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Climate Change Impacts on Coastal Transport Infrastructure in the Caribbean: Enhancing the Adaptive Capacity of Small Island Developing States (SIDS)

Climate Risk and Vulnerability Assessment Framework for Caribbean Coastal Transport Infrastructure

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CLIMATE RISK AND VULNERABILITY ASSESSMENT FRAMEWORK FOR CARIBBEAN COASTAL TRANSPORT INFRASTRUCTURE

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Executive Summary

Small Island Developing States (SIDS) are heavily dependent on coastal transport infrastructure—including ports, airports, and their access roads—for economic activity. That same coastal transport infrastructure is often highly vulnerable to impacts of climate variability and change, including hurricanes, sea level rise, increased temperatures, and changing precipitation patterns.

This report details:

(1) The importance of understanding and addressing coastal transport infrastructure climate change vulnerabilities in SIDS
(2) Key findings from a set of two case studies—one in Jamaica and one in Saint Lucia
(3) A climate risk and vulnerability assessment framework for Caribbean coastal transport infrastructure

The framework provides a structured way for organizations in SIDS to approach climate change adaptation. Climate change adaptation can be daunting, particularly when gaps in data create uncertainties around what conditions may arise and what the costs of impacts and the costs and effectiveness of responses may be over time. This framework is intended to help SIDS overcome these challenges by providing a practical approach that uses available data to inform decision-making at a facility, local, and national level. The primary audience is port and airport managers in Caribbean SIDS, though it will also be relevant to local and national government agencies.

The framework includes four major stages (see Figure 1):

1. **Set Context and Scope –** At the outset, briefly set the parameters for the assessment.
2. **Assess Criticality** – Understand the contributions of different elements of the transport system to the society and economy.
3. **Assess Vulnerability** – Understand how critical elements of the transport system respond to climate stresses, and how risks of costly damages or disruptions may change in the future.
4. **Develop Adaptation Strategies and Mainstream in Existing Processes –** Identify where further analysis is needed (and if so, circle back to stage 3), and where action can be taken without further analysis. Understand available options and strategies to reduce risks from climate variability and change. Monitor and evaluate to adaptively manage over time.

For each stage, the framework provides guidance and examples for how to conduct the assessment. The framework allows for flexibility based on available data, stakeholder engagement, and other relevant factors.

Key lessons reflected throughout the framework include:

- **Many SIDS lack baseline data** that is necessary to conduct more detailed and advanced risk assessments, related to climate change as well as other stresses. For example, many SIDS, including Saint Lucia, lack good data on beaches—including their locations, length, width, slope, grain size, and other parameters. This means that researchers and engineers are often forced to use default or generic assumptions. Investments are needed across the region in data. The Barbados Coastal Zone Management Unit (CZMU, 2017) is an example of a successful data collection effort in the region.

- **Identifying sensitivity thresholds can help streamline the vulnerability assessment process.** Conducting an exercise to identify sensitivity thresholds can help quickly identify what is at stake and where to focus attention in vulnerability assessment efforts.
- **Climate change adaptation often comes down to a policy decision related to risk tolerance.** Scientists can provide information on the range of expected conditions and likelihood of different events, but policymakers (at the national, local, or facility level) will decide how to act on this information based, for example, on what risks are considered acceptable. For example, should facilities be designed to a 50-year event, a 100-year event, the severity of recent events, and should expected climate change be factored into the assignment of probabilities? These decisions are a matter of policy and setting those policies can take time.
- **Communication is key.** Key policymakers and decision-makers need clear, compelling information to understand the risks and how they can help reduce risks. Key messages should focus on near-term impacts and costs of inaction.
- **Ports and airports are already taking action to increase their resilience and need to share their success stories.** For example, Kingston Freeport Terminal, Ltd. (KFTL) in Jamaica is doing mangrove restoration, beach cleanup, and coral reef rehabilitation near their facility. These projects protect both the port and the environment.
- **Organizational "best practices" can increase resilience, and vice-versa.** Organizational and institutional improvements—such as improving coordination across and within organizations, improving knowledge transfer from senior to junior staff, and empowering lower-level staff to problem-solve and report issues upwards—are all ways to increase resilience.
- **There is a need for regional cooperation**, and to build a knowledge base and community of practice around vulnerabilities. Regional organizations like the Caribbean Community Climate Change Centre (5Cs), Organization of Eastern Caribbean States (OECS), Economic Commission for Latin America and the Caribbean (ECLAC), and others all have a role to play. The 5Cs, for example, could support the community of practice, build capacity of countries and facilities to come up with adaptation options, and help connect them to international financing.
- **Financing for capital projects remains a major hurdle.** Caribbean SIDS tend to have capacity in terms of a highly educated and skilled population, but lack capital. Many adaptation strategies will have operational savings over time but require up-front capital spending. Individual facilities and government agencies within Caribbean SIDS need to develop processes for accessing funding sources for adaptation, such as the Green Climate Fund (GCF).

I. Introduction

Transport infrastructure in Small Island Developing States (SIDS) is vulnerable to climate change impacts. As detailed further below, climate-related hazards (e.g., sea level rise, storm surge, increased temperatures) can damage individual transport facilities such as ports and airports, which can in turn disrupt transport services and cripple small island economies.

Strategies to reduce these risks can come from both top-down approaches—such as national policies and plans to increase overall resilience—and bottom-up approaches—such as facility-specific engineering enhancements or operational changes to prevent damage.

This report provides information to help SIDS increase the resilience of their transport infrastructure, with a focus on ports and airports.

The report was developed for UNCTAD under the United Nations Development Account project "Climate change impacts on coastal transport infrastructure in the Caribbean: Enhancing the adaptive capacity of Small Island Developing States."[1] This project included two parallel efforts: (1) two national case studies focused on coastal transport infrastructure vulnerability in Jamaica and Saint Lucia, and (2) the development of a transferable methodology for such vulnerability assessments in Caribbean SIDS.

This report is the culmination of the second effort. The report is organized as follows:

- **Section II** describes the importance of understanding and addressing climate change vulnerability of the transport sector in SIDS.
- **Section III** provides key take-aways from the Jamaica and Saint Lucia case studies.
- **Section IV** provides a framework for climate change vulnerability assessment of SIDS ports and airports. The framework includes multiple options for working with available data to identify and prioritize vulnerabilities, as well as information on identifying and selecting adaptation strategies.
- **Section V** is an **Appendix**, with supplemental materials including:
    - Definitions of key terms
    - An example stakeholder tracking table
    - A summary of data needs and priorities
    - An overview of climate model data available for the Caribbean
    - An overview of sea level rise projections
    - Examples of several port and airport climate change vulnerability assessments
    - Summary of a beach erosion and retreat analysis from the Saint Lucia case study.

The information throughout this report draws on examples of vulnerability assessments and adaptation strategies from around the world, in addition to the two SIDS case studies conducted under this project. These two case studies focus on climate change impacts on coastal transport infrastructure and provide several lessons that inform both national-level and facility-level adaptation planning.

[1] Additional information about this project can be found at http://unctad.org/en/Pages/DTL/TTL/Legal/Climate-Change-Impacts-on-SIDS.aspx. For further information about related work by the UNCTAD secretariat, see unctad.org/ttl/legal.

II. The Importance of Understanding and Addressing Coastal Transport Infrastructure Climate Change Vulnerability in SIDS

Small Island Developing States (SIDS) are island countries that are often insular, remote, and have small economies, populations, and land area (UNCTAD, 2014). They tend to confront similar sustainable development challenges, such as limited economies of scale; small domestic markets; dependence on international trade; long distances for export and import markets; high costs of energy, infrastructure, transport, and communication; and little resilience to natural disasters (UNOHRLLS, 2017). Their populations, agricultural land, and transport infrastructure are concentrated in coastal areas, where sea level rise and extreme events have their most severe impacts. Their economies also rely on particularly vulnerable industries, such as agriculture and tourism (BPOA, 1994). Finally, because SIDS are sea-locked, reliable and functioning transport systems provide vital lifelines for sustaining survival and economic operation. For all these reasons, SIDS—including Caribbean SIDS—are affected disproportionately by climate impacts and, when it comes to climate change vulnerability of the transport sector, SIDS face unique challenges that transport managers and government authorities must recognize and address (UNCTAD, 2009; UNCTAD, 2011a; UNCTAD, 2011b).

1. Caribbean SIDS Rely on Transport Infrastructure

All SIDS, including Caribbean SIDS, rely on transport infrastructure, especially ports and airports, for economic and social development and as vital lifelines for goods movement and tourism. The vulnerability of air and sea transport infrastructure has significant economic implications in SIDS and the impacts of climate change on harbors and coastal airports could impede SIDS connectivity (Peduzzi, 2016).

1.1 Transport infrastructure facilitates goods movement

Transport infrastructure is critical to the success of SIDS economies. Maritime transport accounts for more than 80 per cent of world trade and directly contributes to a country's international competitiveness (Becker et al., 2013). Aging and ill-maintained port infrastructure already compromises the capacity of many SIDS to fulfill their shipping needs (UNCTAD, 2014).

Additionally, air transport is responsible for carrying 40 per cent of the value of freight goods and can act as an economic catalyst by opening up new market opportunities (UNELAC, 2011). In the Caribbean, the aviation sector contributes US$2.5 billion to GDP through direct contributions, indirect contributions (through the aviation sector's supply chain), and spending (by aviation sector employees and the supply chain), and 845,000 jobs (Oxford Economics, 2011). The average air transport support services employee in the Caribbean generates US$43,000 in Gross Value Added annually, which is over 3.5 times more productive than the average employee in the region (Oxford Economics, 2011).

Caribbean countries in particular are heavily reliant on transport infrastructure to facilitate goods flow. They are of small economic size, with a combined nominal Gross Domestic Product (GDP) of US$100 billion in 2014 and a population of 17.8 million (CARICOM, 2014), and resident populations depend on imported goods for vital commodities including food, energy, manufactured goods, equipment, and other valuable items. In addition, Caribbean producers depend on a reliable transport network to bring goods to domestic or international markets. Agriculture and fisheries are important economic sectors in the Caribbean that rely on coastal transport systems—reliable transport networks are especially critical for these sectors, since products are subject to spoilage. Other Caribbean sectors, such as manufacturing and extractive industries, also rely on coastal transport systems (UNECLAC, 2011b).

1.2 Transport infrastructure enables tourism

The critical tourism economies of Caribbean SIDS also rely heavily on transport infrastructure. Sun-Sand-Sea ("3S") tourism contributes significantly to the Caribbean economy, as foreigners flock to these countries to enjoy their environments (Cameron and Gatewood, 2008). Tourism accounts for about 30 per cent of total employment and up to 50 per cent of GDP on average in SIDS (UNCTAD, 2014), larger proportions than in any other region of the world (WTTC, 2015). In fact, the tourism sector is the largest employer and earner of foreign exchange for most Caribbean destinations (5Cs, 2015). The tourism industry is also a key driver of growth in the Caribbean (UNECLAC, 2011b), and has expanded recently in many Caribbean SIDS. In Saint Lucia, for example, cruise ship visitors increased by 8 per cent and 450 more people were employed in the tourism sector in 2014 as compared to 2013 (5Cs, 2015).

The Caribbean region is a major destination for cruise ships, with about 24.4 million passenger arrivals in 2015 (CTO, 2015). Saint Lucia, for example, has direct connectivity to the UK and to major U.S. gateways, and is visited by major cruise liners such as Celebrity, Carnival, Norwegian, and Royal Caribbean (5Cs, 2015). Cruise ships bring tourists into ports, where they can explore the area for day trips. Across the Caribbean, the average expenditure per cruise passenger is US$95.92 but this amount varies throughout the region (FCCA, 2015). Transport infrastructure—including the ports themselves but also the roads and other infrastructure to bring tourists from the port to other destinations—is critical to facilitate this tourism.

In addition, over 28 million stay-over tourists visited the Caribbean in 2015 (CTO, 2015). Stay over tourists must use airports or boats to reach many of SIDS, considering their remote, sea-locked locations. Stay-over tourists spend significantly more than cruise passengers—as much as 70 per cent more (Brida and Zapata, 2010; Hampton and Jeyacheva, 2013). For example, in Dominica, 93 per cent of tourism revenue is generated from 22 per cent of tourists who are stay-over visitors. These guests spend an average of US$1,500, while cruise passengers spend about US$30 (Commonwealth of Dominica, 2015).

Caribbean SIDS rely heavily on transport facilities and infrastructure to enable tourism. Ports and airports allow tourists to access the islands and travel between them, while inland roads carry travelers to points of interest. Infrastructure is a key component of tourism competitiveness (WEF, 2015). Airports serve as key gateways to SIDS, connecting them to the rest of the world. Indeed, many sea-locked countries depend on air transport for their livelihoods, as the tourism that air transport facilitates are a key component of SIDS economies (CDB, 2015). Public infrastructure, such as water and sanitation, telecommunications, power supply, roads, and ports, also support tourism in SIDS (Abdullah et al., 2014).

In sum, tourism requires a well-functioning transport system and infrastructure because developing and maintaining stable infrastructure supports a thriving tourist industry and is a strong reason for tourists' choosing to visit particular locations (Suleiman and Albiman, 2014).

However, most of the infrastructure that Caribbean SIDS require to support goods movement and tourism is vulnerable to climate change.

2. Caribbean SIDS are Highly Exposed to Climate Variability and Change

Climate change threatens the safety, and even existence, of many island states (IPCC, 2014b). SIDS are highly exposed and vulnerable to natural disasters, which are expected to increase in frequency and severity (IMF, 2013; World Bank, 2017). Often SIDS are located in disaster-prone areas like the Caribbean and lack resources to cope with disaster effects (Mohan and Strobl, 2012).

SIDS are particularly vulnerable to climate change because their climates are influenced greatly by ocean-atmosphere interactions, winds, El Niño, and tropical storms, to which they have little protection given their generally small geographic area (UNOHRLLS, 2015). Many SIDS are also located in areas with tectonic activity and variable weather systems, which further increases their exposure to extreme events (UNCTAD, 2014). Overall, the Caribbean is one of the most disaster-prone regions in the world, suffering from 390 natural disasters between 1980 and 2015 (Rasmussen, 2004; UNECLAC, 2015). The Caribbean is exposed to a wide variety of climate change impacts. Climate change could result in:

- **Rising sea levels.** Global sea levels have risen between 1.3 and 1.7 mm per year through the 20th century and, since 1993, at a rate between 2.8 and 3.6 mm per year (IPCC, 2014b). By the end of the century, estimates of global sea level rise are 1.5 m to 2.5 m (NOAA, 2017) and estimates for the Caribbean may be even greater because of gravitational and geophysical factors (Simpson et al., 2009). Sea level rise is a major threat to low-lying coastal areas on islands and presents severe flood and erosion risks. Also, rising sea surface temperatures will result in coral bleaching and degradation of vital reef ecosystems, upon which island communities rely for subsistence and tourism (IPCC, 2014b). Additionally, inundation of land with salt water would endanger freshwater resources (BPOA, 1994). Sea level rise can also increase the extent and depth of storm surge during hurricanes.
- **Changes in the frequency and intensity of extreme weather events, including hurricanes and tropical storms.** Evidence suggests that tropical storms may become even more extreme and more frequent as a result of climate change (UNCTAD, 2014). Hurricanes are a regular concern even today, as storms travel across the Atlantic Ocean from off the coast of Africa. These storms routinely reach the Caribbean where warm waters cause them to intensify and increase their damage potential. Future hurricanes of the north tropical Atlantic will likely become more intense, with larger peak wind speeds

and heavier storm-related precipitation (Government of Saint Lucia, 2011). Also, Caribbean SIDS are located near the Puerto Rico Trench and 75 tsunamis have occurred in this region in the last 500 years, killing more than 3,500 people (UNCTAD, 2014). Recently, Hurricane Matthew in 2016 caused extensive damage in Haiti, Cuba, and the Bahamas. The 2017 hurricane season included major hurricanes Irma and Maria and affected several Caribbean islands including Dominica, the Dominican Republic, Guadeloupe, Montserrat, Saint Kitts and Nevis, Puerto Rico, Turks and Caicos, and the Virgin Islands. These storms highlight Caribbean SIDS vulnerability to hurricanes.

- **Greater variability in precipitation.** This could involve more frequent and intense heavy rainfall or longer periods of drought. In the Caribbean region, there was a reduction in rainfall from the period 1900-2000 (UNCTAD, 2014).
- **Warmer temperatures.** Downscaled climate projections for the Caribbean region project a rise of 1°C to 4°C compared to a 1960-1990 baseline, with increasing rainfall during the wet season (November to January) in the northern part of the region and drier conditions in the southern part of the region. Also, there would be a tendency to drying during the traditional wet season (June to October) (IPCC, 2014b). Warmer average temperature will correspond to increases in the frequency of extreme temperatures and heat waves.
- **The spread of invasive species, pests, and vectors.** Changing temperatures and seasonal patterns has been shown to influence the spread of pests that endanger ecosystem and human health (IPCC, 2014b).

3. Transport Infrastructure in Caribbean SIDS is Vulnerable to Climate Change

3.1 Climate change and extreme weather affect transport infrastructure

The multiple climate hazards outlined above can have specific deleterious impacts on a transport system, leading to direct and indirect damages and system disruptions. Many SIDS have developed and inhabited coastal areas with low-lying infrastructure that will be exposed to damaging events (UNCTAD 2014). Since the population centers and major infrastructure tend to be concentrated along the coasts, sea level rise, storm surge, flooding, and storms pose great risks to the economies and wellbeing of SIDS (BPOA, 1994). Thus, daily port operations may be slowed or halted, in both the long- and short-term, and seaport and airport infrastructure will be exposed to serious impacts as well (UNCTAD, 2014).

Increases in the frequency of heavy downpours can cause flooding of critical road, port, and airport facilities and can deposit debris on roads, blocking access for employees or travelers. Heat events can cause asphalt to soften and rut, cause rail lines to buckle, and affect air operations by reducing payloads and limiting the potential for large plane landings and take-offs. Increased precipitation can cause long-term effects on the structural integrity of roads, bridges, drainage systems and telecommunication systems, necessitating more frequent maintenance and repairs (Oxford Economics, 2011).

Table 1 provides illustrative examples of climate variability and change sensitivity mechanisms for ports, airports, and roads. More specific examples of past impacts from climate hazards are provided in Table 2.

