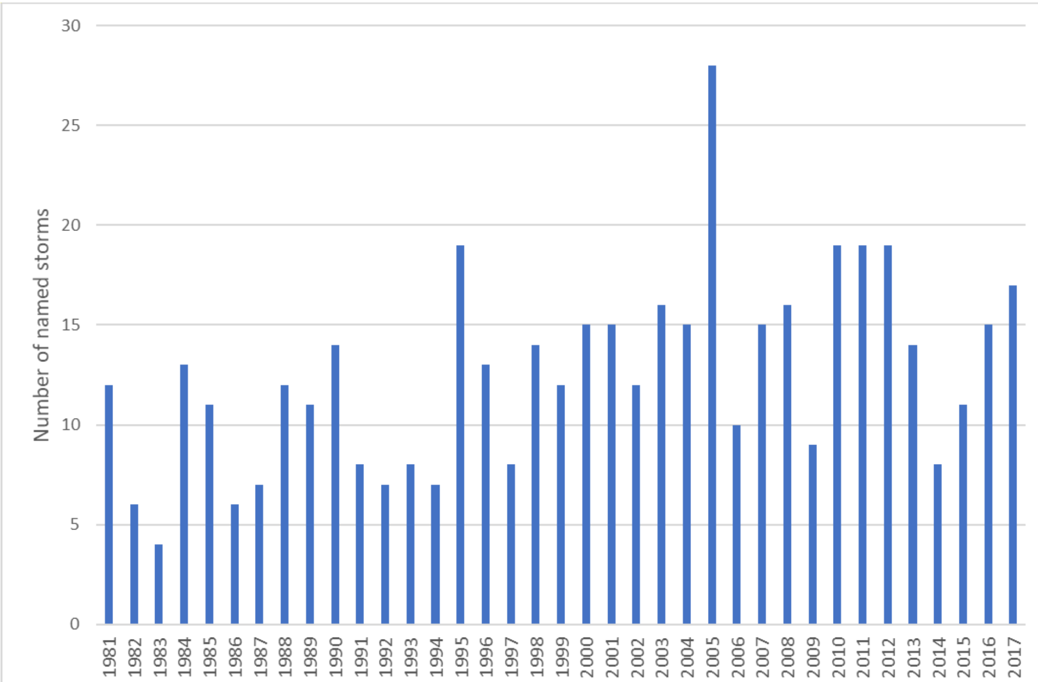
This section describes the main hazards threatening the Caribbean, as well as the potential damage and attendant service disruptions they can cause to water supply and sanitation (WSS) systems and services.

4.1. HURRICANES

In the Caribbean, subtropical and tropical storms and hurricanes are the most common high-wind events. Western hemisphere tropical cyclones are classified by the Saffir-Simpson hurricane wind scale into five categories, numbered 1 to 5, each step up indicating increased severity (Schott et al. 2019). Each category is characterized by a sustained wind speed range. Category 3 and above involve wind speeds greater than 178 km/h and are considered major hurricanes, although lesser hurricanes still can cause considerable damage.

Storms that reach wind speeds of 63 km/h are assigned a name. Figure 4.1 shows the annual occurrence of named storms between 1981 and 2017. The average number of these events is 13 annually, 6 of which are hurricanes, 3 of them major (Jarrell et al. 2001).

Figure 4.1. Occurrence of named Atlantic storms between 1981 and 2017
Subtropical storms, tropical storms, and hurricanes



Source: http://www.stormfax.com/huryear.htm

Locally, wind speeds increase with terrain elevation. For instance, wind gusts are stronger over mountain ridges and cliffs, a common occurrence in the Caribbean. Also, tropical cyclones intensify with warm water temperatures, availability of moisture, and lack of land friction—for example in small islands with low-lying terrain.

Water infrastructure is vulnerable to this hazard to the extent it is exposed to high-velocity winds. For example, elevated water storage tanks could collapse during a high-wind event, whereas underground tanks may not be in danger. High winds can destroy buildings that house critical functions at treatment plants. Buried water lines, hydrants, and sewers will break if winds destroy nearby buildings. This type of damage can occur anywhere in the service area. In addition, damage to overhead power lines, substations, and other electric grid infrastructure often results in a loss of power to water utilities. Wind can disperse chemicals and other supplies. Windborne debris can strike and damage various components. The debris left by a high-wind event can clog collection systems. High winds can also endanger the health and safety of utility workers. In rural areas, high winds can destroy rooftops, where rainwater is often collected for domestic use, and damage basic sanitation facilities. Wind damage to roads and bridges hinders access to rural communities for the supply of emergency water.

Because tropical cyclones can produce storm surges in low-lying areas, high winds can have an impact on flooding. The damage sustained by an infrastructure component can be caused by both hazards combined.

Ideally, all structures built as part of new projects are designed to meet industry-standard wind codes, found, for example, in the International Construction Code (ICC 2018). But these standards require knowledge of peak-gust speeds, which proceed from statistical analyses of geographically based records of wind speed. This information may not be available everywhere in the Caribbean.

Implementation and enforcement of building codes is essential to improving the resilience of new infrastructure for water supply and sanitation. Existing infrastructure can often be retrofitted to meet code specifications. Proper application of the construction code is most essential in large infrastructure design for urban areas. But smaller infrastructure projects also require the careful application of building codes. Therefore, it is essential to develop the proper institutional support for code application.

It is likely that climate change will increase the severity of high-wind effects. Holland and Bruyère (2014) conducted a study that revealed significant regional and global increases in category 4 and 5 hurricanes, which they attributed to global warming. Because water infrastructure components are likely to become more vulnerable, codes and designs should keep up with recent high-wind trends rather than rely solely on historical records.

Focus on the the Bahamas

The Bahamas includes 700 islands and keys; 17 islands house most of the population. The maximum elevation is about 65 meters above sea level. Groundwater is shallow and is the sole source of drinking water. Shallow aquifers are susceptible to saltwater intrusion from storm surges.

In early September 2019, Hurricane Dorian hit the Bahamas as a category 5 hurricane, causing a surge that reached 10 meters and leached saltwater into underlying aquifers. On Grand Bahama, the salinity at the well fields was 114–171 mg/L before Dorian. Salinity levels jumped to 3,000–4,800 mg/L after the hurricane (WSC 2019).

The wells serve a population of 55,000 people on Grand Bahama. Several months after Dorian, the population was still struggling to obtain fresh water. The utility company drilled new wells on higher points on the island to gain access to freshwater.

3.4. URBAN SERVICE PROVIDERS: AN ASSESSMENT

Most urban service providers in the Caribbean are state-owned enterprises (SOEs). A regional benchmarking study analyzed the performance of 14 such SOEs (Table 2.2), identifying their strengths and weaknesses (Burdescu et al., 2020). Of these, 11 are in the 17 countries and territories analyzed in this report.

The objective of the study was to inform the utilities about performance and governance gaps and how SOEs might improve service to their customers. The study considered water utilities in the following jurisdictions: Antigua, The Bahamas, Barbados, Belize, the Cayman Islands, Curaçao, Dominica, Grenada, Guyana, Jamaica, St. Kitts and Nevis, Puerto Rico, St. Lucia, Suriname, and Trinidad and Tobago. Case studies on Belize, Dominica, Grenada, Jamaica, and Saint Lucia were carried out.

Table 2.2. Urban utilities in the regional benchmarking study

Utility	Acronym	Country or territory	Water stressed or scarce?

Antigua Public Utilities Authority	APUA	Antigua and Barbuda	Water scarce
Aqualectra, Curaçao	AQUA	Curaçao	
Barbados Water Authority	BWA	Barbados	Water scarce
Belize Water Services Limited	BWS	Belize	
Central Water and Sewerage Authority, St. Vincent and the Grenadines	CWSA	St. Vincent and the Grenadines	Water scarce
Dominica Water and Sewerage Company Limited	DOWASCO	Dominica	
Guyana Water Incorporated	GWI	Guyana	
National Water and Sewerage Authority, Grenada	NAWASA	Grenada	
Puerto Rico Aqueduct and Sewer Authority	PRASA	Puerto Rico	
Public Utilities Commission, Belize	PUC	Belize	
Surinaamsche Waterleiding Maatschappij, Suriname	SWM	Suriname	
Water and Sewerage Authority, Trinidad. and Tobago	WASA	Trinidad and Tobago	
Water and Sewerage Company, St. Lucia	WASCO	St. Lucia	Water stressed
Water and Sewerage Corporation, The Bahamas	WSC	The Bahamas	Near water stressed

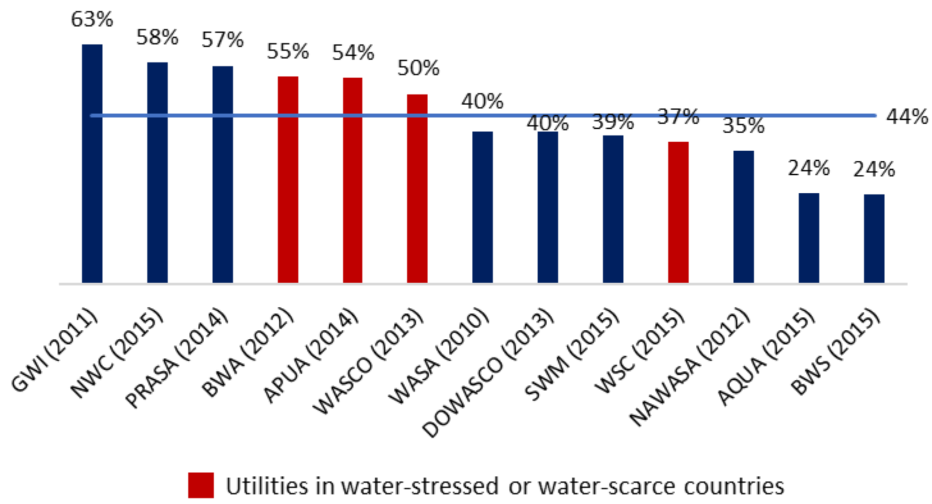
Source: Original compilation.

The benchmarking study determined that many SOEs are underperforming. Their underperformance affects their ability to provide adequate coverage (especially for wastewater), the quality of their service, their operational efficiency, and their financial sustainability. NRW is a noteworthy aspect of this lackluster performance common among SOEs. NRW is treated and sent on its way but then lost or unaccounted for through leaks, theft, or metering inaccuracies. These losses impair the financial capacity of utilities to provide continuous services. Poor service follows as a matter of course. NRW also makes it harder for utilities to deal with droughts or to restore services after a disaster. The NRW values of the 14 SOEs range from a high of 63 percent (Guyana) to a low of 24 percent (Belize) (figure 3.8).

For a given water utility, the optimal NRW value depends on the cost of water production. For example, water from desalination is more expensive to produce than water from a surface source. In general, however, a water utility with NRW greater than 30 percent should take steps to reduce this value. Therefore, all benchmarked utilities, particularly those in water-stressed or water-scarce Barbados, Antigua and Barbuda, St. Lucia, and The Bahamas, would benefit from efforts to reduce their NRW. Section 5.3 discusses building resilience by reducing NRW.