Table 1. Examples of sensitivities of transport assets to climate hazards, including possible outcomes and thresholds

Climate Hazard	Ports	Airports	Roads
Sea Level Rise	Increased risk of chronic flooding and possible permanent inundation of facilities. *Inundated facilities can make a port inoperable.*	Inundation of runways and other pavements, resulting in damage to runways and debris. *Damaged runways can cause flight cancellations and delays.*	Damage to roads, including making them unavailable. *Damaged roads can be inaccessible to travel and transport.*
Storm Surge	Damage to marine port buildings. *Damaged buildings can delay shipping and transport.*	Inundation of runways and other pavements, resulting in damage to runways and debris. *Damaged runways can cause flight cancellations and delays.*	Damaged pavement due to direct wave attack, water flow across the road, and flow parallel to the road. *Damaged roads can be inaccessible to travel and transport.*
Wind	Inability to operate cranes above certain wind speeds. *Cranes often cannot operate at wind speeds above 25 miles per hour. Inoperable cranes can cause delays in shipping.*	Possible damage to aircraft from debris. Delays due to storms and high winds with cross wind components. *Increase in wind speeds can increase the likelihood of flight delays.*	Blown-over road signs and stirred-up dust from unpaved roads. *Downed signs and swirling dust can create confusing and dangerous travel conditions.*
Extreme Heat	Deterioration of paved terminal areas; inoperable cranes. *Damaged terminals or inoperable cranes can delay shipping and transport. Most cranes don't operate at more than 35°C (95°F).*	Concrete pavement buckling, resulting in damaged runways. *Damaged runways can cause flight cancellations and delays. Pavement binder may exhibit sensitivity and damage beginning at 42°C (108°F).*	Asphalt pavement softening, resulting in rutting. *Damaged roads can be inaccessible to travel and transport. Pavement binder may exhibit sensitivity beginning at 42°C (108°F).*
Heavy Precipitation and Flooding	Reduced visibility, flooding that damages port structures and equipment, destroyed electrical equipment, debris movement. *Damaged structures and destroyed equipment can delay shipping and transport. Flooded electrical equipment is often destroyed.*	Overwhelmed existing drainage systems, causing standing water on pavements. *Damaged runways can cause flight cancellations and delays. Heavy rain of 2.5-5 cm per hour can produce standing water on pavement.*	Overwhelmed existing drainage systems, causing flooding and creating pavement and embankment failure and erosion. *Damaged roads can be inaccessible to travel and transport. Multiple instances of complete pavement submersion are likely to cause pavement damage over time.*

Source: FWHA, 2012

3.2 Historical climate events in Caribbean SIDS show the costs to and implications for transport services

A historical review shows how disproportionately damaging past climate events have been to the economies of Caribbean SIDS. The economic cost of natural disasters between 1950 and 2014 was 16 per cent of GDP for small states in Latin America and the Caribbean compared to 2.5 per cent for larger states (IMF, 2016). Additionally, natural disasters affect close to 11 per cent of the population of small states on average compared to 1 per cent in larger states (IMF, 2016). These impacts are exacerbated by the fact that SIDS often depend on exports to support their economies and have fewer ports and roads (Mohan and Strobl, 2012). Damage to critical infrastructure can have enormous impacts on the economy of the state.

Further, when disruptive weather events occur, an outsize portion of impacts affect the transport sector. For example, damages to the transport sector constituted 60 per cent of the damages from Tropical Storm Erika (Commonwealth of Dominica, 2015) and 72 per cent of the damages from the Christmas Trough (Government of Saint Lucia, 2014). More specifically, a Rapid Damage and Impact Assessment of Tropical Storm Erika for the Commonwealth of Dominica showed that transport sector damages were estimated at about US$303 million, or about 54 per cent of Dominica's GDP. Of that, total damages and losses to the airport and seaport transport sector were estimated at US$977,654 (Commonwealth of Dominica, 2015).

Past extreme events also demonstrate how disruptions in transport services feed directly back into broader impact on economies. Natural disasters can reduce the productive capacity of a country and disrupt trade (Mohan and Strobl, 2012). Airport shutdowns cause direct losses to airlines from loss of passenger fees and taxes as well as indirect profit losses due to business interruption in the time after the shutdown and losses during reconstruction (WCTR, 2013). For example, following Tropical Storm Erika, the Douglas-Charles Airport in Dominica could only operate in a very limited capacity. Losses by the airlines serving the airport far exceed those incurred by the airport, with estimated losses of US$14.5 million (Commonwealth of Dominica, 2015). Disruptions in transport infrastructure can raise the cost of agricultural goods due to increased transit cost and jeopardize the safety and quality of goods (EPA, 2016).

Table 2 summarizes damages and impacts from past extreme events in Caribbean SIDS. It does not include impacts from the devastating 2017 hurricane season that included major hurricanes Irma and Maria and affected several Caribbean islands including Dominica, the Dominican Republic, Guadeloupe, Montserrat, Saint Kitts and Nevis, Puerto Rico, Turks and Caicos, and the Virgin Islands.

Table 2. Impacts from past extreme events in Caribbean SIDS

Name and Description	Transport Impacts	Economic Impacts
Hurricane Matthew, 2016 • Haiti • Strong winds, heavy precipitation, and storm surge	• Closed airports until storm passed and flight delays and cancellations occurred (Cavaretta and Owers, 2016) • 60% of roads damaged in SW peninsula (USAID, 2017)	• Caused US$1.9 billion in economic damage (Benfield, 2016) • US$82 million provided by USAID for relief and recovery efforts in Haiti (USAID, 2017)

Name and Description	Transport Impacts	Economic Impacts
	• Blocked and flooded roads, disrupted communications, and washed-out bridges in Haiti (Mercy Corps, 2016) • A critical bridge washed away and rescue workers couldn't use damaged roads (Wright, 2016)	
Tropical Storm Erika, 2015 • Commonwealth of Dominica • Storm triggered flash flooding, slope failure, and debris generation	• 60% of damages were to the transport sector (Commonwealth of Dominica, 2015) • Floods and landslides damaged 17% of roads and 6% of bridges • Both airports were flooded, damaging electrical equipment	• Total damages and losses for transport totaled US$288 million for roads and bridges and US$15 million for airports • Total damages and losses to the airport and seaport transport sector were estimated to be US$977,654 • Loss of airport operations are estimated at US$14.5 million to airlines and US$80,000 to the airport; the airport shutdown additionally impacted the tourism industry
Christmas Trough (December 24-25 2013) • Saint Lucia • Tropical trough system produced heavy rains leading to flash flooding and landslides	• 72% of damages were to the transport sector (Government of Saint Lucia, 2014) • 12 sections of road required extensive reconstruction • Terminal and runway flooding forced the closure of the airport for 48 hours • Possible rerouting of the Vieux Fort river may be required	• Combined loss and damages total US$71.9 million for the transport sector • The losses do not consider the value of the increase in transit time, the impacts on the cost of transport for agricultural goods, the increase in the time and cost of tourism transport, or transport impacts to commerce and industry, all of which significantly impact the economy and social stability of the country
Hurricane Tomas, 2010 • Saint Lucia • High winds, and severe flooding from heavy precipitation	• Both airports were closed (UNECLAC, 2011a) • Roads were damaged from landslides, river bed erosion, or river sedimentation	• Airport losses included air shuttle passenger fees, loss of passenger taxes, clean-up of mud from one runway, and loss of aircraft landing fees • Losses totaled East Caribbean (EC)$999,417 • Total estimated damages to roads were EC$100,638,750
Hurricane Dean, 2007 • Jamaica • Strong winds, heavy precipitation, and storm surge	• The road connecting Kingston and the Norman Manley International Airport was affected by storm surge causing flooding and sand piling (Planning Institute of Jamaica, 2007) • 446 roadways were blocked	• The total effect of the disaster on the road transport sector was estimated as US$1.1 billion • Loss of electrical power affected traffic signals, creating dangerous road conditions
Hurricane Ivan, 2004 • Grenada • Strong winds and storm surge	• Roads were damaged from land slippage, erosion, fallen trees, and wave effects (OECS, 2004)	• Cost to repair road erosion was EC$500,000 • Costs to remove fallen trees blocking roads was EC$1.2 million

Name and Description	Transport Impacts	Economic Impacts
	• Point Salines International Airport experienced damage to navigational aids & tower radio equipment • Damage to main port terminal prevented normal operations for 3 weeks	• Cost of airport repairs was EC$1.0 million • Loss of airport revenues was EC$500,000 • Cost of damages to seaport was EC$3.4 million • Loss of seaport damages was EC$670,000

In addition to direct losses due to natural disasters, SIDS can experience prolonged indirect losses, attributable not to the disaster itself, but to its long-term consequences. These could include output losses (i.e., business or supply-chain disruptions, and lost production), market destabilization, general impacts on human wellbeing, and macro-economic feedbacks such as reduced demand for a service because consumer incomes have been reduced (CRED, 2011). Natural disasters can cause GDP loss for years following a major disaster and increase borrowing costs, especially for indebted nations like those in the Caribbean (GFDRR, 2014a). In terms of transport, if a road is damaged by a hurricane, the indirect costs are the losses because the road is out of commission and inoperable, such as losses in income for businesses that are no longer accessible or losses in shipping. Similarly, if an airport is damaged, there may be indirect losses from tourists who decide not to visit at all (Hallegatte, 2015). Even bus or car rental operations may be impacted by fewer customers if infrastructure is not functional. Or local businesses lost revenues if a cruise ship does not stop at a damaged port.

For the hurricane impact assessments listed in Table 2, some of the assessments factored in indirect losses. Studies found that the Port in Grenada incurred indirect losses of EC$670,000 due to Hurricane Ivan (OECS, 2004). Hurricane Tomas caused indirect losses in the tourism sector from disrupted water supplies (UNECLAC, 2011a). Although few indirect infrastructure costs were identified after Hurricane Dean, the water supply and sanitation sector did lose approximately US$150 million (Planning Institute of Jamaica, 2007). Overall, assessing the full extent of indirect losses can be difficult.

If both direct and indirect losses were assessed accurately, the estimates of overall loss would likely be much higher than current estimates that consider only direct losses (GFDRR, 2014b). Recognizing the different direct and indirect losses incurred by a community is vital for projecting the true impact of a disaster because there is a difference between direct impacts that can be repaired within a few months and indirect losses that could continue for years after an event occurs (Hallegatte, 2015). Thus, indirect losses should be considered as thoroughly as possible when assessing vulnerability and impacts.

4. Reducing Transport Sector Vulnerability in SIDS is Critical

A fully functioning transport system is a vital component of the SIDS economy and contributor to the quality of life of island residents. Disruptions to the transport network can have immediate and potentially severe consequences on the development goals of the island, its economy, and the health and lifestyles of its residents. Social benefits such as access to medical care and higher education rely on the transport system. There is little redundancy in the transport system, which makes it more likely to fail. If it does, SIDS lose key linkages that support tourism and other economic activities. For example, some resorts are accessible only by single roads, which are often prone to landslides. In Saint Lucia, travel from the airport to the capital area of Castries, where 40 per cent of citizens reside and most tourist destinations are located, depends on one major road that is prone to landslides (Census, 2010; UNCTAD, 2017b). If destroyed, the losses incurred could be severe because access to the facility is limited until the infrastructure is recovered.

Climate change can increase and intensify many negative effects already experienced in the region. Climate change is likely to increase the frequency and severity of disruptions to transport infrastructure, causing cascading effects on agriculture, fisheries, tourism, and other key activities. These disruptions threaten resident livelihoods, health, and well-being, by cutting off lifelines through ports and airports. The challenge of maintaining these critical services is already significant and will only increase as the climate changes. Transport managers and ministries must recognize and address these risks as vital concerns to their countries.

The framework that follows presents a method to assess and address critical risks to the coastal transport sector in SIDS. By following the recommendations and steps in the methodology, transport managers and government authorities can work towards identifying critical assets, current and future vulnerabilities, and potential adaptation strategies for the transport sector.

III. Lessons Learned and Recommendations

1. Case Studies

The Jamaica Case Study (UNCTAD, 2017a) assessed the vulnerability of transport facilities to climate change impacts, noting that the greatest threat is from the increasing intensity of storms, which increases the likelihood of facility shutdown. The Case Study also found that higher temperatures and more warm days will place a greater strain on HVAC system, weaken asphalt, and place strain on personnel working outdoors. More droughts will limit the water supply and related functionality and detract from tourism. Finally, higher sea levels will increase the risk of inundation of facility runways, container bays, and access roads.

The Jamaica Case Study also identifies adaptation strategies for each facility assessed. The following strategies, in conjunction with coordination with outside agencies, aim to decrease the overall vulnerability of each facility:

- Sangster International Airport: Raise and extend the runway to combat sea level rise, storm surge, and warmer temperatures affecting lift.
- Norman Manley International Airport: Extend the runway and raise low-lying areas to combat warmer temperatures affecting lift and protect against sea level rise and storm surges.
- Historic Falmouth Cruise Port: Combine efforts with local government to improve infrastructure in Falmouth in order to increase resilience of access roads and improve tourist experience.
- Kingston Freeport Terminal: Invest in better reinforcement for cranes and deploy blooms in Hunts Bay to combat higher wind speeds and control debris outflow.

The Saint Lucia Case Study (UNCTAD, 2017b) also provides an overview of vulnerability for each facility, in addition to an assessment of potential for beach erosion, which could not only reduce natural protections for facility infrastructure, but also change demand for tourism, which in turn drives demand for port and airport services. Hewanorra International Airport (HIA) is largely threatened by precipitation that causes overflowing of the La Tourney River, which is anticipated to increase in intensity and duration in the future. In addition, landslides could limit accessibility between HIA and major tourism destination. GFL Charles Airport is vulnerable to sea level rise and storm surge that could result in runway inundation. Port Castries is threatened by sea level rise, specifically at the Southern tip at the entrance to the Port. Port Vieux Fort itself was not found to be vulnerable to sea level rise, while the Town of Vieux Fort will likely experience flooding from major storms. More broadly, just 0.19 meters of sea level rise, if combined with 1 meter of storm surge, could erode up to 72.5 percent of the nation's beaches and flood up to 97.8 percent of the nation's beaches.

2. Key Findings

The two case studies, in addition to national workshops conducted in each country, generated a wealth of information about the vulnerability assessment and adaptation process in Caribbean

SIDS. Those lessons are reflected throughout this document—particularly in the framework—, but this section highlights major lessons learned from the case studies and recommendations based on the challenges faced in Jamaica and Saint Lucia. These lessons fall into three categories: Data, Awareness and Coordination, and Implementation.

2.1 Data

- **Data collection efforts take time.** Data collection is essential to the success of the assessment and proved to be one of the most challenging elements of the study. It is crucial to allow time for data collection and to consider and allow for scenarios where the data may not be available at all. It is not unusual for developing countries (or developed countries, for that matter), to not have strong data records relating to weather, past disruptions, operations, etc.
- **Many SIDS lack baseline data**. Many SIDS lack baseline data that is necessary to conduct more detailed and advanced risk assessments, related to climate change as well as other stresses. For example, many SIDS, including Saint Lucia, lack good data on beaches—including their locations, length, width, slope, grain size, and other parameters. This means that researchers and engineers are often forced to use default or generic assumptions. Investments are needed across the region in data. The Barbados Coastal Zone Management Unit (CZMU, 2017) is an example of a successful data collection effort in the region. Specific data needs for climate risk assessments include:
    - **Climate data –** In many Caribbean SIDS, the ideal highest-resolution downscaled data from a huge ensemble of climate models may not be available. Rather, downscaled data for one model might be more likely. A good benchmark is to seek out the data that the country is using for other contexts. To understand the state of climate science in the country, a good place to begin is the National Communications to the UNFCCC. Working with local academics is another way to ensure you are using the best available data. Having an understanding of useful variables could help direct the analysis. For example, for sea level rise modeling, one question to ask is "what might be inundated and by how much?" Similarly, extreme temperatures could be measured in the number of day above 35°C or by asking "what is the threshold for airport runway lengths?"
    - **Geospatial data** – Geospatial mapping of potential sea level rise or storm surge inundation is very important in SIDS, where development is often concentrated in a very narrow band around the coast. High-resolution elevation data are critical to such an assessment and in order to know which areas are more at risk than

Recommendation: LiDAR Data

In the Caribbean, there is a need for high resolution elevation data to inform more detailed geospatial assessments of coastal risk. Barbados is currently the only area in the Caribbean with Light Detection and Ranging (LiDAR) data, a technology that uses a pulsed laser to generate precise, three-dimensional information about surface characteristics with great accuracy. Because SIDS transport infrastructure is often located along the coast, high resolution elevation data are essential to determining which assets are at highest risk to coastal hazards.

others. As of 2016, high resolution elevation data availability is very limited in the Caribbean. Only Barbados has high-resolution LiDAR mapping data. This information is critical to procure for the Caribbean, where sea level rise elevations can easily fall within the bands of a low resolution elevation model.
    - **Impact data** – SIDS may have limited documentation of past weather and climate-related impacts. Post-event damage assessments, even when available, may lack key information about physical and especially societal impacts.
- **Site visits to affected facilities and interviews with local stakeholders are a vital source of information.** As discussed, data are like to be limited, especially related to past impacts at facilities. Site visits at affected facilities and interview with facility managers and other stakeholders are therefore a vital source of information. Site visits can allow visual understanding of site conditions and potential vulnerabilities, and provide an opportunity to gather information about the facility from those who know it best. Care must be taken, however, to ensure such information is reliable (see below).
- **Steps to validate stakeholder input from facility managers can ensure high-quality input.** In the context of limited data, stakeholder engagement provides a critical source of information. In SIDS and elsewhere, information from stakeholders—particularly about past vulnerabilities or impacts—is not always reliable. Past experience on this project and others have shown that stakeholders are not always either aware of or willing to admit impacts from previous events. This can have many causes, including:
    - The sense that any past impacts represent a shortcoming of the facility;
    - Stakeholders may not have been employed in their current role at the time of prior impacts;
    - Stakeholders may not have directly witnessed the prior impacts, and because the impacts were never documented, they are not a part of the facility's institutional memory; and
    - Facility managers may question the adequacy of future climate projections.

  It is important to be aware of these tendencies for future projects. Ways to encourage high-quality stakeholder input include:

    - Validate stakeholder input with multiple people and any written documentation available, and

Recommendation: Improve Routine Data Collection

Systematic collection of information on event impacts as they occur can help build the case for resilience investments over time. For example, track data on:

- Frequency of flooding, operational shutdowns
- On-time departures
- Passenger throughput
- Revenue generated
- Facility closure duration
- Time from beginning of weather event to dissemination of information to travelers

This can minimize the need to rely on faulty human memory and can be extremely useful toward development of an adaptation strategy.

    - Frame questions so that it is clear that no blame or judgment would be associated with any past impacts.
- **Identifying sensitivity thresholds can help streamline the vulnerability assessment process.** Conducting an exercise to identify sensitivity thresholds (as described in the framework, step 3.1) can help quickly identify what is at stake and where to focus attention in vulnerability assessment efforts.

2.2 Awareness and Coordination

- **Communication is key.** Key policymakers and decision-makers need clear, compelling information to understand the risks and how they can help reduce risks. Key messages should focus on near-term impacts and costs of inaction.
- **Ports and airports are already taking action to increase their resilience, and need to share their success stories.** For example, Kingston Freeport Terminal, Ltd. (KFTL) in Jamaica is doing mangrove restoration, beach cleanup, and coral reef rehabilitation near their facility. These projects protect both the port and the environment.
- **There is a need for regional cooperation**, and to build a knowledge base and community of practice around vulnerabilities. Regional organizations like the Caribbean Community Climate Change Centre (5Cs), Organization of Eastern Caribbean States (OECS), Economic Commission for Latin America and the Caribbean (ECLAC), and others all have a role to play. The 5Cs, for example, could support the community of practice, build capacity of countries and facilities to come up with adaptation options, and help connect them to international financing.

2.3 Implementation

- **Organizational "best practices" can increase resilience, and vice-versa.** Organizational and institutional improvements—such as improving coordination across and within organizations, improving knowledge transfer from senior to junior staff, and empowering lower-level staff to problem-solve and report issues upwards—are all ways to increase resilience.
- **"Mainstream"** adaptation activities into existing planning and decision-making processes. For example, incorporate adaptation concepts into the facility Master Plan. Adaptation strategies may be more effective if incorporated into existing processes and "owned" by those responsible (USAID, 2009). The Climate Change Policy Framework of Jamaica (Government of Jamaica, 2015) is an example of a national framework for mainstreaming.

Recommendation: Increase Regional Coordination

As described above, regional cooperation is needed to:

- Exchange best practices
- Build a knowledge base
- Identify and connect to international financing

Regional organizations like the Caribbean Community Climate Change Centre (5Cs), Organization of Eastern Caribbean States (OECS), Economic Commission for Latin America and the Caribbean (ECLAC), and others all have a role to play.

- **Climate change adaptation often comes down to a policy decision related to risk tolerance.** Scientists can provide information on the range of expected conditions and likelihood of different events, but policymakers will be the ones to act on the information, and decide what risks are acceptable. For example, should facilities be designed to a 50-year event, a 100-year event, the severity of recent events, and should expected climate change be factored into the assignment of probabilities? These decisions are a matter of policy, and setting those policies can take time.
- **Financing for capital projects remains a major hurdle.** Caribbean SIDS tend to have capacity in terms of a highly educated and skilled population, but lack capital. Many adaptation strategies will have operational savings over time, but require up-front capital spending. Individual facilities and government agencies within Caribbean SIDS need to develop processes for accessing funding sources for adaptation, such as the Green Climate Fund (GCF).
- **Ecosystem enhancements can play a significant role in reducing natural hazard risks, including coastal hazards and inland flooding**. This type of resilience approach uses the capacity of natural resources through sustainable delivery of ecosystem related services. Ecosystem enhancements offer co-benefits beyond resilience. For example, these actions can support biodiversity, store carbon, provide recreational area, and contribute to food supply (Chatenoux and Wolf, 2013). A combination of adaptation strategies, including improved processes, engineering actions, *and* ecosystem enhancements will ensure effective adaptation at all levels.

Recommendation: Address Non-Climate Hazards to Increase Resilience

Non-climate stressors are fundamentally linked to climate change adaptation challenges. For example, poor waste management in many Caribbean SIDS can exacerbate infrastructure problems during flooding. In Kingston, Jamaica, for example, heavy rains wash large-scale debris (refrigerators, etc.) into the harbor, and the Port cannot operate until that debris is removed (UNCTAD, 2017a).

Ongoing development activities can thus increase resilience to climate variability and change.

IV. Climate Risk and Vulnerability Assessment Framework for Caribbean Coastal Transport Infrastructure

Overview and Key Principles

The framework developed and presented here emphasizes a “thresholds first” approach (IDB, 2015b). This approach can increase the cost-effectiveness of a vulnerability assessment by focusing effort on the climate variables and changes that could have the greatest effect on the facility or system.

This approach is consistent with several other tested frameworks, such as the:

- UK Climate Impacts Programme (UKCIP) framework (UKCIP, 2013) – most recently tested at the Port of Manzanillo in Mexico
- USAID Climate-Resilient Development Framework (USAID, 2014) – tested in five medium-sized cities in developing countries through the Climate Resilient Infrastructure Services (USAID, 2015b)
- U.S. Federal Highway Administration Climate Change and Extreme Weather Vulnerability Assessment Framework (FHWA, 2012) – tested in Mobile, AL (U.S. DOT, 2015); Austin, TX (CAMPO, 2016); and 23 other pilot projects across the United States (FHWA, 2016)
- International Standard for Risk Management, ISO 31000:2009 – tested in the Cook Islands (Cox et al., 2013).

This framework provides a structured way for organizations in SIDS to approach climate change adaptation. Climate change adaptation can be daunting, particularly when gaps in data create uncertainties around what conditions may arise and what the costs of impacts and the costs and effectiveness of responses may be over time. This framework is intended to help SIDS overcome these challenges by providing a practical approach that uses available data to inform decision-making at a facility, local, and national level. The primary audience is port and airport managers in Caribbean SIDS, though it will also be relevant to local and national government agencies.

The framework includes four major stages (see Figure 1):

1. **Set Context and Scope** – At the outset, briefly set the parameters for the assessment.
2. **Assess Criticality** – Understand the contributions of different elements of the transport system to the society and economy.
3. **Assess Vulnerability** – Understand how critical elements of the transport system respond to climate stresses, and how risks of costly damages or disruptions may change in the future.
4. **Develop Adaptation Strategies and Mainstream in Existing Processes** – Identify where further analysis is needed (and if so, circle back to stage 3), and where action can be taken without further analysis. Understand available options and strategies to reduce

risks from climate variability and change. Monitor and evaluate to adaptively manage over time.

For each stage, the framework provides guidance and examples for how to conduct the assessment. The framework allows for flexibility based on available data, stakeholder engagement, and other relevant factors.

The framework outlines a continuum of approaches that can be used depending on data available, ranging from a quantitative "Sensitivity Threshold Method" to more qualitative approaches within the same overall framework. Text boxes and other examples throughout provide alternate methods that may be preferable in some circumstances.

Three **key principles** apply throughout the process, and can inform the method used for each step:

Key Principles

#1: Keep the end goal in mind. The purpose of assessing climate change vulnerability is to improve decision-making with respect to climate variability and change. If possible, identify specific decisions the vulnerability assessment should inform. For example:

- Long-range transport system planning
- Capital investments in transport infrastructure
- Siting for future transport infrastructure projects
- Facility maintenance investments and facility operations.

#2: Work within data limitations. In any climate change vulnerability assessment, data availability will be less than ideal. Data limitations—be they gaps in data on current assets, historical weather, future climate, or others—need not curtail adaptation efforts. This framework provides guidance on dealing with specific data deficiencies at each stage.

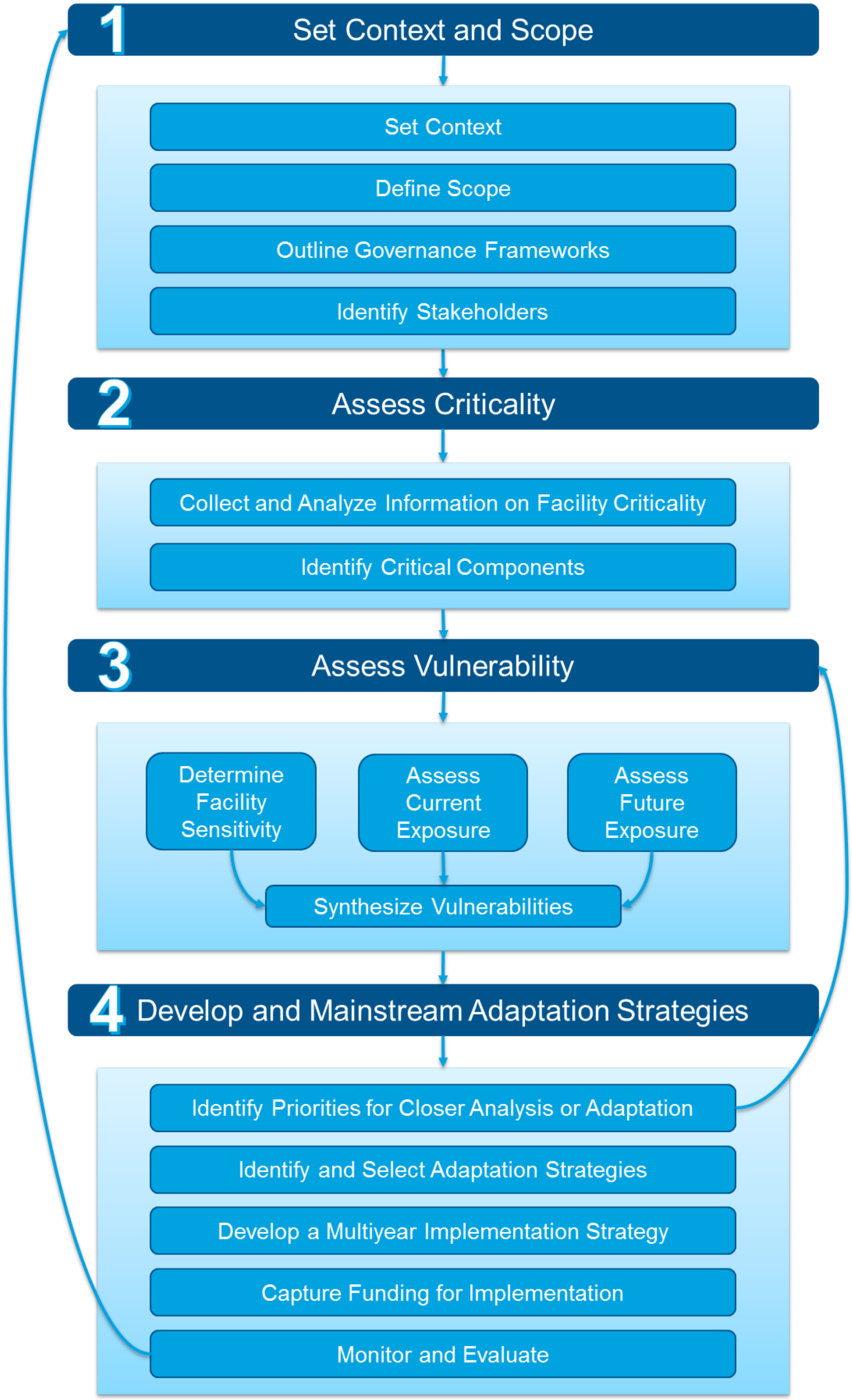
#3: Engage stakeholders. Stakeholder engagement is central to an effective climate change vulnerability assessment process. Stakeholders for port and airport adaptation may include:

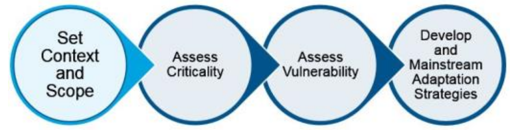
- Port and airport managers
- Port and airport authorities (e.g., Maritime Authority, Airport Authority)
- Private sector operators (e.g., ship owners, airline representatives)
- Asset owners and operators of interdependent infrastructure (e.g., energy, water)
- Government agencies overseeing:
  - Transport: infrastructure, port services, airport services
  - Environment: natural resources, water, land
  - National development: planning, sustainable development, national works
  - Disaster preparedness: emergency management
- Meteorological service
- Local or regional universities
- International or other organizations who have done related work in the study area (e.g., World Bank).

Engaging these stakeholders throughout the process has multiple benefits, including to:

- **Help fill data gaps –** Facility operations, maintenance, management staff, and private sector operators may have informal “data” and information on climate change vulnerabilities, either through historical experience or through expert judgment. For example, facility managers in both the Saint Lucia and Jamaica case studies provided critical insights into facility vulnerabilities.
- **Build support for adaptation efforts –** Involve stakeholders who will be ultimately responsible for implementing the adaptation strategies. This enables them to understand the purpose and importance of adaptation and weigh in on the feasibility of different strategies, both of which make adaptation easier.
- **Build capacity –** Climate change adaptation requires some skill sets and expertise not often common among facility or government employees (e.g., risk analysis, climate science, and engineering). Involving stakeholders throughout the assessment can build their capacity to understand and address climate change risks.

Figure 1. Climate risk and vulnerability assessment framework for Caribbean coastal transport infrastructure





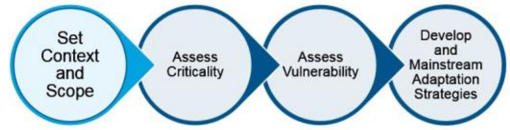
1. Stage 1: Set Context and Scope

At the outset, briefly set the parameters for the assessment.

1.1 Set context

Review existing studies to understand the following and document what you find for internal reference:

- **What are the pre-existing stressors to the transport system?** Consider how aging infrastructure, land use change, population growth, port and airport usage rates, economic shocks, waste management, crime, pollution, and enforcement of regulations are influencing success of development strategies, programmes, and projects. There is no need to do a formal analysis of these stressors at this point, but keep them in mind as you move forward, so as not to assess climate change vulnerabilities in isolation. For example, poor waste management in many Caribbean SIDS can exacerbate infrastructure problems during flooding. In Kingston, Jamaica, for example, heavy rains wash large-scale debris (refrigerators, etc.) into the harbor, and the Port cannot operate until that debris is removed (UNCTAD, 2017a).
- **How does your adaptation effort fit into the development needs of the country?** For example, review National Communications to the United Nations Framework Convention on Climate Change, Climate Change Policy Frameworks from the Government, and other applicable national-level strategies.
- **What related work has been done so far?** Consider what government or other agencies exist that are working on climate change adaptation, and draw from existing materials to the extent possible. Other organizations that may have done relevant work include the World Bank, USAID, IADB, other development organizations, or neighboring countries.
- **Who are the main agencies and individuals responsible for adaptation?** Identify key players who can be engaged in the vulnerability assessment and apply its results.
- **What key decisions are you trying to inform?** Desired outputs from the vulnerability assessment may vary depending on, for example, whether you are trying to inform long-term airport planning or trying to decide how long to extend a specific runway.



Case Study Example:

For Saint Lucia, existing studies or assessments completed prior to the case studies included:

- CARIBSAVE Climate Change Risk Atlas, Climate Change Risk Profile for Saint Lucia
- World Bank Report: Climate Change Adaptation Panning in Latin America and Caribbean Cities, Final Report: Castries, Saint Lucia
- Second National Communication on Climate Change for Saint Lucia

The team could use information on climate change projections from those resources rather than starting from scratch. These resources also helped clarify the scope of the case study analysis.

1.2 Define scope

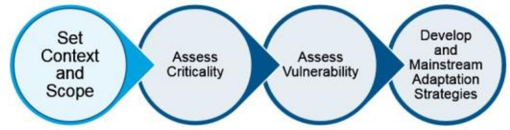
Define the scope of the vulnerability analysis. Decide on:

- **Physical Scope** – Choose specific facilities and/or geographies to include in the analysis. Physical scope is likely to be first constrained by available resources (e.g., Are there sufficient resources to include all facilities? How many facilities can the project address?). Once a feasible number of potential facilities is identified, select specific facilities based on factors such as criticality (see Stage 2), data availability, and level of engagement of key stakeholders.
- **Temporal Scope** – Choose a specific time period(s) (e.g., 2040-2060) to analyze for vulnerability. Consider relevant planning horizons, expected asset lifetimes, data availability, and other factors. For example, choose a time period that aligns with the long-term master plan for the facility.
- **Climate Scope** – Choose which climate hazards you intend to cover. Examples include extreme heat, heavy precipitation, sea level rise, tropical storms, landslides, drought, and wildfire.

Case Study Example

The scope of the Jamaica and Saint Lucia case studies was set as follows:

- **Physical scope** – Four specific assets in each country (e.g., Hewanorra International Airport, George F. L. Charles Airport, Port Castries, and Port Vieux Fort in Saint Lucia). These assets were selected on the basis of their economic and cultural importance to each nation.
- **Temporal Scope** – Mid-century (2050s), to align with a 35-year long-term planning horizon, which corresponds with expected asset lifetimes and relevant long-term transport plans.
- **Climate Scope** – Primarily focused on coastal hazards of sea level rise and tropical storms, with secondary emphasis on inland flooding and extreme heat.



1.3 Outline governance frameworks

Once the scope has been set, outline the following for the selected transport facilities:

- **Ownership and Operational Framework –** What entities own and operate the facilities, and to whom are they responsible? (see example in text box below)
- **Legislative and Regulatory Framework –** What laws or statutes govern the behavior of the facilities?

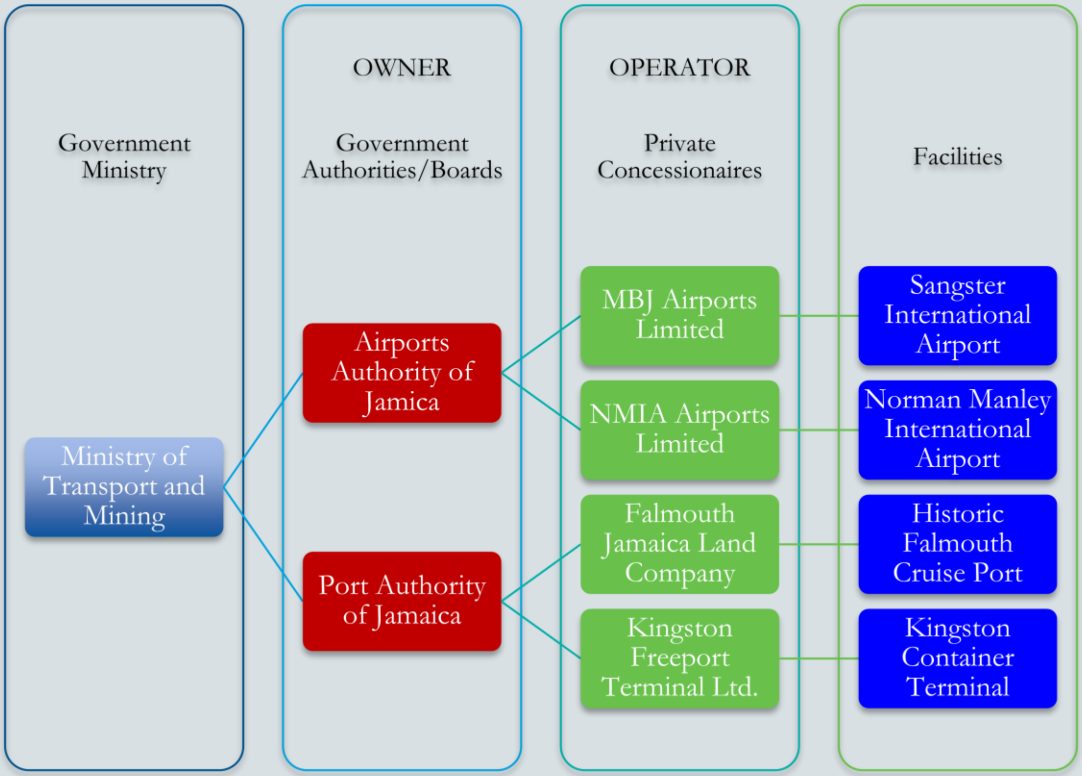
This is important to understand the practical constraints and lines of authority over ultimate adaptation decisions.

Case Study Example

The Jamaica case study ultimately focused on four facilities: Norman Manley International Airport, Sangster International Airport, Kingston Freeport Terminal, and Historic Falmouth Cruise Port.