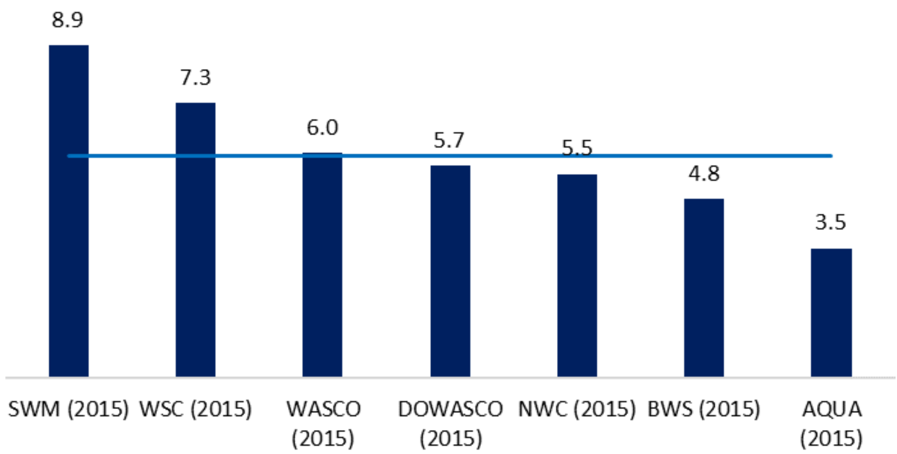
Another aspect dealt with in the benchmarking study is the efficiency of the labor force, which represents a large component of utilities' operation and maintenance expenditures. One performance indicator is the number of employees per thousand connections. The results suggest that some of these water utilities are overstaffed (figure 3.9). The indicator ranges from the least efficient ratio of 8.9 in Suriname to the most efficient of 3.5 in Curaçao. As a reference, Kingdom and Tynan (2002) suggest a target of five staff per thousand connections, which is based on the top 25 percent of water utilities in high-income countries.

Figure 3.8. Nonrevenue water for utilities in the regional benchmarking study



Source: Burdescu et al. (2020).

Figure 3.9. Number of utility employees per thousand connections for a subset of utilities



Source: Burdescu et al. (2020).

The benchmarking study also analyzed access to WSS services, quality of service, operating performance, financial performance, and affordability and tariffs. For detailed information, the reader is referred to Burdescu et al. (2020).

Salient findings of the study are the following:

- The utilities in the region should increase access to piped water.
- Collection and treatment of wastewater are severely lacking.
- Utilities need to establish reliable income streams to cover costs and invest in their systems.
- Data management and recordkeeping are deficient—yet indispensable for assessing performance.

- Countries should have clear baselines on performance and establish multiyear targets for increasing quality of service and operating efficiency and agree on sources of funding to cover the associated costs.
- Countries should seek to increase the transparency and accountability of SOEs.

While access to basic water supply services is generally high in the region, there remain segments of the population that lack services, thus greatly increasing their vulnerability to shocks. These vulnerabilities are magnified by inadequate management of water resources, with some countries already facing serious constraints on freshwater availability as noted earlier. Urban populations largely benefit from piped water services, with some notable exceptions such as in Haiti, Guyana, and the Turks and Caicos Islands.

Access to sewerage and wastewater treatment, in contrast with water supply, is significantly lacking across the region, posing risks to water resources and human health and increasing the vulnerability of urban populations (particularly during floods).

The strength and efficiency of WSS providers varies widely across the region and will influence their ability to respond and recover from different shocks.

4.2. FLOODS

Tropical cyclones in the Caribbean cause flooding in two ways: seaborne events flood coastal areas after storm surges; land-borne events arise from intense rainfall that causes rivers to overrun their banks and overwhelms urban drainage systems. Floods are also caused by heavy rainfall in parts of the Caribbean that are less susceptible to hurricanes or tropical storms. Flooding damages buildings and infrastructure, creates debris, disrupts business and productivity, and brings injury and death. As reported by Fontes de Meira and Phillips (2019), 119 flooding events hit the region between 1990 and 2018, affecting more than 6 million people and causing nearly $1.5 billion in damage.

Focus on the Dominican Republic

In November 2003, floods devastated the Cibao region in the Yuna and Yaque del Norte river basins of the Dominican Republic. Total losses reached more than $42 million, primarily in agriculture, which sustained 73 percent of the losses. An additional 8 percent of the losses affected housing, health services, and water and sewer services. The largest social impact fell on women, who were forced to head their households and recover from the disaster while their husbands sought employment elsewhere (CEPAL 2004).

In water systems, many components need to be located near rivers or coastlines—for example, river intakes for water treatment plants and entire wastewater treatment plants lying near the coast. Proximity places water infrastructure components in floodplains and exposes them to flood hazards. Inundation can damage components, physically damaged by fast-flowing water or indirect consequences of service loss (World Bank 2020a).

The vulnerability of water infrastructure (e.g., a water treatment plant) depends on a component's characteristics and the severity of exposure to the flood hazard. The function of a component is compromised when floodwaters reach a threshold (such as a critical elevation or flow magnitude) that prevents the component from performing as designed. Under some circumstances, performance may be affected by flood-related issues; for example, debris after heavy rainfall can clog drainage systems and intakes. In all cases, it is necessary to understand the impact of various flood events to assess the vulnerability of the component (World Bank 2020a). In rural areas, flooding can disrupt water withdrawals from creeks and rivers, contaminate wells, and damage sanitation facilities. Washed-out roads and bridges hinder emergency access to rural communities to provide water and other supplies.

As with other hazards, vulnerability to floods proceeds from exposed physical assets as well as exposed individuals and communities (CEPAL 2014). In the Caribbean, the vulnerability of infrastructure arises from a mix of disregarded building codes, poor land-use planning, socioeconomic factors, and an institutional framework unable to formulate proper risk-management policies.

Climate projections have annual precipitation falling by 3.7 to 14.1 percent between 2030 and 2090 (CEPAL 2011). But the projections also indicate that precipitation will likely *intensify*, producing extreme rainstorms alternating with severe dry spells. These projections suggest that flooding will continue to be a major development challenge for the Caribbean (Fontes de Meira and Phillips 2019).

4.3. DROUGHTS

The occurrence and duration of droughts are difficult to predict. The point at which a dry spell becomes a drought is also difficult to discern. While floods, high winds, and earthquakes tend to be abrupt occurrences that resolve within minutes or days, it can take weeks to determine if a dry spell is in fact a drought, which can then last months or years. Drought hazards require a long-term evaluative approach, particularly because official drought declarations trigger a set of emergency measures. An equally complex decision is required to announce the drought's end. Although single indicators can be used to measure severity—for example, the Palmer drought severity index (Alley 1984)—there are location-specific, science-based processes with an accepted set of indicators (e.g., precipitation, temperature, surface water levels, reservoir volume, and soil moisture) that can be used to declare a drought when indicators cross established thresholds. Water utilities can monitor these indicators before a drought is declared (e.g., reservoir levels) to prepare for a potential water shortage (World Bank 2020a).