Ownership and Operations Framework

At the outset of the assessment, the study team outlined the ownership and operations framework of these facilities, as shown in the diagram below:



This was determined in consultation with stakeholders and through review of publicly available documents and websites of the relevant organizations.

Legislative and Regulatory Framework

The study team also consulted with stakeholders to identify any legislative or regulatory constraints on the airports, such as:

- Civil Aviation Regulations of 2004 – These regulations identify requirements for operations of aerodromes, including management of obstacles and hazards at aerodromes. Any physical changes to the airports would have to meet or exceed the minimum standards to which an aerodrome operator is obligated to meet to operate in Jamaica.
- Protected Areas Policy of the Palisadoes Peninsula – For NMIA, any physical changes to the facility would have to comply with this policy to protect the sensitive ecosystem surrounding the airport.

Source: UNCTAD, 2017a

1.4 Identify stakeholders

Finally, with the context understood, develop a list of all stakeholders to engage throughout the assessment process. Stakeholder engagement is a critical element of any vulnerability assessment, not only for providing critical information about facility vulnerabilities and adaptation options, but also to build capacity and willingness of decision makers and staff to implement and sustain the resilience efforts (Cox et al., 2013; FHWA, 2012; USAID, 2014).

See the “Key Principles” text box for a list of the types of stakeholders to engage. Use a table such as the one provided in Table 17 to keep track of stakeholder names, roles, and contact information, as well as how often you engage them throughout the process.

2. Stage 2: Assess Criticality

Defining Criticality

Criticality is the overall importance of an asset or system. *Resource and time limitations generally require that assessments focus on assets or systems that are most critical.* Specific definitions or criteria for criticality can vary by organization or individual. This section provides guidance on defining and assessing criticality for the purpose of conducting a climate change vulnerability assessment.

Criticality can be dealt with in two ways:

(1) To screen for or identify the most critical facilities or components within a system. For example, to identify the most critical transport facility or to narrow the scope of a vulnerability assessment (U.S. DOT, 2011; U.S. DOT, 2014a) (a “criticality screening”)
(2) To quantify or otherwise assess the criticality of an individual facility, in order to determine the potential consequences of disruption (Cox et al., 2013; UNCTAD, 2017b; UNCTAD, 2017a) (“criticality assessment”).

The remainder of this section focuses conducting a criticality *assessment.* See U.S. DOT (2014a) for more detailed guidance on conducting a criticality *screening*. The criticality assessment will help you characterize and quantify, to the extent possible, the potential consequences of damage or disruption at a facility. The results of the criticality assessment can be used later to assess the potential consequences and risks of climate change and extreme weather impacts.

The criticality assessment stage includes two main steps: (1) collecting and analyzing information on facility criticality, and (2) identifying critical components within the facility.

2.1 Collect and analyze information on facility criticality

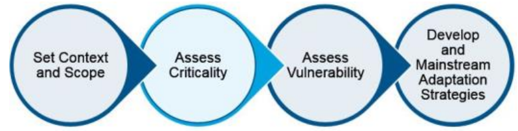
In Caribbean SIDS, ports and airports have implications for the country’s development goals, economy, tourism, society, environment, and more. Facilities may be critical because of their economic contributions (as measured by passenger or freight throughput, for example), health and safety contributions (such as their role in evacuation or emergency management), or other value. Table 3 summarizes example criticality criteria and where data may be available to quantify the criticality of a given facility.

Table 3. Information to consider in facility criticality assessment

Category	Criticality Criteria	Potential Data Sources
Facility operations	Volume of passengers (daily, monthly, or annual)	• Facility manager • Port Authority • Existing economic impact studies • Newspaper articles • Local governments • Damage assessment reports • Other stakeholders
	Number of movements (daily, monthly, or annual)	
	Value of cargo transported	
	Cost to replace or repair the facility	
	Revenue generated at the facility	
Economic contributions	Contributions of facility to tourism (e.g., % or number of tourists)	
	Contribution of facility to GDP	
	People employed at the facility	
Health/safety implications of facility	Whether facility is necessary for hurricane evacuation	
	Whether facility is necessary for access to hospital or healthcare	
	Whether facility is necessary for emergency management	
Interconnectivity	Whether facility provides access to economic centers	
	Whether facility provides access other modes of transport	
	Whether facility provides access to employment centers	
	Whether facility is necessary for roads to operate	
	Whether facility is necessary to provide fuel supplies	
	Whether facility is necessary for power systems to operate	
	Whether facility is necessary for communications systems to operate	
	Whether facility is necessary to maintain access to water supplies	
	Whether facility is necessary to maintain access to food supplies	
	Whether facility is necessary to maintain access to basic goods	
	Whether facility is necessary to maintain operations of waste services	
Other	Lack of redundancy	
	Warehousing capacity (e.g., how long can facility be out of service before impacts are felt)	

Source: Criteria compiled from U.S. DOT, 2014a and Cox et al., 2013

Data on **facility operations or economic contributions** are more likely to be quantitative, and likely to be available from the port or airport management, in national transport statistics, or in existing reports about the port or airport operations. Post-disaster damage assessment reports can be a valuable source of information, summarizing and quantifying the impacts of past disruptions. For example, the damage assessment report of Hurricane Ivan in Grenada quantified that the storm damaged the Port Salines International Airport navigational aids and tower radio equipment, which cost EC$1.0 million to repair, and cost the airport EC$500,000 in lost revenues (OECS, 2004).



Data on the **health and safety contributions** and **interconnectivity** of facilities are more likely to be qualitative, and best gathered through interviews or surveys with stakeholders. The most relevant stakeholders include port or airport managers or other government staff. For example, a vulnerability assessment of Avatiu Port in the Cook Islands included a survey of several key stakeholders,[2] each of whom were asked to rate the importance of the port on various interconnected infrastructure and vice-versa (Cox et al., 2013). The role of the port or airport in the interconnected island system can be difficult to quantify, but is important to articulate, at a minimum in general terms.

For example, Cox et al. (2013) found that all connected infrastructure—roads, bridges, drainage, water supply, water and solid waste, fuel, airport, power, food and goods, communications, tourism, emergency management, and environmental services—would be directly impacted by extreme weather and climate change. Avatiu Port, however, has "high" reliance on the road and bridges, but only "medium" reliance on other infrastructure, according to port managers (Cox et al., 2013).

Not all data will be available within a reasonable timeframe or level of effort. At this stage, gather as much information as is readily available. You can gather more detailed information during the vulnerability assessment stage, if needed.

Case Study Example: Sangster International Airport

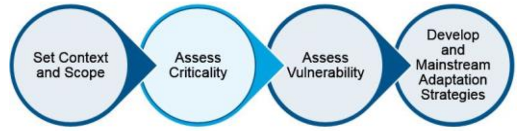
The criticality assessment for Sangster International Airport (SIA) in Jamaica included the following information, which came from the noted sources:

- Of the approximately 1.7 million annual visitors to Jamaica, 72% use SIA as their primary airport (Source: SIA airport website and Airports Authority of Jamaica)
- The share of visitors using SIA as their primary airport has been increasing since the 2008/2009 fiscal year (Source: Airports Authority of Jamaica)
- On average, 3.5 million persons traveled through the airport annually from 2010 to 2015 (Source: arrivals and departures data from SIA)
- Nearly 65,000 kilos of cargo and mail came through SIA in 2015 (Source: data from SIA)
- Because of its location on the north coast, close to hotels and tourist attractions, the airport serves as a critical tourist gateway into the island, without which arriving passengers would have to travel long hours from NMIA to reach their north coast destinations (Source: stakeholder interviews).

Source: UNCTAD, 2017a

As evidenced by the case study example above, the criticality assessment does not need to cover every criteria from Table 3, nor does it have to be exclusively quantitative. Rather, the goal of the assessment is to gather available information to make the case for why ensuring operability of the facility is important.

[2] The key stakeholders surveyed in this example were the port Chief Executive Officer, Port Operations Manager, Harbour Master, Finance and Administrative Staff, Ministry of Infrastructure and Planning staff, Cook Islands Trading Corporation General Manager, National Environment Service staff, and the power authority Chief Executive Officer.



2.2 Identify critical components

Finally, you may want to identify critical *components* of the facility in this assessment, and define the relationship of different components to the functioning of the whole facility. Do this in consultation with stakeholders.

Diagramming the asset network is one way to do this, by identifying the key facility capabilities (transport passengers, provide berthing space, provide supplies, etc.) and identifying which facility components (docks, runways, terminals, power supplies, water supplies, etc.) are necessary to achieve that capability (see Burks-Copes, 2013, slide 19 for an example).

Port components may include (Cox et al., 2013):

- Docks and berths
- Cranes
- Utilities
- Buildings and warehouses
- Access roads
- Utilities.

Airport components may include (ACRP, 2015):

- Commercial passenger terminal facilities
- Runways, taxiways, and holding areas
- Gates
- Aircraft parking aprons
- Stormwater drainage
- Water distribution systems
- Communications systems
- Aircraft fueling infrastructure
- Navigational aids
- Access roads
- Parking facilities
- On-site electrical infrastructure
- Curbside amenities
- Administrative areas
- Personnel and passengers
- Environmental performance (e.g., noise, air quality, water quality)
- Aircraft performance
- Aircraft rescue and firefighting
- Grounds and landscaping
- Airport demand.

Case Study Example: Norman Manley International Airport

At Norman Manley International Airport (NMIA) in Jamaica, there are several critical components, primarily due to lack of redundancy:

- **Runway** – This is the sole runway at NMIA, therefore its operability is directly connected to the operability of the airport
- **Access Road** – Although not an official component of NMIA, the airport's access road on Norman Manley Highway is the only way of accessing the airport, both for customers and staff.

Other infrastructure at the airport is important, such as the control tower, terminal building, and the electrical power system, but airport stakeholders note that backup options are available in the case of damage or disruptions.

Source: UNCTAD, 2017a

At the conclusion of the criticality assessment you should understand the importance of the facility to the island, and whether there are individual components of the facility that are particularly critical for maintaining operations.

3. Stage 3: Assess Vulnerability

The goal of the vulnerability assessment is to identify whether and how expected changes in climate will impact individual transport facilities and their services.

This is carried out through four steps, summarized in Figure 2:

1. Determine Facility Sensitivity
2. Assess Current Exposure
3. Assess Future Exposure
4. Synthesize Vulnerability

Key Vulnerability Definitions

- **Exposure** – The extent to which the asset is subject to a climate hazard (assessed in Step 3.3)
- **Sensitivity** – The extent to which the asset will be positively or negatively affected if it is exposed to a climate hazard (assessed in Step 3.1)
- **Adaptive Capacity** – The ability to take actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities from current climate extremes and long-term climate change.

Source: USAID, 2016

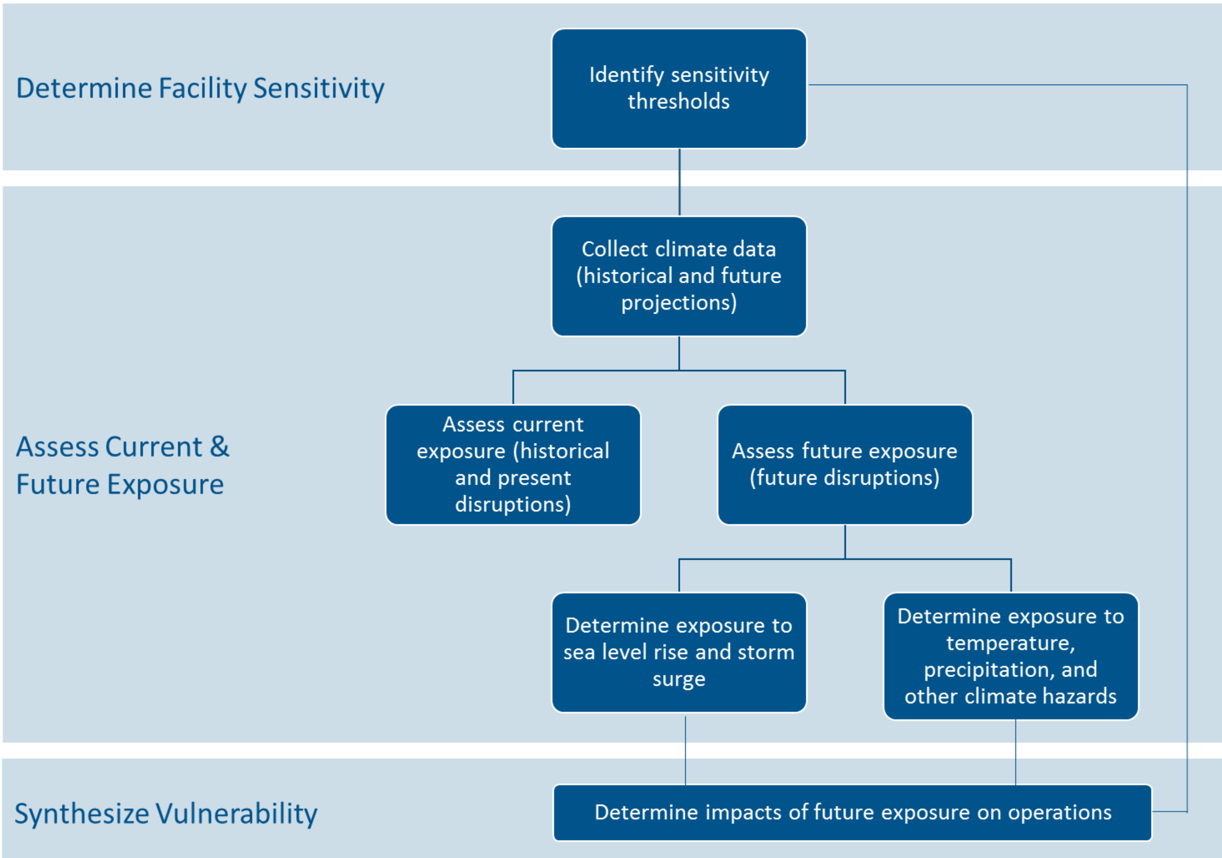


Figure 2. Sensitivity threshold methodology for vulnerability assessment

The assessment can be quantitative, qualitative, or a hybrid, depending on data availability and how the assessment will be used (see box below). The remainder of this section provides practical information on options and strategies for assessing facility vulnerability.

Choosing Between Quantitative and Qualitative Vulnerability Assessment Methods

In Caribbean SIDS, reliable data about facility operations, economic impacts, weather, and expected climate may not be easily available.

Especially when data are not available, qualitative assessments (e.g., low, medium, high) of vulnerability can be useful, particularly as a way of prioritizing vulnerabilities for more detailed analysis (Cox et al., 2016; USAID, 2016) at a later stage.

Quantitative assessments can be helpful in choosing between specific adaptation options and understanding the costs and benefits of adaptation.

Advantages and disadvantages of quantitative and qualitative assessments are summarized below, per USAID (2016):

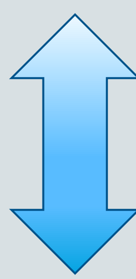
	Advantages	**Disadvantages**
Qualitative	Easily understandable Useful for prioritizing action Relatively low cost to prepare	Does not communicate complex or less obvious aspects of vulnerability well May be open to interpretation and therefore contain uncertainties Does not directly imply the nature of adaptations that would be helpful
Quantitative	Helpful for informing cost-benefit analyses of adaptation options Takes advantage of available data Can communicate complex or less obvious aspects of vulnerability	Can be time and resource intensive Can be long, technical, hard to follow and thus not used effectively if sufficient outreach is not conducted May not have all desired data

One way to decide the correct approach is to decide based on the intended use of the vulnerability assessment, per the diagram below.

How will the assessment be used?

- To identify priorities for more detailed study
- To inform land use planning decisions
- To inform long-term facility plans
- To inform infrastructure investment decisions
- To build the economic case for adaptation
- To design adaptation strategies

More qualitative



More quantitative

3.1 Determine facility sensitivity

Sensitivity is the degree to which the facility is likely to experience one of the following in response to exposure to a climate hazards:

- **Direct physical damage** to infrastructure, resulting in added repair costs and potential operational disruptions, or
- **Operational disruptions** (partial or complete), meaning services (e.g., flights, cargo movements) are limited or stalled for a period of time.

The first step to determining potential climate change vulnerability is to understand how sensitive facilities are to damage or disruption from different climate hazards.

3.1.1 Establish General Sensitivity Relationships

As a quick initial exercise, begin by qualitatively identifying the mechanisms by which climate change can affect port and airport infrastructure. Develop a "sensitivity matrix" documenting these relationships. Start with the examples provided in Table 4 and Table 5, and modify them, as needed, for local conditions. If known thresholds are available, insert them here. Later steps will attempt to further quantify these relationships.

Facility managers can help review these matrices, and provide information on specific sensitivity relationships and thresholds, as available.

Table 4. Port climate sensitivities

Climate Hazard	Docks	Crane Operations	Access	Other
Sea Level Rise	Higher sea levels can increase the risk of chronic flooding and lead to permanent inundation of dock facilities, making a port inoperable.	Not sensitive.	Sea level rise could affect port access routes.	Not applicable.
Tropical Storms/ Hurricanes/ Storm Surge	Storm surge can damage marine port facilities, causing delays in shipping and transport. For example, Hurricane Ivan in Grenada damaged the main port terminal and prevented normal operations for three weeks (OECS, 2004).	Not sensitive.	Tropical storms can cause roadway damage and debris movement, blocking access to the port for staff and ground transport.	Port operations may be halted for the duration of the storm. Floodwaters or winds can also transport debris that must be removed before operations can resume.
Wind	Not sensitive.	Cranes cannot be used above certain wind	Wind can blow over road signs and stir up dust from unpaved roads.	High wind speeds could create hazardous working

Climate Hazard	Docks	Crane Operations	Access	Other
		speeds. Inoperable cranes can cause delays in shipping.	Downed signs and swirling dust can create confusing and dangerous travel conditions.	conditions for port staff. Winds can also transport debris that must be removed before operations can resume.
Extreme Heat	Not sensitive.	Not sensitive.	Extreme heat can result in asphalt pavement softening or rutting, or cracks in concrete pavement.	Extreme heat can create hazardous working conditions for port staff and could deteriorate paved terminal areas. Extreme heat can also raise energy costs for cooling.
Heavy Precipitation /Flooding	Heavy rain can reduce visibility and create flooding, causing damage to port structures and equipment and delaying shipping and transport.	Flooding can cause damage to crane equipment, making it inoperable and halting or slowing operations and goods handling.	Heavy rain can overwhelm existing draining systems and cause flooding, creating pavement and embankment failure, erosion, debris movement, and restricted port access. Heavy precipitation can also cause increased sedimentation of the port basin, reducing drat clearance for vessels and terminal access.	Flood waters can transport debris that must be removed before operations can resume. For example, this has occurred at Kingston Freeport Terminal, requiring tugs and manpower to remove the debris before operations can resume (UNCTAD, 2017a).

Source: Adapted from U.S. DOT, 2014b and IDB, 2015b.