As mentioned above, total renewable resources are declining in the region, with some countries trending toward "water stressed," like the Bahamas (1,770 m^3/capita/year), Grenada (1,855 m^3/capita/year), and Dominican Republic (2,183 m^3/capita/year) (see table 2.1). Other countries have already reached water scarcity: St. Vincent and the Grenadines (910 m^3/capita/year), Antigua and Barbuda (510 m^3/capita/year), St. Kitts and Nevis (434 m^3/capita/year), and Barbados (280 m^3/capita/year). Because of its reliance on rainfed agricultural production, the region is vulnerable to variable and unpredictable rainfall (FAO 2016).

The prevalence of droughts constrains utilities from delivering water in needed volumes to customers in the service area. In rural areas that rely on harvested rainwater, low rainfall will cut into household uses. Reduced water availability can trigger conservation measures, from restrictions on usage to service interruptions over large areas. Therefore, the most severe consequences of drought occur at the system level. Nevertheless, there are localized impacts on individual components as well. For example, river intakes may lose submergence if the water level drops below a given minimum elevation, which may affect the performance of raw water pumps, possibly causing mechanical problems. Drought may lower groundwater levels, impairing the operation of well pumps and inflicting mechanical damage. The distribution network loses efficiency as greater variability in hydraulic behavior deviates from design conditions (Fontanazza et al. 2008). Low water pressure may damage pipes.

In general terms, drought preparedness is attained through demand management (e.g., public awareness, water rationing) and supply augmentation (e.g., monitoring and forecasting, additional storage, irrigation optimization). The first, demand management, is preferred because it has lower implementation costs.

Effective policy making for droughts calls for a combination of these two options—demand management and supply augmentation—yet there are major institutional hurdles in the Caribbean. The main one is inadequate national coordination, followed by lack of capacity to make plans and policies, review them, and implement them. Another important deficiency is poor land management, which exacerbates the degradation of land and of water resources. Insufficient financial capability of service providers and a citizenry unaware of the true value of water pose additional difficulties. Finally, the lack of transparent mechanisms to address upstream/downstream uses creates conflicts among users (FAO 2016).

As mentioned, climate projections for 2030 to 2090 forecast a drop in annual precipitation. Together with the volatility of more intense rainfall events alternating with longer dry spells, droughts in the region are likely to become more frequent and more severe.

4.4. EARTHQUAKES

The countries of the eastern and northern Caribbean are particularly susceptible to earthquakes. The region's high population density and extensive coastal development are major risks during earthquakes and tsunamis. In the past 500 years, 12 major earthquakes of magnitude 7.0 or greater have occurred in the Caribbean near Puerto Rico, the U.S. Virgin Islands, and the island of Hispaniola. Several of these generated tsunamis. For example, in 1946, an earthquake with a magnitude of 8.1 triggered a tsunami that killed approximately 1,600 people (Woods Hole Oceanographic Institution 2005).

Focus on Haiti

On January 12, 2010, an earthquake of 7.0 magnitude caused widespread damage and more than 222,000 deaths in Haiti's capital city of Port-au-Prince and its surroundings (Flores et al. 2012). Before the earthquake, more than half of the population of Port-au-Prince had no water service, and only 10 percent had piped connections with intermittent service. After the earthquake, distribution networks were non-functional for most of the city. With wastewater collection networks nonexistent in the city before the earthquake, sewage became a major problem after it, contaminating fresh water and triggering outbreaks of disease (Ballantine 2012).

Earthquakes can permanently shift the landscape, causing costly damage to water supply and wastewater services, particularly since most system components are built with nonductile materials (e.g., concrete, cast iron). A water or wastewater system can experience hundreds or thousands of breaks. Earthquakes create many cascading and secondary effects that may include:

- structural damage to buildings, infrastructure, and equipment
- water tank damage or collapse
- realignment of or damage to water source transmission lines
- damage to distribution network due to shifting ground and soil liquefaction
- loss of power and communications
- difficult access to treatment plants and other facilities due to debris and damage to roadways

Nearly all reservoirs and storage tanks are likely to sustain damage, especially where the buried pipe system connects with the reservoir structure. Similarly, nearly all pump stations will be damaged at the connection point with the pipes. Treatment plants and other infrastructure built on liquefiable soils, without the benefit of special design, are likely to suffer foundation failure. Chemicals storage tanks that are not designed to withstand lateral forces will likely spill their contents. Earthquakes cause severe disruptions to rural water provision.

Earthquakes have major secondary impacts as well. For example, the condition of transportation infrastructure, including roads and bridges, will affect the repairs of damaged water system components. Also, electrical power outages and shortages of fuel will severely limit operation of pump and backup generators. Breaks in water pipes will cause additional damage from inundation, drain water-storage facilities, and produce loss of pressure. During rain events, broken storm sewers will cause localized flooding.

These effects result in water losses, service interruptions, impaired fire-fighting capacity, low pressure at delivery points, contaminated treated water, sinkholes, and localized, large pools of water throughout the service area (EPA 2015). In the Caribbean, critical facilities—treatment plants, pumping stations, and reservoirs—may have been built before the adoption of seismic design codes, leaving them particularly vulnerable to seismic hazards.

The limited institutional capacity of water service providers to prepare, respond to, and recover from an earthquake compounds the risk posed by these vulnerable facilities. Utilities should have the resources and technical support to prepare for an earthquake by, for example, drafting an emergency response plan and training staff. Other examples of preparedness include developing a plan for emergency drinking-water-supplies and mapping critical facilities; restoring service to those facilities should be a priority. Power and fuel are important as well. Utilities should have an earthquake emergency plan that inspects all components for damage, repairs breaks, monitors water quality, establishes temporary connections, and accounts for personnel. Service providers should have the financial capacity to complete permanent repairs and return to normal service. The recovery plan should also identify mitigation measures that boost service resilience. Without the institutional capacity to draft and implement these plans, service providers are likely to see recurrent damage in the future (EPA 2015).