Table 5. Airport climate sensitivities

Climate Hazard	Airport Runways/Tarmac	Airport Buildings	Access	Other
Sea Level Rise	Standing water on runways can prevent flight operations. Disruptions are dependent on duration of potential inundation, and are driven by elevation and other conditions. Severity may range from occasional (e.g., during extreme high tides), to twice daily, to permanent.	Sea level rise could inundate low-lying coastal buildings. Impacts may range from nuisance to permanent loss of facility operations.	Sea level rise could also affect airport access routes.	Not applicable.
Storm Surge	Tropical storms and storm surge may deposit large amounts of debris onto runways (e.g., vegetative debris, sand). Operations cannot resume until debris is cleared.	Tropical storms can damage airport buildings through roof damage or thrown debris. Documents and equipment on the ground flood could be destroyed.	Tropical storms can cause roadway damage and debris movement, preventing airport access.	Airport operations may be halted for the duration of the storm.
Wind	Strong winds can prevent aircraft takeoff and landing. Winds can also deposit debris onto runways that requires cleanup before operations can resume.	Very strong winds can damage buildings through roof damage or flying debris.	Wind can blow over road signs and stir up dust from unpaved roads. Downed signs and swirling dust can create confusing and dangerous travel conditions.	Strong winds and debris movement could create dangerous working conditions for airport staff.
Extreme Heat	High temperatures can increase required takeoff lengths. They can also cause pavement softening or cracking, which can increase maintenance costs.	High temperatures can increase building energy costs.	Extreme heat can result in asphalt pavement softening or rutting, or cracks in concrete pavement. Airport access is unlikely to be affected, however.	Extreme heat can create hazardous working conditions for airport staff. Extreme heat can also raise energy costs for cooling.
Heavy Precipitation /Flooding	Heavy rain can overwhelm existing drainage systems, causing standing water on	Heavy rain can overwhelm existing drainage systems,	Heavy rain can overwhelm existing roadway	Heavy rain can reduce visibility and

Climate Hazard	Airport Runways/Tarmac	Airport Buildings	Access	Other
	pavements and inhibiting operations. Water on the runways can prevent planes from landing. Flood waters can also deposit debris onto runways that requires cleanup before operations can resume.	causing flooding in buildings. Impacts may range from nuisance to permanent loss of facility operations.	drainage systems and cause flooding, creating pavement and embankment failure, debris movement and erosion and restricting airport access.	create hazardous working conditions for airport staff.

Source: Adapted from U.S. DOT, 2014b

Scope Alert:

The vulnerability assessment should be as thorough as is necessary to inform the decisions or purposes for which it is designed. If facing capacity or financial constraints, now can be a time to narrow the scope of the vulnerability assessment, by identifying and prioritizing the most important sensitivity relationships. Use the following questions to help narrow the scope:

- Which impacts are potentially most damaging or disruptive to the facility?
- Which climate hazards are most likely to occur at the facility?

3.1.2 Establish Sensitivity Thresholds

Where possible, build on the qualitative sensitivity relationships to identify whether there are any specific thresholds at which these impacts occur. For example, from "extreme heat can create hazardous working conditions for airport staff," identify that temperatures above 46°C (115°F) can create hazardous working conditions for airport staff. The goal of obtaining this information is to identify how often these thresholds may be exceeded in the future (in Step 3.3) and estimate the potential cost or other impact of such events.

Table 6 provides known thresholds for ports and airports to use as a starting point, compiled from international organizations and existing port or airport vulnerability assessment studies.

Ask experienced facility managers to confirm whether these thresholds are applicable to the facility in question. Ask facility managers to help identify additional thresholds as well, as Table 6 also does not include thresholds for several variables, as none are available in the literature.

Frequently Asked Questions

- **What is a sensitivity threshold?**

  A sensitivity threshold is a level of weather conditions at which a facility or piece of infrastructure experiences disruption or damage.

- **Who sets sensitivity thresholds?**

  Sensitivity thresholds are inherent to the individual facility or component. Thresholds for damage are likely set within the engineering or design specifications of the asset. Operational thresholds—e.g., the port shuts down when wind speeds exceed X m/s—are set by facility managers based on safety and other risk considerations.

- **How do I know my sensitivity thresholds?**

  See below for a discussion of possible data sources for sensitivity thresholds.

- **What do I do if I do not have any known sensitivity thresholds?**

  The section below includes guidance on how to determine sensitivity thresholds at your facility. If you are unable to do so with available resources, see the "Alternate Approach" text box on page 43.

Key questions to ask to determine sensitivity thresholds are:

- **In which conditions is the facility unable to operate?** Conditions could include temperatures, precipitation amounts, precipitation intensities, wind speeds, wave heights, standing water levels, or others.
  - **Does the facility have official operational manuals that specify thresholds?** For example, facilities may specify that port operations must cease once wind speeds reach a certain threshold.
  - **In which conditions has it been unable to operate in the past?** Stakeholders may not know the specific threshold offhand, but they may know the date of specific events that have disrupted operations. In that case, use weather station data to gather information about the specific temperature, precipitation, and wind conditions during that event to determine the threshold.
- **In which conditions would the facility be damaged?** To know this, identify:
  - **In which conditions has it been damaged in the past?** Damage assessment reports or interviews with stakeholders such as facility managers can identify these conditions.
  - **What conditions is it designed to withstand?** This information may be drawn from known generic standards and thresholds.

This information may be available from:

- **Generic standards and thresholds –** Table 6 compiles known thresholds for ports and airports. These could be used as a starting point, but 1) does not include information on all possible thresholds, and 2) needs to be verified as applicable by local stakeholders.

- **Interviews with facility managers –** Individual port or airport facilities are the first place to check for relevant thresholds.
- **After-action reports** – Similarly, after-action reports or post-disaster assessments can provide quantitative and qualitative information on impacts of past events. Past events can be used as a rough proxy for future events that may change with climate.
- **Proxy facilities –** If specific thresholds are not known or available for the facility in question, the information may be available from similar facilities.
- **Industry guidelines** – Information on certain thresholds will vary by airport, but can be looked up in various design or operational manuals. Common ones, and methods for using them, are found in text boxes below Table 6:
    - Pavement and temperature
    - Runway length and temperature
    - Aircraft takeoff requirements and temperature

Table 6. Compilation of available port and airport climatic sensitivity thresholds

Climate Hazard	Component	Impact	Example Threshold	Source
Ports				
Extreme Heat	Operations	Energy costs	1°C warming = 5% increase in energy costs (in one illustrative terminal)	IDB, 2015b
	Paved surfaces	Asphalt pavement softening	Depends on asphalt pavement grade (**see box below for how to determine thresholds based on pavement grade and location**)	U.S. DOT, 2014
Heavy Rain	Cranes	Low visibility inhibits crane operation	In Manzanillo, intense rainfall > 20 mm within 24 hours reduces visibility enough to impair operations	IDB, 2015b
	Goods handling	Inability to handle water-sensitive goods	Precipitation > 1 mm within 24 hours	IDB, 2015b
Flooding	Operations	Flooding in some locations of the port could impair operations.	Conditions that cause flooding will vary by facility.	
Tidal Flooding	Docks	Flooding	Dock elevation/quay height (**see box below for more information**)	IDB, 2015b
Wind Speeds	Cranes	Ability to operate	Varies by crane type. For example, 25 m/s (56 mph, 48.6 knots) for a CONTECON SSA	IDB, 2015b
	Navigational channel	Ability to berth ships (due to waves)	Varies by facility.	UNCTAD, 2017a

Climate Hazard	Component	Impact	Example Threshold	Source
			For example, at Kingston Container Terminals (KCT) in Jamaica: • Winds ≥ 18 m/s (40.3 mph, 35 knots) force operational shutdown • With winds of 12.8-18 m/s (28.8-40.3 mph, 25-35 knots), discretion is applied At Falmouth Cruise Port: • Winds > 12.8 m/s (28.8 mph, 25 knots) create unmanageable docking trajectories	
Airports				
Extreme Heat	Runways	Ability of aircraft to take off	Runway length requirement varies based on plane type, weight, and runway length. **See box for how to determine thresholds for any aircraft and location**. Rule of thumb: Runway length requirements increase by 1% for every 1°C by which the mean daily maximum temperature of the hottest month exceeds 15°C (assuming runway is at sea level) (ICAO, 2006)	ICAO, 2006, Chapter 3
	Flight operations	Aircraft maximum take-off operational temperature	47.7°C (118°F)	ACRP, 2016
	Personnel	Reduced employee ability to work safely outdoors (need for more breaks)	Heat Index* over 39.4°C (103°F) is "high" risk Heat Index* over 46°C (115°F) is "very high" risk	ACRP, 2016
Heavy rain	Flight operations	May decrease runway friction to aircraft cannot take off	Varies by airport	ICAO, 2002, Chapters 6-7
Flooding	Flight operations	Inability of aircraft to land or take off	Any flooding on the runway can impair operations. Conditions that cause flooding will vary by airport.	ICAO, 2002, Chapter 2
Sea Level Rise	Flight operations	Flooding on the runway	Runway elevation	U.S. DOT, 2014
Wind Speeds	Flight operations	Inability of aircraft to land or take off	Commercial airports: sustained winds of 20 m/s (45 mph, 39 knots) or frequent gusts of 26 m/s (58 mph, 50.4 knots)	ACRP Report 160

Climate Hazard	Component	Impact	Example Threshold	Source
			General Aviation airports: 11.2 m/s (25 mph, 21.7 knots)	

*Heat Index is a function of temperature and relative humidity. See http://www.nws.noaa.gov/om/heat/heat_index.shtml. For a relative humidity of 70%, Heat Index would exceed 39.4°C (103°F) at 32.2°C (90°F) and would exceed 46°C (115°F) at 34°C (94°F).

Identifying Thresholds: Pavement and Temperature

Pavement binders are named by the temperature assumptions built into them. For example, Performance Grade (PG) 64-22 means that the highest temperature the pavement is expected to reach is 64°C, 22 mm below the surface. The following formula can be used to convert the 22 mm temperature (T22m) into ambient air temperature (Tair):

$$T_{22mm} = ((T_{air} - 0.00618\ lat^2 + 0.2289\ lat + 42.2)\ (0.9545) - 17.78$$

Using this equation for the latitude of Kingston, Jamaica (18.0179°N) yields the following air temperature thresholds for different pavement binders:

Pavement Binder	Air Temperature (T_{air}) Threshold in Kingston, Jamaica
PG 46-X	22.5°C (72.5°F)
PG 52-X	22.8°C (83.8°F)
PG 58-X	31.1°C (95.1°F)
PG 64-X	41.4°C (106.4°F)
PG 70-X	47.6°C (117.8°F)
PG 76-X	53.9°C (129.1°F)

Note:

Note, however, that climate change happens slowly relative to most pavement lifecycles (e.g., 20-40 years), so in most cases immediate adaptation for pavements is not necessary (FHWA, 2015b). However, climate change should be considered in pavement design for new, long-lived projects (FHWA, 2015b).

Source: U.S. DOT, 2014c; U.S. DOT, 2014b

Identifying Thresholds: Runway Length and Temperature

The ICAO Aerodrome Design Manual, Part 1: Runways (ICAO, 2006), provides detailed guidance in Chapter 3 regarding the factors influencing runway length requirements. Among these are typical weather conditions, including surface wind and temperature.

Section 3.5 explains runway length corrections for elevation, temperature, and slope.

Identifying Thresholds: Aircraft Runway Length Requirements and Temperature

Individual aircraft manufacturers set minimum runway length requirements related to temperature. To determine the requirements for your airport:

- Identify the type of aircraft that use the airport or might use it in the future.
- For major aircraft categories, find airport specifications on the manufacturer's website.
  - For example, Boeing provides "Airplane Characteristics for Airport Planning" at: http://www.boeing.com/commercial/airports/plan_manuals.page
  - The Boeing 737 manual (Boeing, 2013) provides "F.A.R. Takeoff Runway Length Requirements," in a series of charts beginning on page 104. Each chart shows the runway length requirements for a different air temperature (e.g., pg. 104 shows a "Standard Day" of 15°C (59°F), and pg. 105 shows a "Standard Day" plus 15°C, or 30°C (86°F).
- Read the tables for the elevation of your airport to determine how runway length requirements change with temperature. For example, the table below shows the takeoff runway length requirements for two models of Boeing 737 aircraft under multiple temperature conditions, assuming the airport is at sea level.

Takeoff Runway Length Requirements by Temperature and Aircraft

	Mean maximum daily temperature of the warmest month				
	STD* 15°C (59°F)	STD+15°C 30°C (86°F)	STD+22.2°C 37.2°C (99°F)	STD+25°C 40°C (104°F)	STD+35°C 50°C (122°F)
Boeing 737-600	7,000 ft. (2,134 m)	7,600 ft. (2,316 m)	10,000 ft. (3,048 m)	n/a	11,500 ft. (3,505 m)
Boeing 737-700/-700W	9,200 ft. (2,804 m)	10,000 ft. (3,048)	12,500 ft. (3,810 m)	n/a	15,000 ft. (4,572 m)
Boeing 737-800/-800W/BBJ2	7,800 ft. (2,377 m)	8,100 ft. (2,469 m)	n/a	10,100 ft. (3,078 m)	15,000 ft. (4,572 m)

Source: Boeing, 2013
All values assume the following conditions: maximum aircraft takeoff weight, sea level, dry runway, zero wind, zero runway gradient, air conditioning off, and optimum flap setting.
*STD = Standard Day

Example

In Saint Lucia, George F. L. Charles Airport has a runway length of 1,898 m (6,227 ft.) and Hewanorra International Airport (HIA) has a runway length of 2,744 m (9,003 ft.) (DAFIF, 2012). The table shows, for example, that Boeing 737-600 aircraft would not be able to take off from HIA if the average daily high temperature in September (the hottest month of the year in Saint Lucia), exceeds 37.2°C (99°F) without reducing aircraft loads. None of these planes are able to land at George F. L. Charles Airport in September. If average temperatures increase due to climate change, the current infrastructure will be insufficient and airport operations will be negatively impacted if they do not consider future climate projections and respond to these changes.

Identifying Thresholds: Sea Level Rise

For sea level rise, the key threshold is typically whether any areas or components of the facility might be inundated by sea level rise. Additional guidance is provided in section 3.3 on determining the potential extent of inundation.

However, simply measuring the vertical distance between immediate coastal infrastructure (such as docks) and mean higher-high water levels can provide an indication of how much “room” the facility has to accommodate sea level rise.

3.1.3 Determine Impacts of Crossing Thresholds

To the extent possible, quantify the costs and other impacts of exceeding these thresholds. If thresholds are linked to damage, identify the replacement value of the infrastructure as a key illustrative metric. If thresholds are linked to disruption, characterize the potential length of disruptions and the impacts of those disruptions. Much of this information may have already been collected in the criticality assessment from Stage 2. Impacts may be both direct (e.g., damage to facility infrastructure) and indirect (e.g., potential setbacks to the agricultural industry, inability of tourists to arrive on the island, disruption to fuel supply).

Example: Falmouth Cruise Port

During the Jamaica “national workshop” conducted under this project, a representative from Falmouth Cruise Port indicated that when winds exceed 30-35 knots, they have to turn away ships. This happened 15 times in 2016, which lost the port 45,000 cruise passengers.

Key questions, to be answered through interviews with stakeholders or review of past damage assessments include:

- What were the impacts of a previous event, such as a hurricane, on:
  - Facility infrastructure?
  - Facility operations?
  - Staff ability to access the facility?
- How long did it take to return to normal operation?
- What are your most pressing challenges related to facility maintenance and operations?
- What data or information do you maintain on damages or maintenance costs associated with past events?
- Were problem areas fixed or upgraded after the last event? Do you think you would be more or less impacted by a future event?
- What are the indirect impacts of damage to the facility?

Quantify the impacts you can, and list those impacts that are known, but not possible to quantify.

Keep in mind that this is not a substitute for the analysis of future climate change, which is discussed beginning in Step 3.3. The consideration of thresholds in response to past events is merely a starting point that can help you determine the importance of future climate change.

Data sources include:

- **Facility operators** – Facility managers and staff may have institutional knowledge about past events from facility records or institutional memory.
- **After-action reports** – Similarly, after-action reports or post-disaster assessments can provide quantitative and qualitative information on impacts of past events. Past events can be used as a rough proxy for future events that may change with climate. Organizations that issue after-action reports include:
    - International development organizations (World Bank, Caribbean Development Bank, USAID, etc.)
    - Local engineering firms.
- **News articles** – Look up news stories describing impacts of past events (see text box, “Using News Stories to Supplement Data” on page 44).

Alternate Approach (if sensitivity thresholds are not available):

If specific sensitivity thresholds from manuals or other sources are not available, expand Table 4 and Table 5 to identify, to the extent possible:

- The particular climate variables relevant to the facility (e.g., rather than "extreme heat," clarify whether relevant factors are daily high temperatures or extended heat waves).
- Quantitative or qualitative impacts associated with each sensitivity relationship.

Develop a qualitative rating for the effect of each climate hazard on each operational area. This can be done through a workshop or survey.

For example, in the Port of Avatiu vulnerability assessment, the study team asked several experienced managers and stakeholders to rate the historical severity of past hazards, using the following scale (Cox et al., 2013):

- Insignificant
- Minor
- Moderate
- Major
- Extreme

Example

For an airport, start with the first row (directly from Table 5), and provide additional information on how that sensitivity relationship works at your specific airport.

	Airport Runways/Tarmac	Airport Buildings	Access	Other
Sensitivity Relationship	High temperatures can increase required takeoff lengths…	High temperatures can increase building energy costs…	Extreme heat can result in asphalt pavement softening…	Extreme heat can create hazardous working conditions….
Additional information	Runways are paved with PG 64-22, which can withstand regular temperatures of up to 41.4°C (106.4°F). Runway is just long enough to allow the largest aircraft to take off, and on very hot days we reduce aircraft weight to ensure takeoff.	In the particularly hot summer of 2014, energy costs increased 5% compared to previous years, which reduced our ability to do planned maintenance.	Heat has never affected airport access in the past, nor do we anticipate the potential for heat to affect access roads.	Hot temperatures mean outdoor staff have to take frequent breaks, reducing operating efficiency.
Sensitivity rating	Moderate	Minor	Insignificant	Moderate

Rows in gray come from earlier example

At the end of this step, you should have an expanded version of Table 4 and/or Table 5, with specific thresholds and the impacts of crossing them.

3.2 Assess current exposure

Build on the sensitivity assessment to understand how frequently the facility experience climate or weather-related impacts historically. This can be helpful to contextualize future impacts from climate variability and change.

Use historical meteorological data to determine how frequently the relevant sensitivity thresholds from Step 1 have been exceeded in the past. This involves the following steps:

- Collect the longest possible time series of data for each relevant weather variable (e.g., temperature, precipitation, water level, wave height). See Data Sources section below. If you don't have data, see the alternate approach on page 46.
- Plot data against known sensitivity thresholds and calculate the number of times the sensitivity thresholds have been exceeded historically.
- For dates when known thresholds were exceeded, investigate the impacts on those dates. Information sources include facility managers and staff, facility records, and news story archives (see text box, "Using News Stories to Supplement Data"). Build a database of possible impacts in terms of disruption duration, costs, and other impacts as shown in the example template in Table 7.