4.5. OTHER HAZARDS

Other events can compromise the provision of WSS services, for example demographic shifts, land-use changes, pandemics, social unrest, political and economic crises, volcanic eruptions, landslides, and cyberattacks.

The planet is urbanizing. Today, 55 percent of the world's population lives in urban areas; by 2050, the figure will be 68 percent.[3] The Caribbean, already heavily urbanized, will urbanize even further as its population grows. Sudden migration to cities could be caused by social unrest or political instability. WSS service providers will need to serve more people, amplifying existing challenges.

Land-use changes from rural to urban and from forest to agriculture impose major modifications in the hydrologic regime. Urbanization goes hand in hand with the expansion of impervious surfaces such as rooftops, parking facilities, and roads—as well as with soil compaction. These two factors yield increased runoff and urban pollutants that endanger receiving waters (NOAA 2014). Water quality is also affected by agricultural runoff and mining waste.

The COVID-19 pandemic that began in March 2020 revealed another aspect of how vital WSS services are—and how vulnerable the service providers (Butler et al. 2020). Frequent and proper handwashing was deemed early on to be a basic defense against the spread of COVID-19. Yet this option is unavailable to huge swaths of the population. The second-most-important impact was reduced demand for WSS services as countries and territories locked down, which caused shifts in demand, disrupted supply, and altered emergency-response measures. For example, the decline in tourism forced the closure of hotels and other attractions. Another example: low-income customers could obtain the partial suspension of

3 https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.

water billing. But due to both causes, service providers experienced steep revenue losses. The pandemic also affected the WSS workforce. Utility crew members contracted the virus and were unable to work.

5. IMPROVING RESILIENCE

World Bank–financed projects often include new installations or upgrades to existing systems—for example, expansions of water-distribution or wastewater collection networks, or provision of new or upgraded water or wastewater treatment plants. Most water infrastructure components have a long design life, exposing them to various shocks that include natural hazards (Smith et al. 2019; Hallegatte et al. 2012).

“Lifelines: The Resilient Infrastructure Opportunity” (Hallegatte, Rentschler, and Rozenberg 2019) presents the Bank’s rationale for investments in resilient infrastructure. Low- and middle-income countries invest $1 trillion annually in infrastructure, equivalent to 3.4–5.0 percent of gross domestic product (GDP), and it is estimated that these countries lose more than $390 billion annually due to service disruptions caused by natural hazards. The correlation between GDP and the number of annual infrastructure failures is clear: the poor are disproportionately affected by natural disasters. Nevertheless, the impact of these disruptions can be mitigated. The cost of building up infrastructure’s resilience is estimated to be only 3 percent of the capital investment in the infrastructure, amounting to avoided costs of $4.2 trillion over the useful life of new infrastructure—a $4 benefit for each dollar invested in resilience.

5.1. THE WORLD BANK RESILIENCE FRAMEWORK

Utilities need to reimagine the paradigm of water management to handle today’s complexities and uncertainties, bearing in mind their interconnections and anticipating the range of unpredictable events and changes: natural and anthropogenic disasters, demographic shifts, pandemics, land-use changes, and other shocks. Water utilities and national governments must evaluate investments not only in terms of the traditional analysis of coverage, access, and financial indicators but also under the lens of resilience, considering how infrastructure must be built to respond to extreme or unusual events and to the unforeseen and unpredictable (Paltan et al. 2020).

The World Bank offers technical assistance to providers of water supply and sanitation (WSS) services to help them improve the resilience of their systems and reduce the occurrence of service disruptions in the face of multiple hazards. Specific to the water sector, the Bank developed the decision tree framework (Ray and Brown 2015), an analytical model for evaluating the potential impacts of climate change and for supporting robust and flexible decision making for water resource planning. The Bank also published a resource guide entitled “Building the Resilience of Water Supply and Sanitation Utilities to Climate Change and Other Threats: A Roadmap” (World Bank 2018). The roadmap outlines a general approach to plan for and evaluate the impact of natural hazards at the utility level. Finally, the Bank produced the “Resilient Water Infrastructure Design Brief” (World Bank 2020a), which focuses on practical tools to incorporate resilience into the design of drinking water and sanitation infrastructure. The design brief focuses narrowly on mitigation of the impacts of three hazards: floods, droughts, and high winds.[4]

4 Other resources are available. For example, the U.S. Agency for International Development has produced a toolkit (USAID 2017) for a water utility to develop three documents essential for resilience: (1) a vulnerability assessment, (2) a climate-resilient business plan, and (3) an emergency response plan. These documents are linked to a set of practices and should be implemented in tandem. The emergency response plan should be strength-tested in annual desktop exercises. This toolkit was written primarily for medium to large water utilities, but it can be used by other service providers with the proper local adjustments.

The roadmap and the design brief can be applied independently of one another, but they work more effectively in tandem. The hope is that Bank-funded investments will be evaluated with both. Ideally, the roadmap would be applied first for master planning and ascertaining priority investments; the design brief would be applied in the infrastructure design process. Application of the methodology outlined in the design brief will guide evaluations of the vulnerability of various water system components, assessments of the consequences of component failure on service provision, and selection of suitable mitigation options to improve resilience.

The following sections provide a brief overview of the decision tree, roadmap, and design brief frameworks. Because the roadmap and the design brief are aimed at WSS utilities, the descriptions below emphasize these two more than the decision tree, which applies more generally to water resource planning. Documented applications have been implemented in Ecuador (Paltán et al. 2020), México (St. George Freeman et al. 2020), Peru (Kaira et al. 2015), Niger (Ghile et al. 2014), and Cameroon (Grijsen 2014).

5.1.1. The Decision Tree Framework—Climate Uncertainty for Water Resources

The decision tree framework (DTF) outlines a risk-assessment process for water-resource projects that serves as a decision support tool for planning under uncertainty. It is based on "decision scaling," a robustness-based, bottom-up approach to water-resource system planning that uses a stress test to identify system vulnerabilities and techniques for the iterative reduction of those vulnerabilities through design modifications. The approach is different from top-down approaches whose usefulness depends on the accuracy of climate projections downscaled from general-circulation models.

The DTF is hierarchical, with phases of analysis triggered by the findings of the previous phase. The procedure consists of four successive phases: phase 1, project screening; phase 2, initial analysis; phase 3, climate stress test; and phase 4, climate risk management. A detailed description of the DTF can be found in Ray and Brown (2015).

5.1.2. The Roadmap—WSS Resilience

This roadmap is an adaptation of the DTF to better suit the decision-making process and concerns of WSS utilities. Both the DTF and the roadmap move away from the conventional practice of "predict then act." However, the roadmap differs from the DTF in that it considers all possible uncertainties, including climate change, from the start and throughout the process of designing and installing water infrastructure. The roadmap assumes that climate change amplifies other uncertainties and thus should not be evaluated in isolation.

The roadmap is divided into three phases, which take place in a facilitated process to answer questions about the system and how it can be strengthened. Phase 1 investigates the service delivery system, phase 2 identifies its vulnerabilities, and phase 3 chooses the actions to improve the resilience of the system.

Phase 1: Knowing the System

This phase identifies the context in which the WSS utility operates and seeks to answer questions about:

- the utility's objectives
- uncertainties that may make those objectives difficult to achieve
- the options for addressing the uncertainties

- the tools, data, and models available to explore the options

Phase 2: Identifying Vulnerabilities

The information identified in phase 1 helps ascertain the future conditions that might cause the utility to miss its objectives. This vulnerability assessment is made by stress-testing a variety of options over a spectrum of uncertainties. Stress-testing can range from analysis of a few qualitative scenarios to simulating thousands of scenarios when data and models are available. With the results of the analysis, the metrics of interest are computed for all the actions being considered. These stress tests help answer the following questions:

- What are the critical components in the system?
- How do the selected options perform across a wide range of potential future conditions?
- Under what conditions do these options fail to meet their goals?
- Are those conditions sufficiently likely that utility managers should choose a different option?
- What are the tradeoffs between meeting the options' goals and their performance on other factors, e.g., cost, impact on other users?

Phase 3: Choosing Actions

Using the results of the vulnerability analysis in phase 2, new or modified strategies are proposed to accentuate robustness—that is, strategies that achieve the utility's objectives over a range of plausible future conditions. The analysis helps identify tradeoffs and highlights the strengths and limitations of each action so that stakeholders can make informed decisions. Phase 3 helps decide how the utility might upgrade its infrastructure and management to reduce its vulnerabilities. The analysis helps answers questions such as the following:

- Are there low- or no-regret options that help achieve objectives regardless of future conditions?
- Are any combinations of options robust over all plausible futures?
- If not, what are the tradeoffs among the options?
- Can the utility defer some actions and later implement them if conditions change?
- Can the utility make its plans more robust by monitoring and adjusting over time?

The roadmap offers a framework to evaluate a series of measures that improve efficiency and reliability, thus providing the ability and resources to implement engineering projects at the system level. The following is a list of the most important utility-wide measures that can improve resilience (World Bank 2020a):

- acquire adequate insurance coverage against natural disasters
- perform and maintain a program of asset inventory and management
- develop and implement contingency and preparedness plans, including continuity of operations plans and supply chain readiness
- develop water-use efficiency programs aimed at all users—residential, commercial, industrial, agricultural, and institutional

- implement water-metering programs to support fair tariff schemes
- formulate realistic and fair tariffs and efficient organizational management.
- establish agreements among service providers to improve regional resilience
- train staff on emergency operations
- develop outreach and education programs for customers
- conduct effective maintenance programs.
- invest in research and development of innovative options for water supply and reuse
- identify and correct regulatory and governance weaknesses
- stockpile parts and supplies for emergency readiness
- develop and regularly update a master plan
- develop science-based regional drought management plans
- develop sound floodplain management regulations
- apply seismic codes
- improve hydrometeorological monitoring networks
- develop debris management plans
- develop an emergency response plan
- develop a communication plan to facilitate timely communication of relevant information, to officials, decision makers, and the public.

5.1.3. Design Brief—Infrastructure Resilience

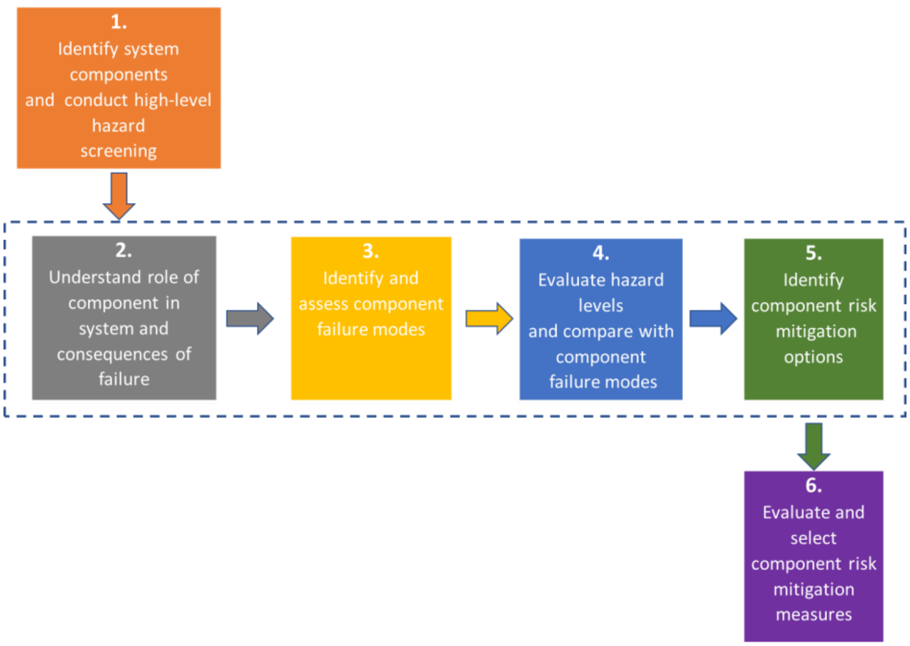
Water service providers need to plan capital improvements with resilience in mind. Therefore, in addition to the utility-level evaluations in the roadmap, specific infrastructure components require evaluation.