> **Using News Stories to Supplement Data**
>
> Historical news articles can be a valuable source of information on both meteorological conditions and impacts associated with past extreme weather events that may not have been systematically recorded elsewhere. This topic is explored in depth in Ribera et al. (2011). In the absence of any good historical records of storms or other extreme weather, a detailed reconstruction of the record from a review of local, regional, and national newspapers can be very valuable.
>
> Even in the absence of a comprehensive newspaper review, targeted searches into news stories about past events can provide useful information where gaps remain.
>
> For more information, see:
>
> Ribera, P, Gallego D, Pena-Ortiz C, Del Rio L, Plomaritis TA, and Benavente J (2011). Reconstruction of Atlantic historical winter coastal storms in the Spanish coasts of the Gulf of Cadiz, 1929-2005, *Natural Hazards and Earth System Sciences*, Volume 11, pp 1715-1722.

Table 7. Example template for compiling information on historical vulnerabilities

Date	Precipitation	Disruption Duration (hours)	Damage Costs	Other

- Analyze to what extent threshold exceedance is associated with impacts. For example, on what per cent of days that the threshold was exceeded did the facility experience impacts? Do impacts correlate with precipitation or temperature?
- The outcome of this activity should be a measure of the historical frequency and consequences of exceeding relevant sensitivity thresholds.

Data Sources

Historical Weather Data (sources listed in order of preferences):

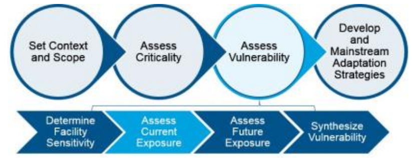
- National meteorological service
- Caribbean Institute for Meteorology and Hydrology
- Global Climate Observing System
- Global Historical Climatology Network – Daily (GHCN-Daily)
- World Meteorological Organization (WMO) World Weather Information Service
- Reconstruction from news archive (see text box, “Using News Stories to Supplement Data”)
- Climate model hindcasts (more information on climate model sources in section 3.3).

Case Study Example

The Saint Lucia case study used climate model hindcasts to estimate how frequently the following thresholds were exceeded in the past, from 1970-1999:

- Heat Index over 30.8°C (87.5°F) with relative humidity of 80% (when risk for outdoor workers is high): 0.6 days per year
- Days with temperature > 31°C (when Boeing 737-400 cannot take off from Hewanorra International Airport): 0.33 days per year
- Rainfall > 20 mm (when crane operations are limited): 45.9 days per year

Source: UNCTAD, 2017b



Alternate Approach (if historical weather data or sensitivity thresholds are not available):

If you don't have information on how frequently sensitivity thresholds have been exceeded in the past, ask experts to apply a qualitative rating system.

For example, in the Port of Avatiu vulnerability assessment, the study team asked several experienced managers and stakeholders to rate the historical frequency and severity of past hazards, using the following scale (Cox et al., 2013):

Likelihood (of high wind, high rainfall, high ways, temperature, sea level rise, or tropical cyclone):

- Rare
- Unlikely
- Possible
- Likely
- Almost Certain

Example

	Airport Runways/Tarmac	Airport Buildings	Access	Other
Sensitivity Relationship	High temperatures can increase required takeoff lengths…	High temperatures can increase building energy costs…	Extreme heat can result in asphalt pavement softening…	Extreme heat can create hazardous working conditions….
Additional information	Runways are paved with PG 64-22…	In the particularly hot summer of 2014, energy costs…	Heat has never affected airport access…	Hot temperatures mean…
Sensitivity rating	Moderate	Minor	Insignificant	Moderate
Exposure Rating (frequency of past occurrence)	Possible	Likely	Rare	Possible

Rows in gray come from earlier example(s)

3.3 Assess future exposure

The next stage of the vulnerability assessment framework is to estimate how climate change could affect the frequency or severity of facility disruption in the future.

3.3.1 Determine exposure to sea level rise and storm surge

Sea level rise and storm surge are often dominant climate change hazards in SIDS, and determining which locations are most likely to be inundated can be challenging due to data limitations.

First, determine how much sea level rise may be expected in your location during the time period under consideration. See Appendix V.5 for additional guidance on this topic.

Next, determine which locations might be affected by this estimated sea level rise. There are several approaches to this including:

- **Review of pre-existing inundation maps and data**
- **Inundation mapping**
- **Qualitative assessment**

Each of these are discussed in turn below. Possible data sources, which could apply to multiple options, are provided after all three.

Option 1: Pre-existing inundation maps and data.

Geospatial data and models can help identify the locations most likely to be inundated under different sea level rise or storm surge scenarios. Data sources include:

- **Existing locally-specific studies.** For example, the World Bank completed a project on climate change vulnerability in Castries, Saint Lucia that included maps of how sea level rise would affect coastal areas (see Figure 3). Check with project stakeholders to see whether they are aware of or have access to existing inundation maps.
- **European Commission Joint Research Centre (JRC) Large Scale Integrated Sea-level and Coastal Assessment Tool (LISCoAsT) climate change wave and storm surge modeling.** The JRC is currently developing projections of different water level return intervals for all SIDS.

Figure 3. Map of Castries 100-year coastal flooding event with sea level rise (ICF GHK, 2014, citing CDB, 2006)

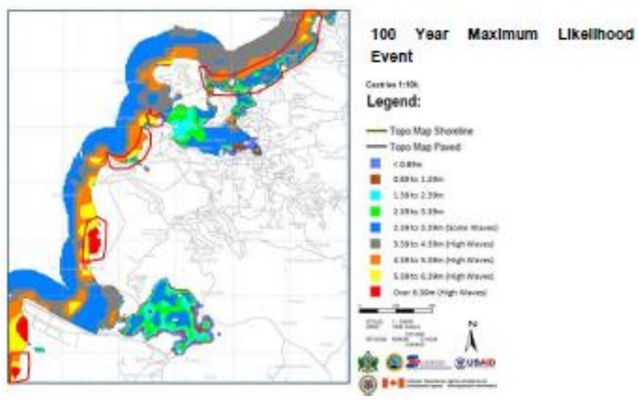
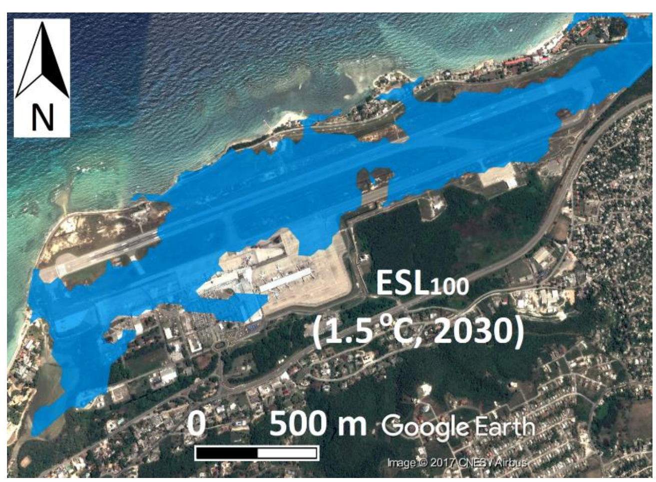


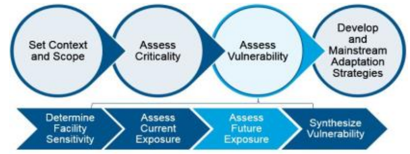
Figure 4. Example inundation modeling from LISCoAsT



Option 2: Develop inundation maps.

To do your own mapping of potential sea level rise or storm surge inundation, you need the following:

(1) **Sea level rise scenarios** (i.e., estimates of how much sea level may change within the study period). See Appendix V.5.
(2) **Current tidal surface elevation** (mean higher-high water). Available from tide gauges.



(3) **Digital elevation model** (DEM) of the study locations. Elevation data should be as high resolution as possible. For coastal hazard mapping, both horizontal and vertical resolution are recommended to be less than or equal to 0.5 m, such as those developed using LiDAR (CHARIM, 2016).

The United States' National Oceanic and Atmospheric Administration (NOAA) provides detailed instructions for how to use basic GIS tools to map sea level rise inundation (see NOAA, 2012). The data required include tidal surface elevation, sea level change projections, and a digital elevation model of the location (at as high a resolution as possible). Other examples of studies that have completed inundation mapping include Seaport Resilience to Climate Change: Mapping Vulnerability to Sea Level Rise (Chhetri et al, 2014), which maps vulnerability to sea-level rise at Port Kembla, Australia, and the Gulf Coast Study, Phase 2 (U.S. DOT, 2015).

Case Study Example

In the Saint Lucia case study, the study team used elevation data from CHARIM, tide gauge information from the national meteorological service, and sea level rise projections from a local climate modeler to develop GIS maps of which locations around the studied ports and airports might be inundated under sea level rise.

Option 3: Qualitative assessment.

If GIS analysis is not possible, estimate potential flood risk areas using best available information and professional judgment. For example, meet with stakeholders to identify low-lying areas and places that historically flood during high tide events.

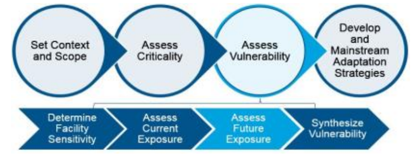
Data Sources

Sea level rise scenarios:

- **Existing synthesis reports and scientific literature.** Global and local sea level rise scenarios are constantly evolving. The Intergovernmental Panel on Climate Change (IPCC) provides the latest scientific consensus for global sea level rise projections. The IPCC Fifth Assessment Report (AR5) projects an increase in global sea levels of 0.45 to 0.82 meters by 2100 relative to 1986-2005 (IPCC, 2014a). The most recent estimates, produced by the National Oceanic and Atmospheric Administration, finds a higher projection for global mean sea level rise, up to 2.5 meters by 2100 (NOAA, 2017). See Appendix V.5 for more information.

Tidal surface elevation:

- **National meteorological service**
- **Permanent Service for Mean Sea Level**
- **Global Sea Level Observing System**



Facility or land elevation:

- **Local or regional LiDAR analysis** – LiDAR is remote sensing method used to develop high-resolution elevation models. As of 2016, availability is limited in the Caribbean.
- **Facility design specifications –** If evaluating exposure of specific facilities, facility managers or engineers may have access to data about facility elevation.
- **Caribbean Handbook on Risk Information Management (CHARIM)** – This initiative is assembling the best available Digital Elevation Models (DEMs) for Belize, Dominica, Grenada, Saint Lucia, and Saint Vincent and the Grenadines.

3.3.2 Determine exposure to temperature, precipitation, and other climate hazards

Background on Climate Change Projections

Climate models provide projections of future climate, such as temperature, precipitation, humidity, wind speeds, and more, based mathematical representations of the "physical and dynamical processes in the atmosphere, ocean, cryosphere, and land surfaces" (5Cs, 2015).

There are three broad types of climate model data:

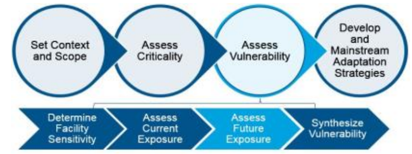
- Global Climate Models (GCMs) – These models capture global processes, and provide projections at a coarse geographic scale.
- Statistically downscaled GCM data – Many research institutions have applied statistical methods to interpret GCM data at a finer spatial scale.
- Dynamically downscaled GCM data – Dynamical downscaling is carried out using Regional Climate Models (RCMs). RCMs apply similar mathematical representations as GCMs, but are restricted to a smaller geographic domain and simulate climate at a finer spatial resolution (typically less than 100 km).

GCM data are used to inform the IPCC assessment reports and are the most widely available. Statistically or dynamically downscaled data are often used in regional or local-scale vulnerability assessment studies.

The goal of this step is to gather information about how climate is expected to change in your location and, therefore, how often sensitivity thresholds may be crossed in the future. Several options exist for gathering information on future climate conditions.

The appropriate choice of method and data source depends on the type of data needed which, in turn, will depend on the level of detail involved in the vulnerability assessment.

For example, if you have identified specific sensitivity thresholds of interest, you can use daily-scale climate data to calculate how those thresholds may be exceeded in the future. If you have done a qualitative assessment thus far, then it may be sufficient to understand overall trends in temperature and precipitation.



These three options are described in turn following an overview of data sources: (1) Quantitative assessment of future threshold frequency, (2) Qualitative assessment of future threshold frequency, or (3) qualitative assessment.

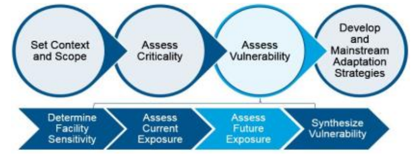
To choose the climate change data for the project, review available options and choose the one that corresponds with the level of resources available for the project and level of rigor required.

Data Sources

There are two overall categories of climate change information:

(1) **Pre-existing synthesis reports** – These reports provide information and some data on estimated future trends in several climate factors. Start with these sources to determine whether they are sufficient for the analysis. For example, do they include information on estimated future trends in the specific climate factors of interest (i.e., those tied to sensitivity thresholds)? Existing synthesis report options in the Caribbean include:

- **National Communications to the UN Framework Convention on Climate Change** – These reports typically provide a synthesis of the high level climate projections for each country such as change in average temperature, but some provide projections for more extreme variables. The level of detail in each report varies by country. Available for all non-Annex I countries at: https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/national-communications-and-biennial-update-reports-non-annex-i-parties/national-communication-submissions-from-non-annex-i-parties
- **Inter-American Development Bank (IADB) Climate Change Projections in Latin America and the Caribbean: Review of Existing Regional Climate Models' Outputs** – This 2016 report provides projections of variables specifically related to transport infrastructure thresholds. The variables include the 20-year 24-hour precipitation intensity, 100-year 24-hour precipitation intensity, number of days with temperature higher than 29.5°C, and sea level rise. The data cover Argentina, the Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, the Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay, and Venezuela. Available at: https://publications.iadb.org/handle/11319/7746?locale-attribute=en.
- **CARIBSAVE Climate Change Risk Atlas** – This 2011 analysis includes full climate change risk profiles for 15 Caribbean countries. The projections cover mean temperature, total precipitation, wind speed, relative humidity, sunshine hours, sea surface temperatures, frequency of hot days, frequency of hot nights, frequency of cold days, frequency of cold nights, per cent of rainfall falling in heavy events, maximum 1-day rainfall, and maximum 5-day rainfall. Data are derived from an ensemble of 15 GCMs and the PRECIS RCM (driven by two GCMs). Available at: http://www.caribbeanclimate.bz/?s=CARIBSAVE+Climate+Change+Risk+Atlas



- **Other nationally-specific studies** – Some countries have additional analyses of climate change projections and potential impacts available, conducted by the national governments, local universities, or development banks. Examples include the Climate Change Policy Framework for Jamaica and a World Bank study on Climate Change Adaptation Planning in Latin America and Caribbean Cities.

(2) **Raw climate model data (for temperature and precipitation projections)** – If the specific variables of interest (e.g., number of days above a specific threshold) have not yet been analyzed in another study, it is possible to calculate the projections from the raw climate model data. Data are typically available at either the daily or monthly resolution. Using raw data is generally more resource-intensive than drawing from pre-existing studies, but can provide projections for variables that are specifically relevant to a given facility. Possible data sources include:

- **Caribbean Community Climate Change Centre (5Cs) database** – The 5Cs website is a portal for climate change information in the Caribbean, and includes a portal to view and download climate projections. Available at: http://www.caribbeanclimate.bz/. New datasets are added regularly. Current datasets include:
  - PRECIS Regional Climate Model – 50-km spatial resolution, daily-scale projections of temperature, precipitation, humidity, and wind speed
  - GCMs – 25-km spatial resolution daily-scale projections in soil moisture content, convective rainfall rate, evaporation rate, large scale rainfall rate, maximum temperature, minimum temperature, humidity, wind speed, and other variables. Available for 15 GCMs.
- **World Bank Climate Change Knowledge Portal (CCKP)** – The CCKP includes national-level summaries of historical, GCM, and downscaled projections as well as downloadable raw data. Downscaled data include maximum/minimum monthly temperature, percentage of "very warm" and "very cold" days, heating degree days, and cooling degree days. Available at: http://sdwebx.worldbank.org/climateportal/

Additional details about available climate data sources for the Caribbean are found in Table 19 in the Appendix. Table 8 summarizes the pros and cons of different climate data options.

Table 8. Climate change data options

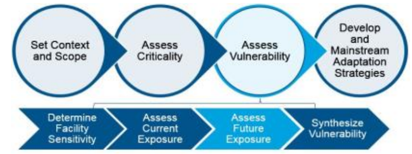
Source	Pros	Cons
Regionally downscaled data (e.g., PRECIS in the Caribbean)	Regionally tailored, may be easily accessible and usable with minor additional analysis. Daily-scale data can be used to determine projections of how frequently certain temperature or precipitation thresholds may be exceeded.	Quality depends on resolution and number of models run (in general, higher resolution and more models are better).
Customized downscaled data (developed in	Locally tailored, and project-specific.	Time and resource-intensive.

Source	Pros	Cons
coordination with climate modelers)		
National Communications to the UNFCCC	Already exist, no need for further analysis. Consistent with the data in-use in country.	Likely to be high-level (e.g., description of changes in annual average temperature and precipitation).
Other pre-existing syntheses	Already exist, no need for further analysis.	May not include required variables, may not be consistent with other data sources (if using multiple) in terms of time periods, models, or emission scenarios chosen.

Option 1: Quantitative assessment of future threshold frequency

Determine how frequently specific sensitivity thresholds may occur over time. Check whether this information is already provided in existing synthesis reports and, if not, use daily-scale climate data to calculate how often the thresholds may be crossed over time.

This can be done in a basic spreadsheet software like Microsoft Excel, or more sophisticated programs.



Example

For each day in the 20-30 year climate period (both baseline and historical), calculate the number of days when a threshold is exceeded, such as in the example below. From this, you know that the port may be exposed to 4 days per year above the operational threshold in the 2030s, as compared to 2 days per year historically.

Start with…

Day	Precipitation (mm)
1/1/1950	15.0
1/2/1950	7.2
1/3/1950	2.4
1/4/1950	21.0
…	…
12/31/2100	20.1

Arrive at…

	Average days/year with precipitation ≥ 20 mm
Observed	2
Modeled, 1970-1999	3
Modeled, 2020-2040	5
Estimated change (∆)	2
Projection (Observed + ∆)	**4**

Case Study Example

The Saint Lucia case study used daily-scale climate data from the PRECIS Regional Climate Model on the 5Cs database to calculate the estimated change in the number of times various sensitivity thresholds may be crossed in the future.

Requesting the data:

The St. Lucia case study team used daily-scale climate data from the PRECIS Regional Climate Model (ECHAM5) on the 5Cs clearinghouse. The team selected future projections based on the A1B scenario, which is compatible with the RCP 6.0.