The design brief establishes a resilient-design process that can be applied to new infrastructure and to upgrades and retrofits, specifically against floods, droughts, and high winds. (Future versions of the brief will cover other hazards and shocks as well.) Unlike the traditional engineering approach in which infrastructure is designed to meet a given performance standard (e.g., a water treatment plant that can withstand a category 3 hurricane), resilient design seeks to provide answers to the following questions:

- How is “failure of a water system” defined? For example, what level of service interruption is considered unacceptable.
- What are the consequences if a component of a water system fails? For example, if an elevated finished-water tank collapses during a hurricane, will water not be available to the distribution network?
- At what hazard level is the component vulnerable to failure? For example, during a drought, what is the minimum level in a river for an intake pump to function properly?
- What is the potential range of hazard levels that could affect the component? For example, what is the likely range of gusts in a hurricane?
- What are the various risk-mitigation measures to strengthen the component, and how much do they cost? For example, what high-wind retrofits can be implemented in a water treatment plant?

In summary, the resilient design process seeks to avoid bad outcomes; so it looks first at where a component could fail due to a natural hazard, and then retrospectively considers the likelihood that the hazard might reach that level of severity. The process is summarized in figure 5.1; a detailed discussion can be found in the design brief, along with specific mitigation measures for an array of water system components (World Bank 2020a).

Figure 5.1. The process of resilient design for water infrastructure components



Source: World Bank 2020a.

5.2. EXAMPLES OF IMPLEMENTATION

The World Bank has undertaken this type of analysis in several locales, particularly with a focus on pinpointing robust solutions in the face of climate change, demographic shifts, land-use changes, and other factors that introduce a high degree of uncertainty (e.g., Ray et al. 2015; Freeman, et al. 2020). Other examples include a water security case study in the Philippines (AECOM 2018) and a study of resilience of Japanese water utilities facing natural hazards (Shibuya and Bradshaw 2018). Despite their continental locations, the systems evaluated in these studies can be helpful to Caribbean countries.

The following paragraphs describe individual initiatives in island states. These are not summaries of comprehensive resilience studies but useful references from the Caribbean and islands elsewhere around the world.

5.2.1. Culturally Sensitive Solutions to Water Resilience in South Tarawa, Kiribati

The World Bank conducted a study of urban water resilience in South Tarawa, Kiribati (World Bank 2019). Kiribati is one of the world's smallest, most remote, and most geographically dispersed countries, located in the central Pacific. The water supply for the capital city of South Tarawa is vulnerable due to its small volume and lack of storage capacity. The country has only two water reservoirs, and these are under pressure from squatters and their proximity to the airport.

> **Focus on Kiribati**
>
> The frugal and collectivist water-management practices of Kiribati, shaped by a long history of water scarcity, should be reintroduced in efforts to improve the resilience of communities to future water supply shocks. The path toward resilience needs to respond to technical-economic drivers as well as to people's social and cultural relationship with water.

Thanks to Kiribati's traditions of frugality and collectivism, the population has been resourceful and creative in coping with the inadequate water supply. The Public Utilities Board, the local utility, delivers 10 liters per capita per day (lpcpd) through a piped system that conveys water from groundwater and a desalination plant. Rainwater harvesting, a traditional water source, accounts for 2 lpcpd, a marginal amount. Average annual rainfall in Kiribati is approximately 2,100 mm, of which about 900 mm fall between May and October. Well water, which is typically brackish and contaminated with nitrates and pathogens, yields 22 lpcpd and is used for nonpotable purposes. In some areas, seawater is piped for toilet flushing.

Per capita freshwater availability has been declining and now hovers around the absolute scarcity limit of 500 cubic meters annually. The water sector will remain vulnerable to various threats. Droughts are the most immediate natural threat. The groundwater source is a freshwater lens threatened by human impacts and salination due to seawater overtopping, which will become worse with sea-level rise. Vulnerability also exists in the desalination and transmission system because there is no backup in case a technical issue, fire, or other factor interrupts service. In addition, the performance of the water utility is dismal: a NRW rate of and a cost recovery of only 34 percent.

The proposed solution to improve the resilience of South Tarawa consists of four components in order of priority: (1) low-regret measures[5] including conservation, direct graywater reuse, and pollution prevention; (2) recharge of water lenses; (3) addition of aboveground tanks for storage and a backup desalination plant; and (4) expansion of rainwater harvesting. The effectiveness of the water utility needs to be improved to be able to implement these initiatives.

5.2.2. Tuvalu's Technology Update of Rainwater Harvesting

Tuvalu, a low-lying atoll in the Pacific, is one of the Pacific islands most dependent on rainwater harvesting. Annual precipitation averages more than 3,000 mm but is highly variable from one year to the next. The country consists of nine islands with a total land area of 27 km^2 dispersed over 500,000 km^2. Of the approximately 11 thousand people on the atoll, about one-third have no access to surface water. According to the United Nations Development Programme, per capita availability of water is 40

[5] Low- or no-regret decisions or actions are those that make sense anyway regardless of the circumstances.

lpcpd and can sink as low as 20 lpcpd during a drought. Wastewater from septic tanks causes chronic contamination of wells and the lagoonal coast. Seawater incursions have turned the groundwater brackish (Fujita et al. 2013).