Processing the data:

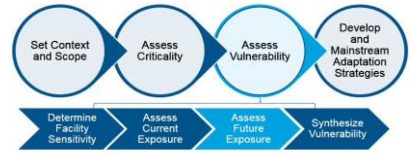
Using Microsoft Excel, the project team analyzed the climate data to determine how often key sensitivity thresholds would be surpassed in the future. For example, as discussed previously, employee ability to work safely outdoors depends on the Heat Index (a function of temperature and relative humidity). For a relative humidity of 80 per cent, Heat Index would be "High" risk at air temperatures of 30.8°C (86.8°F). The frequency of temperatures of 30.8°C (86.8°F) in Saint Lucia is shown in the table below. The days when workers may be at high risk—and thus may need more frequent breaks or be otherwise limited from about 1 day per year currently to over 11 within 15 years.

	Disruptions (average days/year)				
Threshold	**1986-2005**	**2006-2030**	**2031-2055**	**2056-2080**	**2080-2100**
Temperatures over 30.8 °C (87.5 °F) with relative humidity 80% ("high" risk for outdoor workers)	1.25	1.96	11.86	29.13	55.33

Source: UNCTAD, 2017b

Option 2: Qualitative assessment of future threshold frequency

If you know specific sensitivity thresholds but cannot determine the estimated change in climate that is specific to those thresholds, work with the best available climate data to determine a potential trend or directionality of the change.



Example

According to the Saint Lucia National Adaptation Strategy and Action Plan (5Cs, 2015), mean annual temperature in Saint Lucia is expected to increase by approximately 0.3 to 1.2°C by the 2030s, with more warming in the winter and fall. In addition, GCM projections “indicate substantial increases in the frequency of days and nights that are considered ‘hot’ in the current climate. The annual frequency of warm days and nights is expected to increase to 28-67% by the 2060s, relative to the current climate.” (5Cs, 2015).

With this information, you can build on the previously-developed sensitivity and past exposure information to incorporate the estimated directionality of impacts, as shown in the table below. And even without knowing whether specific thresholds will be crossed, you could determine that increased energy use is the most certain impact of temperature increases at the airport.

	Airport Runways/Tarmac	**Airport Buildings**	**Access**	**Other**
Sensitivity Relationship	High temperatures can increase required takeoff lengths…	High temperatures can increase building energy costs…	Extreme heat can result in asphalt pavement softening…	Extreme heat can create hazardous working conditions….
Sensitivity rating	Moderate	Minor	Insignificant	Moderate
Exposure Rating (frequency of past occurrence)	Possible	Likely	Rare	Possible
Change in exposure with climate change	**More Likely**	**More Likely**	**More Likely**	**More Likely**
Future exposure	Likely	Almost Certain	Unlikely	Likely

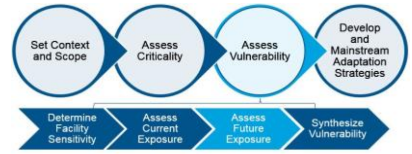
Rows in gray come from earlier example(s)

Option 3: Qualitative assessment

If you do not know specific thresholds, review existing synthesis reports (see the list above) to understand how relevant climate factors will change in the future. At a minimum, identify the directionality of potential change.

For example, the Port of Avatiu vulnerability assessment had stakeholders evaluate the historical frequency of impactful weather events, and simply rated whether those impacts would become: More Likely, Less Likely, or No Change (Cox et al., 2013).

In the Caribbean, the following ratings are likely to apply (5Cs, 2015):



- Extreme heat – More likely
- Heavy precipitation – Depends on country
- Drought – Depends on country
- Coastal flooding – More likely
- Storm surge – More likely.

3.4 Synthesize vulnerabilities

With information about how climate hazards may change and how the facility responds to hazards, identify potential vulnerabilities and areas of greatest potential vulnerability to prioritize for further research or adaptation.

3.4.1 Evaluate adaptive capacity

In consultation with stakeholders, determine the capacity of each asset to prepare for and recover from exposure to climate or weather hazards. Consider questions such as:

- What does the facility's current ability to prepare for and recover from hurricanes and other tropical storms suggest about its ability to cope with such events in the future?
- Is the facility already able to accommodate changes in climate?
- Are there barriers to the facility's ability to accommodate changes in climate?
- Is the facility already stressed in ways that will limit the ability to accommodate changes in climate?
- How long does it typically take for infrastructure projects to be completed, from when they are first proposed?
- Is the rate of climate change, as estimated by projections, likely to be faster than the adaptability of the system?
- Are there efforts already underway to address impacts of climate change related to the system?

Example:

	Airport Runways/Tarmac	**Airport Buildings**	**Access**	**Other**
Sensitivity Relationship	High temperatures can increase required takeoff lengths…	High temperatures can increase building energy costs…	Extreme heat can result in asphalt pavement softening…	Extreme heat can create hazardous working conditions….
Sensitivity rating	Moderate	Minor	Insignificant	Moderate
Exposure Rating (frequency of past occurrence)	Possible	Likely	Rare	Possible
Change in exposure	**More Likely**	**More Likely**	**More Likely**	**More Likely**

with climate change				
Future exposure	Likely	Almost Certain	Unlikely	Likely
Adaptive Capacity Description	Runways are sited and designed for the long-term. Repaving the runways is possible but would be very disruptive.	The airport operating budget is tight. Increased energy bills would be paid, but that money would come out of other needs.	There is only one way to access the airport, and the airport has no control over maintaining the road to prevent disruptions.	The airport can update construction and work schedules on short-notice, or provide short-term relief during heat waves.
Adaptive Capacity Rating	Low	Moderate	Low	High

Rows in gray come from earlier example(s)

Consider adaptive capacity qualitatively alongside measures of sensitivity and exposure to evaluate overall vulnerability.

3.4.2 Synthesize vulnerabilities

As with all stages of the process, multiple options exist to summarize the vulnerability information. Keep in mind the key principles identified at the beginning of this framework to ensure the final results are useful to the relevant decision makers.

Combine the information you have collected so far on criticality, sensitivity, current exposure, and future exposure to assess overall vulnerability to climate change.

Depending on the level of data you have compiled so far, the vulnerability assessment may range from quantitative to qualitative. Two examples are shown below showing the extreme ends of this spectrum. Many assessments are likely to be a combination of the two. For instance, where the overall vulnerability rating is assessed qualitatively, but additional quantitative information supplements the analysis.

Example #1 – Quantitative

Identify how often sensitivity thresholds are expected to be exceeded in the future and, using the information developed during the criticality assessment, quantify the impacts of exceeding that threshold in terms of anticipated operational disruption, anticipated cost of damage, or other metrics.

Combine previously developed information to synthesize vulnerabilities across potential climate hazard and port or airport components.

- Component: Crane operation at port
- Climate hazard: Heavy precipitation
- Criticality: Port X moves 100,000 tonnes of freight per hour. Each hour of delay costs the port operator $10,000. Moreover, it delays the ability of goods to reach consumers.

- Sensitivity: Cranes at the port are unable to operate any time rainfall is greater than 20 mm in a day. Operational disruptions typically last up to 6 hours.
- Exposure: Data show that historically the port experiences 2 days per year with more than 20 mm of daily precipitation, and that climate change will double the likelihood of these events by the 2030s.

Knowing the potential frequency and severity of climate-related impacts enables an approximation of risk, as in the table below.

Table 9. Quantitative vulnerability assessment example

Operational Threshold	Impact Description	Quantified Impacts	Current Frequency	Future Frequency	Current Risk	Future Risk
Precipitation > 20 mm per day	Cranes at the port are unable to operate	6 hours / $60,000	2 days/year	4 days/year	12 hours / $120,000	24 hours / $240,000

Example #2 – Qualitative

Combine the information you have collected so far on criticality, sensitivity, current vulnerability, and exposure to identify the potential climate change vulnerabilities. Options include a vulnerability matrix, risk matrix, qualitative ranking, or vulnerability profile (USAID, 2016).

For example, using risk matrices like the one shown in Table 10 can be a simple way to use qualitative exposure, sensitivity, and criticality ratings. Risk is a function of the likelihood of an event (in this case, damage or disruption) and its consequence. Likelihood of occurrence corresponds with exposure, and magnitude of consequence corresponds with sensitivity.

Table 10. Example qualitative risk matrix (Cox et al., 2013)

		Consequence of Hazard				
		Insignificant	**Minor**	**Moderate**	**Major**	**Extreme**
Likelihood of Hazard	**Almost Certain**	Medium	High	Very High	Very High	Very High
	Likely	Medium	Medium	High	Very High	Very High
	Possible	Low	Medium	Medium	High	Very High
	Unlikely	Low	Low	Medium	Medium	High
	Rare	Low	Low	Low	Medium	Medium

In the airport heat example used throughout this framework, three of the four components would have high risk, and one would have low risk. For example, the sensitivity rating for airport runways is "Moderate," and the future exposure rating is "Likely," so that aligns with "High" risk according to the matrix in Table 10. See Figure 5.

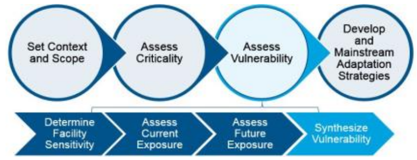


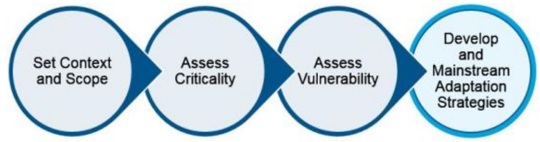
Figure 5. Qualitative risk assessment example

	Airport Runways/Tarmac (1)	Airport Buildings (2)	Access (3)	Other (4)
Sensitivity Relationship	High temperatures can increase required takeoff lengths…	High temperatures can increase building energy costs…	Extreme heat can result in asphalt pavement softening…	Extreme heat can create hazardous working conditions….
Sensitivity rating	**Moderate**	**Minor**	**Insignificant**	**Moderate**
Exposure Rating (frequency of past occurrence)	Possible	Likely	Rare	Possible
Change in exposure with climate change	More Likely	More Likely	More Likely	More Likely
Future exposure	**Likely**	**Almost Certain**	**Unlikely**	**Likely**
Adaptive Capacity	Low	Low	Moderate	High
Vulnerability /Risk	**High**	**High**	**Low**	**High**

		Consequence of Hazard				
		Insignificant	**Minor**	**Moderate**	**Major**	**Extreme**
Likelihood of Hazard	**Almost Certain**		Buildings			
	Likely			Runways Worker Safety		
	Possible					
	Unlikely	Access				
	Rare					

Plotting all components and stressors onto a similar matrix can help identify priorities for more detailed analysis.

Components with “high” or “very high” risk would be candidates for adaptation strategies, while “medium” risk components may be candidates to monitor and evaluate risks over time (PANYNJ, 2011).



4. Stage 4: Develop and Mainstream Adaptation Strategies

4.1 Identify priorities for closer analysis or adaptation

After completing the primary vulnerability assessment, consider whether there are specific elements of the port or airport system that might warrant closer analysis before implementing adaptation actions. Closer study of specific assets can provide more detail to assist in making decisions about the most effective type of adaptation. A crucial step in the adaptation planning process is identifying which actions can be implemented in the near-term, and which require further study.

Further analysis is especially useful in situations where the costs of adaptation could be high. For example, a vulnerability assessment that has determined an airport runway is vulnerable to flooding could be supplemented by an engineering-level analysis to ensure that elevating the surface or improving drainage would serve as effective steps in improving resilience to flooding before undertaking those measures. Additional information on engineering-level analyses for climate change can be found in the Gulf Coast Study engineering assessments (U.S. DOT, 2014c), the “Transportation Engineering Assessments for Climate Resilience” (expected release in 2017), or the Canadian Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol (Engineers Canada, 2017).

In contrast, some adaptation measures can be justified from economic, social, and environmental perspectives regardless of the future changes in climate (Climate-ADAPT, 2016). For example, improved maintenance of drainage structures can pay off by improving drainage under existing conditions and extending the useful life of infrastructure. These “no-regrets” adaptation measures complement those that require closer analysis before implementation.

4.2 Identify and select adaptation strategies

Climate change adaptation strategies take many forms, ranging from asset-specific, technical strategies (e.g., infrastructure hardening, elevation) to planning and policy.

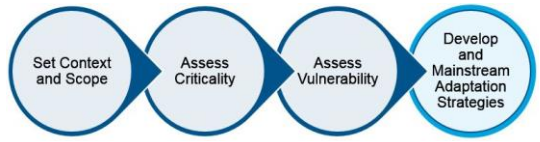
Adaptation of the transport sector in SIDS is also the responsibility of many actors, including national and local policymakers as well as port and airport operators.

The remainder of this section provides example adaptation strategies, organized by actor (policymakers and planners, port managers, and airport managers), and strategy type (process enhancements, ecosystem enhancements, and engineering enhancements).

Selection of strategies to pursue should be based on careful evaluation of the net costs and benefits of the strategies (beyond simple economic terms) and consultation with stakeholders.

Key principles for adaptation include:

- **“Mainstream”** adaptation activities into existing planning and decision-making processes (USAID, 2009).
- **Define “success”** for a resilient transport system. For example, what is an acceptable length of time for specific facilities to be out of service?



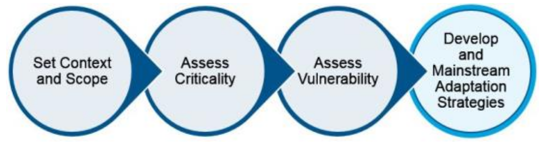
- **Promote adaptive management**, the process of actively monitoring and revising management practices over time (Climate-ADAPT, 2016).
- **Select low-regret options** that yield benefits even in the absence of climate change and where the costs of adaptation are low compared to the benefits of acting (Climate-ADAPT, 2016).
- **Select "win-win" options** that have the desired result in terms of minimizing climate risks or exploring potential opportunities but also have other social, environmental, or economic benefits (Climate-ADAPT, 2016). For example, ecosystem-based adaptation approaches like beach nourishment, coral reef protection, and mangrove protection all have multiple co-benefits in addition to reducing coastal hazards.
- **Favor reversible and flexible options**, which allow changes to be made as more information becomes available over time (Climate-ADAPT, 2016). For example, acquiring land can provide opportunities for infrastructure relocation if needed (USAID, 2015a).
- **Add "safety margins" to new investments** to ensure responses are resilient to a range of future climate impacts (Climate-ADAPT, 2016).
- **Promote soft adaptation strategies**, which could include building adaptive capacity to ensure an organization is better able to cope with a range of climate impacts (e.g., through more effective planning) (Climate-ADAPT, 2016).
- **Pre-plan for disaster response**, especially in coastal areas where disasters are likely. Advanced planning can increase the resilience of recovery efforts, rather than building back quickly as things were before the storm (USAID, 2015a).
- **Increase system flexibility**, for example, by ensuring back-up options are available to transport goods and people between major origins and destinations.
- **Use existing disaster risk reduction efforts to support adaptation** (UNFCCC, 2016).

Adaptation can be incorporated into regular planning and implementation procedures through different avenues and stakeholders, including national or regional policy, sectoral investments and projects, and sub-national initiatives (USAID, 2009). Each entry point has its own challenges and should be considered in order to target mainstreaming efforts to meet the needs of different stakeholders. For example, strategies for port and airport operators include cross-cutting planning or policy changes to promote resilience (that can be implemented in the near-term) and strategies to reduce vulnerabilities of specific infrastructure assets that they manage. More information on mainstreaming adaptation is in USAID's Guidebook for Development Planners: Adapting to Coastal Climate Change (USAID, 2009).

4.2.1 Policymakers and Planners

National-level policymakers play a critical role in improving the resilience of ports and airports to climate change impacts. Policymakers have an opportunity to anticipate changes in climate when making today's investments and planning decisions. While much adaptation will take place at the facility-level, under control of facility operators, governments can provide supporting policies, information, and systems. More specifically, governments can facilitate adaptation by:

- Providing an appropriate political, legal, and administrative environment, including monitoring and enforcement.



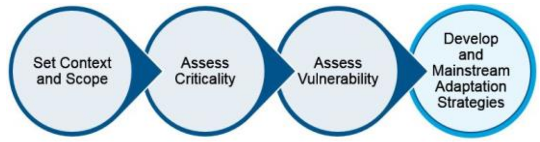
- Assisting in the mobilization of new and additional financial resources
- Encouraging the participation of all government entities in the development of appropriate climate hazard risk mitigation measures
- Promoting sustained partnerships with non-state actors (5Cs, 2009).

Example

Cuba's government has successfully engaged in disaster risk reduction and climate change adaptation policy and has a specific research agenda to inform its approach to crafting such policy (UNELAC, 2011). Cuba's government has worked to establish a favorable enabling environment at a regional level for the effectiveness and sustainability of adaptation investment. More specifically, Cuba has focused on consolidating and making available information on ecosystem-based adaptation and strengthening provincial and municipal governments in order to increase the resilience of populations in the coastal regions of Artemisa and Mayabeque provinces (UNDP, 2015).

National-level adaptation policy for developing countries is a broad topic that has been extensively covered elsewhere in the literature. The following resources provide more specific information on climate-resilient development for policymakers:

- Climate Change and the Caribbean: A Regional Framework for Achieving Development Resilient to Climate Change, 5Cs
- Study on the Vulnerability and Resilience of Caribbean Small Island Developing States, United Nations Economic Commission for Latin America and the Caribbean
- Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change, U.S. Agency for International Development (USAID)
- Climate Change and Coastal Zones: An Annex to the USAID Climate-Resilient Development Framework, USAID
- Coastal Hazard Wheel, United Nations Environment Programme (UNEP).



Coastal Hazards Management

One key role of national policymakers in SIDS is coordinating overall coastal hazard risk management. Cross-cutting policies relevant in Caribbean SIDS—which are exposed to tropical storms and hurricanes, in addition to beach erosion, sea level rise, and other stressors—include:

- Coastal zoning
- Ecosystem based management
- Groundwater management
- Beach nourishment
- Coastal setbacks
- Dikes
- Flood proofing
- Managed realignment
- Breakwaters
- Groynes
- Revetments
- Sea Walls
- Flood mapping
- Flood shelters
- Flood warning systems

Additional information about all of these strategies can be found in the UNEP “Managing Climate Change Hazards in Coastal Areas” catalogue of hazard management options at http://www.coastalhazardwheel.org/media/1218/catalogue-coastal-hazard-wheel.pdf (UNEP, 2016).

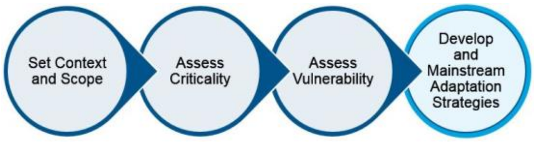
For each strategy, this document provides a description as well as the advantages, disadvantages, costs and financial requirements, institutional and organizational requirements, barriers to implementation, and opportunities for implementation.