Rainwater collection in cisterns remains the most viable option for Tuvalu given the lack of resources to install and operate desalination plans. Closed cisterns for rainwater collection avoid contamination, while first-flush diverters prevent the first and dirtiest flow of rainfall out of the cistern (Balch 2015).

5.2.3. Financial Resilience: NRW Management in New Providence, Bahamas

The Bahamas' water sources are overstressed, and New Providence is one of the most overstressed cities in the Caribbean (IDB, 2018). Freshwater is limited to fragile lenses in karstic limestone lying atop of the shallow saline water less than two meters from the ground surface. Reverse osmosis provides more than 50 percent of the country's drinking water supply, although the source is groundwater due to restrictions on marine environment withdrawals (Green Climate Fund 2020). Currently, despite its cost, desalination is the only viable source of water for New Providence.

The Water and Sewerage Corporation (WSC) began operations in 1976 in good financial condition. However, WSC's historical problems of poor water quality, low pressure, and occasional rationing eroded the utility's financial condition as customers departed. Deficient service has made the government reluctant to authorize tariff increases, which, following the vicious cycle described in the sidebar, has exacerbated WSC's financial problems. Since the 1990s, this cycle culminated in the need for large government subsidies.

Reducing NRW is a complex undertaking—financially, institutionally, and politically. WSC had addressed it in a sporadic manner that did not achieve major improvements—for example, leak detection and repair. With a larger NRW control program needed by 2008–2009, WSC developed a comprehensive plan using a performance-based contract, a plan that included several technical interventions to reduce leakage. The conditions of WSC in New Providence made a performance-based contract the most cost-effective option (IDB, 2018). The technical skills required to execute NRW programs are straightforward, but expertise is essential for a proper diagnosis and for the design of an effective program.

Focus on the Bahamas

A serious NRW problem inevitably leads to a well-known vicious cycle that erodes financial resilience. Low tariffs and low rates of collection discourage responsible water use, which in turn increases costs. Inadequate funding also leads to poor maintenance and postponed investments, which further deteriorate service so that more and more customers are unwilling to pay. The service provider appeals for government subsidies, but these may not arrive owing to political pressures. As the situation becomes more dire, the utility cannot pay salaries and other operating costs. Service deteriorates further and infrastructure becomes inoperative. The utility becomes bankrupt and customers are forced to seek alternative, more expensive, sources of water (Baietti et al., 2006).

5.2.4. Resilience against Water Insecurity: A Water Policy Update in St. Lucia

The economic future of St. Lucia is inextricably tied to the availability and quality of its water resources. The country's activities depend on the reliability of water services and their ability to withstand and recover from natural disasters. Despite having drafted a water policy in 2004, St. Lucia is more water insecure now than then. Flood risk is higher, water infrastructure is older, wastewater management has not improved, and water quality continues to be an issue because of unregulated discharge of pollutants into water bodies (World Bank 2020b). Climate change only makes the problems more dire. Deficiencies in the provision of water services could compromise the sustainability and competitiveness of St. Lucia as a high-end tourist destination.

Focus on St. Lucia

The proposed 2020 Water Policy in St. Lucia and its implementation plan are articulated in 17 goals and 47 tasks that align with the following 5 strategies (World Bank 2020c):

1. Water management and investment decisions will be supported by an efficient, state-of-the-art information system.

2. The governance of the water sector will be improved by: (i) strengthening regulatory decision making and the financial capability of the Water Resource Management Authority and the National Utilities Regulatory Commission; and (ii) improving the allocation of jurisdictional responsibilities for water management across government agencies.

3. The ability to meet long-term water demand will be enhanced through the deployment of an effective flood warning system and resilient infrastructure to withstand natural disasters.

4. The efficiency, financial stability, and professional management of the Water and Sewerage Commission will be raised to enable it to provide reliable services.

5. Management of wastewater will be improved; investments will be made in sewerage and wastewater treatment infrastructure; and the disposal of grey water will be better regulated.

The vision of the 2020 Water Policy is that water resources will be sustainably managed for current and future generations of St. Lucians. Water services will be efficient and affordable to all.

6. CONCLUSIONS

WSS services are considered critical lifelines. Therefore, services must be predictable, robust, and able to be brought back online quickly in the event of failure. Because they have a long useful life, water infrastructure is more vulnerable than that in some other sectors.

To increase resilience, a water service provider needs to identify its threats and vulnerabilities and address those that create the most significant risks. The Caribbean region is characterized by high risks and small island states exposed to many hazards, including hurricanes, floods, drought, earthquakes, and tsunamis. Other issues include land-use changes, demographic shifts, and pandemics. Climate change amplifies must of these shocks. Limited tax revenues from small populations limit the capability of governments to handle their consequences.

Nevertheless, access to basic WSS services is relatively high in the region. Access to basic water supply exceeds 90 percent for all countries except Haiti (65.5 percent). Access to basic sanitation is over 85 percent for all countries except Dominica (77.9 percent) and Haiti (34.7 percent).

Most service providers in the Caribbean are state-owned enterprises, many of them underperforming. Their operational and financial challenges make them more vulnerable to shocks. Non-revenue water, water that is supplied but that is either lost in leakage or not paid for is a problem in most countries, especially for those categorized as “water stressed.”

The World Bank has developed a framework to integrate resilience into every step of water infrastructure projects. A “decision tree framework” (Ray and Brown 2015) offers an analytical model for water-resource planners to use in evaluating potential impacts and to support robust and flexible decision making. A “roadmap” (World Bank 2018) offers a way to plan for and evaluate the impact of natural hazards at the utility level. A “design brief” (World Bank 2020a) focuses on practical tools to incorporate resilience into the design of drinking water and sanitation infrastructure, specifically for floods, droughts, and high wind.

Caribbean nations should strive to develop a resilient WSS sector. This effort will require a paradigm shift to cross-sectoral preparedness that enables sound policies, strong institutions, and enforceable regulations. This needed shift also requires that governments, the private sector, and multilateral institutions invest in innovative solutions, particularly in financing.

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