In additional to national-level policy-makers, regional organizations play a pivotal role in supporting climate adaptation. Regional organizations in the Caribbean include the Caribbean Meteorological Organization, the Caribbean Tourism Organization, the University of the West Indies, the Caribbean Disaster Emergency Response Agency, and others. These types of organizations can support resilient development by (5Cs, 2009):

- Strengthening national capacities through training, programme support, technical assistance, and resource mobilization
- Facilitating information sharing, documentation, and comparative analyses of issues
- Coordinating sub-regional or regional disaster risk reduction projects
- Developing common regional or sub regional policy platforms and advocating regional policy initiatives in global forums
- Undertaking comprehensive, post-disaster damage assessments.

4.2.2 Ports

There are many strategies that port owners and operators can undertake to increase climate resilience. These strategies include process, ecosystem, and engineering enhancements. A combination of strategy types ensures effective adaptation at all levels.



Example

A recent study on the Port of Manzanillo in Mexico aimed to analyse the climate risks and provide an adaptation plan for the port. The adaptation actions recommended in the plan work within the context of adaptation planning and port planning at the Federal, State, and Municipal levels, and provide a range of strategy types. The plan includes no regret measures, low regret adaptation measures (measures for which the associated costs are relatively low and for which the benefits under future climate change may be large), win-win adaptation measures (actions with other social, environmental, or economic benefits), and flexible adaptation management options (measures that can be implemented incrementally) (IDB, 2015b).

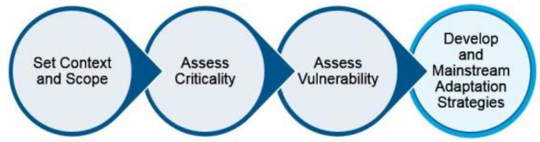
The following sections provide information on specific types of adaptation measures. Low regrets strategies are shaded in green.

Process Enhancements

Improved processes—implemented through policies or subtle operational changes—provide an opportunity to increase organizational resilience across a variety of hazards (climate and otherwise). These strategies can include improved transition planning, data collection, research, monitoring, reviewing, and incorporating new information into existing port policies and plans. At ports, other operational strategies include adjustments in maintenance programmes, early warning systems for workers, and procedures to cease operations under certain conditions. Table 11 provides specific system enhancement adaptation strategies.

Table 11. Process enhancement adaptation strategies for ports

Adaptation Option	Relevant Climate Hazards
Improve transition planning to ensure staff with more experience transfer their institutional knowledge to new staff	Sea Level Rise, Tropical Storms/Hurricanes/ Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Review all planned capital investments with lifetimes > 20 years to ensure they are designed with future climate in mind	Sea Level Rise, Tropical Storms/Hurricanes/ Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Account for sea level rise when doing inventories for replacement and refurbishment of equipment and infrastructure	Sea Level Rise
Review flood early warning systems	Heavy Precipitation/Flooding
Implement traffic management measures to minimize bottlenecks during extreme events	Storm Surge, Extreme Heat, Heavy Precipitation/Flooding
Enhance emergency evacuation plans	Storm Surge, Heavy Precipitation/Flooding
Take strategic actions to help spread the risk and manage future uncertainty, including diversification of trading partner countries and growing a broader range of business lines	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Support improved waste management activities in the nearby community to reduce debris.	Storm Surge, Wind, Heavy Precipitation/Flooding
Provide warnings of extreme temperatures to minimize heat stress risks for workers	Extreme Heat
Review and update plans for business continuity during extreme events	Storm Surge, Extreme Heat, Heavy Precipitation/Flooding



Engage with stakeholders to plan landscape-level flood management options	Heavy Precipitation/Flooding
Incorporate rising temperatures into energy audits	Extreme Heat
Engage with the government on the importance of developing a climate resilient transport system	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Adjust maintenance programs to ensure that the maximum capacity of the existing drainage system inside the port is being achieved	Heavy Precipitation/flooding
Update dredging programs and schedules to reduce loss of draft clearance	Heavy Precipitation/flooding
Undertake review and adjust maintenance programs to ensure that maximum capacity of existing drainage system is being achieved (e.g., frequency of drain clearance)	Heavy Precipitation/Flooding
Close port and stop handling operations before operating thresholds for equipment are reached	Wind
Increase standards of port construction to deal with higher winds	Wind
Increase funding for dredging and beach nourishment programs	Sea Level Rise, Storm Surge
Develop plans to ensure port *services* are functional over time (and make contingency plans if those services cannot be provided by this port in the future)	Sea Level Rise, Storm Surge

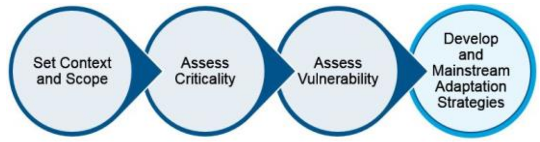
Source: IDB, 2015b; Becker et al., 2013

Example

The Port Authority of New York and New Jersey adopted design guidelines that specify specific future flood levels and temperature conditions that new infrastructure above a certain value threshold be designed to withstand (PANYNJ, 2015). This is an example of a process enhancement, whereby PANYNJ has established procedures that allow them to systematically ensure that all new infrastructure projects are designed to incorporate expected sea level rise and other climate changes. It required review of climate projections for the region and decisions about what would be the appropriate design levels in light of the agency's risk tolerance. For example, the guidelines set different flood levels for critical vs. non-critical infrastructure.

Ecosystem Enhancements

Ecosystem-based adaptation approaches involve protecting, strengthening, and even rebuilding ecosystems to buffer against climate-related impacts. They can also increase the resilience of the population and provide co-benefits, such as food supply, cleaner water, and tourist value (UNEP, 2010). Examples of ecosystem-based adaptation approaches for ports include mangrove management and landscaping measures. Ecosystem-based adaptation strategies are often "no regrets" and "win-win" options because they are natural and environmentally friendly, cost-effective, low maintenance, store carbon, support biodiversity, and increase esthetical value (European Commission, 2013; UNEP, 2010).



Example

The Risk and Vulnerability Assessment Methodology Development Project (RiVAMP) developed a tool to account for ecosystems and climate change in disaster risk and vulnerability assessments (UNEP, 2010). The tool is targeted at local governments in SIDS to focus on tropical cyclones and their secondary effects (storm surges, flooding, and winds) and sea level rise. The assessment areas include:

- Ecosystems and ecosystem services;
- Environmental change;
- Local livelihoods and vulnerability; and
- Environmental governance.

A pilot of the tool conducted in Negril, Jamaica, demonstrated the value of coral reefs and sea grasses in protecting coastlines; that ecosystem degradation was increasing the risk of local hazards; and sea level rise and extreme storm surges are predicted to have an extreme impact on Negril's beaches and coastal infrastructure. Coral reefs are particularly vital, being 23.5 times more efficient than sea grass at mitigating erosion (Peduzzi, 2016). This project emphasizes the importance of ecosystems in building resilience against climate-related risks.

Healthy coastal and marine ecosystems, such as coral reefs, mangrove forests, and sea grass meadows can provide natural protection against wave energy, reduce storm surge and mitigate soil erosion (UNEP, 2010). Ecosystem enhancements can play a significant role in reducing natural hazard risks, including coastal hazards, inland flooding, and beach erosion. Table 12 provides specific ecosystem enhancement adaptation strategies.

Table 12. Ecosystem enhancement adaptation strategies for ports

Adaptation Option	Relevant Climate Hazards
Support beach nourishment, coral reef protection, sea grass buffers, and other ecosystem restoration efforts to reduce coastal flood risk.	Sea Level Rise, Storm Surge, Beach Erosion
Implement mangrove management programmes to ensure the distribution, diversity, and health of species. Mangroves are proven to act as coastal protection from flooding.	Sea Level Rise, Storm Surge
Support sustainable land use and development to avoid slope destabilization and landslides.	Heavy Precipitation/Flooding
Consider catchment-level landscape planning and ecosystem based adaptation options for reducing risk of drainage overflow.	Heavy Precipitation/Flooding
Protect and restore forest cover, especially on hillsides.	Heavy Precipitation, Landslides

Source: IDB, 2015b; UNEP, 2010; Peduzzi, 2016

Engineering Enhancements

Infrastructure adaptation measures include engineering and hard structural solutions. At ports, infrastructure improvements for adaptation include improving existing systems and elevating or relocating structures. These strategies are often first to come to mind, and may be necessary in many cases, but can be more expensive and less flexible than process or ecosystem improvements. Table 13 provides specific engineering adaptation strategies.

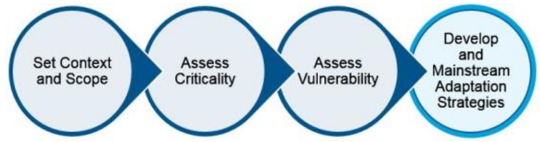
Table 13. Engineering enhancement adaptation strategies for ports

Adaptation Option	Relevant Climate Hazards
Raise port elevations	Sea Level Rise, Storm Surge
Raise quay height	Sea Level Rise, Storm Surge
Retrofit infrastructure or assets that are vulnerable to flooding	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Upgrade and improve sediment traps	Heavy Precipitation/Flooding
Increased covered areas for goods handling	Heavy Precipitation/Flooding; Extreme Heat
Improve tie down systems for cranes. A ductile link system would assist in improving the load distribution to the various components of the tie-down system and prevent failure of one or more tie-downs.	Wind
Isolate electrical connections to reduce incidents of loss of power to reefers and consequent extra energy for re-cooling\refreezing	Extreme Heat
Improve cranes' braking systems and wind speed prediction systems	Wind
Implement physical measures to reduce wave reflected around piers and improve berthing availability such as concrete drawers in areas exposed to high waves	Storm Surge
Build new coastal defenses	Sea Level Rise, Storm Surge
Expand dredging and nourishment programs to handle increased quantity of sediment shifting	Sea Level Rise, Storm Surge
Increase breakwater dimensions	Sea Level Rise, Storm Surge
Increase port size to deal with bottlenecks	Sea Level Rise, Storm Surge
Install back-up generators to maintain pumping systems and other critical facilities	Storm Surge

Sources: Becker et al., 2013; IDB, 2015a; IDB, 2015b

4.2.3 Airports

Similar to ports, there are many strategies that airport owners and operators can undertake to increase climate resilience. These strategies include process, ecosystem, and engineering enhancements. A combination of strategy types ensures effective adaptation at all levels.



Example

Boston Logan International Airport, operated by the Massachusetts Port Authority (Massport) in the United States, provides an example of one airport that has taken a comprehensive approach to resilience, encompassing a wide range of strategies. An approach like this requires high-level executive commitment to resilience at the facility in order to dedicate the necessary staff and other resources to these initiatives. The Massport resiliency strategies include strategic convening (create a task force of partnering agencies with common goals), research and planning (analyse resilience capacity for other threats), resilient design (execute infrastructure-specific designs and specifications), education and training (create accessible resources such as a website or online library), and operational preparedness (develop ground transport plans for staff to reach work during disruptive events) (Massport, 2016).

The following sections provide information on specific types of adaptation measures. Low regrets strategies are shaded in green.

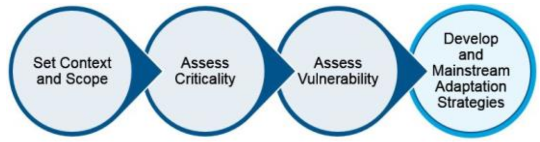
Process Enhancements

Improved processes—implemented through policies or subtle operational changes—provide an opportunity to increase organizational resilience across a variety of hazards (climate and otherwise). These strategies can include improved transition planning, data collection, research, monitoring, reviewing, and incorporating new information into existing airport policies and plans. Airports have several existing systems and processes in place, such as master planning, strategic planning, capital planning, operations, maintenance, asset management, staff management, emergency management, and internal communications protocols.

Integrating climate change into these systems is one way to facilitate resilient decision-making over time (e.g., by using the systems and processes listed above to reduce extreme weather risks). Table 14 provides specific process enhancement adaptation strategies for airports.

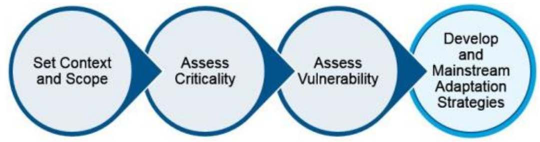
Table 14. Process enhancement adaptation strategies for airports

Adaptation Option	Relevant Climate Hazard
Improve transition planning to ensure staff with more experience transfer their institutional knowledge to new staff	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Review all planned capital investments with lifetimes > 20 years to ensure they are designed with future climate in mind	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Account for sea level rise when doing inventories for replacement and refurbishment of equipment and infrastructure	Sea Level Rise
Review flood early warning systems	Heavy Precipitation/Flooding
Take strategic actions to help spread the risk and manage future uncertainty, including diversification of trading partner countries and growing a broader range of business lines	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Support improved waste management activities in the nearby community to reduce debris.	Storm Surge, Wind, Heavy Precipitation/Flooding
Provide warnings of extreme temperatures to minimize heat stress risks for workers	Extreme Heat



Add climate change resilience as a factor in the Airport Master Plan	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Review and update plans for business continuity during extreme events	Storm Surge, Extreme Heat, Heavy Precipitation/Flooding
Establish a policy so that climate resilience enhancements are encouraged when infrastructure is due for replacement or renovation	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Diversify infrastructure related to fuel supply to ensure continued operations during disruptions	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Modify design criteria based on an understanding of potential climate change effects	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Engage with the government on the importance of developing a climate resilient transport system	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Establish a climate change contingency fund	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Establish methods to track the costs of weather events over time (e.g., charge codes or incident reports)	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Relocate critical operational centers or records (e.g., Met Service) from ground floor to higher floors	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Develop irregular operations protocols	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Plan for increased debris removal operations	Sea Level Rise, Storm Surge, Wind, Heavy Precipitation/Flooding
Enhance building codes to increase setback distances	Sea Level Rise, Storm Surge
Engage with stakeholders to plan landscape-level flood management options	Heavy Precipitation/Flooding
Adjust maintenance programme to ensure that the maximum capacity of the existing drainage system inside the port is being achieved	Heavy Precipitation/flooding
Update dredging programmes and schedules to reduce loss of draft clearance	Heavy Precipitation/flooding
Undertake review and adjust maintenance programmes to ensure that maximum capacity of existing drainage system is being achieved (e.g., frequency of drain clearance)	Heavy Precipitation/Flooding
Increase monitoring, maintenance and cleaning of stormwater systems	Heavy Precipitation/Flooding
Schedule more frequent pavement inspections on very hot days	Extreme Heat
Procure land to allow for future runway extensions, if possible	Extreme Heat
Educate employees about heat injuries	Extreme Heat
Incorporate rising temperatures into energy audits	Extreme Heat
Schedule cooling breaks for employees on very hot days	Extreme Heat
Improve temperature control and monitoring strategies	Extreme Heat
Close airport and stop handling operations before operating thresholds for equipment are reached	Wind
Require tie-downs for larger aircraft to prevent wind damage	Wind

Sources: ARCP, 2012; IDB, 2015a; IDB, 2015b; ACRP, 2015



Ecosystem Enhancements

Ecosystem-based adaptation approaches involve protecting, strengthening, and even rebuilding ecosystems to buffer against climate-related impacts. They can also increase the resilience of the population and provide co-benefits, such as food supply, cleaner water, and tourist value (UNEP, 2010). Ecosystem enhancements can play a significant role in reducing natural hazard risks, including coastal hazards and inland flooding, that threaten airport infrastructure. Examples of green infrastructure measures for airports include mangrove management and landscaping measures. In some cases, the airport may not have direct control over ecosystem enhancements, but could work with relevant local, regional, or national entities to support these enhancements. Table 15 provides specific ecosystem enhancement adaptation options for airports.

Table 15. Ecosystem enhancement adaptation strategies for airports

Adaptation Option	Relevant Climate Hazard
Support beach nourishment, coral reef protection, mangrove protection, and other ecosystem restoration efforts to reduce coastal flood risk.	Sea Level Rise, Storm Surge
Implement mangrove management programmes to ensure the distribution, diversity, and health of species. Mangroves are proven to act as coastal protection from flooding.	Sea Level Rise, Storm Surge
Support sustainable land use and development to avoid slope destabilization and landslides.	Heavy Precipitation/Flooding
Consider catchment-level landscape planning and ecosystem-based adaptation options for reducing risk of drainage overflow.	Heavy Precipitation/Flooding
Encourage green landscaping and tree planting to reduce heat island effect	Extreme heat
Plan for increased wetland mitigation activities	Sea Level Rise, Storm Surge

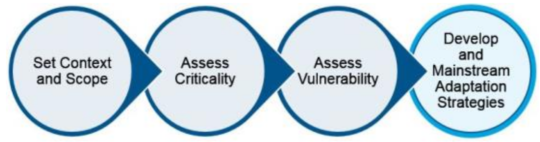
Source: IDB, 2015b; ACRP, 2015

Engineering Enhancements

These strategies focus on directly protecting specific assets or facilities by either reducing their exposure or sensitivity to the hazard. Examples of infrastructure measures include installing flood barriers, elevating critical facility components, or changing construction materials to be more salt- or heat-resistant. For example, the Australian Government constructed a new runway at the Brisbane Airport that accounted for climate change by elevating the runway and placing the runway in an area allowing for future lengthening (Commonwealth of Australia, 2013). Table 16 provides specific engineering adaptation strategies for airports.

Table 16. Engineering enhancement adaptation strategies for airports

Adaptation Option	Relevant Climate Hazards
Retrofit infrastructure or assets that are vulnerable to flooding	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding



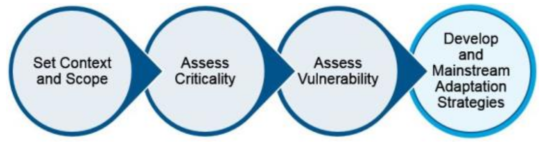
Install flood barriers to protect flood-prone areas	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Install on-site, raised and protected backup power supplies	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Install pavement sensors to monitor runway degradation from the sun or from standing water	Sea Level Rise, Storm Surge, Extreme Heat, Heavy Precipitation/Flooding
Relocate high-value, high vulnerability infrastructure to reduce risk	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Elevate runways or buildings at risk from sea level rise	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Elevate critical equipment	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Protect exposed utilities to reduce potential for flood damage	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Install erosion control structures	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Increase water removal capacity	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Increase drainage capacity	Heavy Precipitation/Flooding, Sea Level Rise
Increase stormwater retention capacity	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Modify fill material to prevent foundation heave	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Use modular sea walls and flood walls along streets	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Install pumping systems for low areas	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Plant vegetation around airport buildings to lower surface and air temperatures, and manage stormwater runoff.	Extreme heat, Heavy Precipitation/Flooding
Reduce heat sensitivity of runway/tarmac pavements (e.g., upgrade asphalt pavement binder)	Extreme heat
Install white roofs to reduce building energy load	Extreme heat
Improve building envelope (fenestration, roofing materials, cladding material, vapor barriers, retarders, etc.)	Extreme heat
Lengthen runway	Extreme heat
Use hard stands to prevent loss of pavement integrity	Extreme heat

Sources: ARCP, 2012; IDB, 2015a; IDB, 2015b; ACRP, 2015

4.3 Develop a multiyear implementation strategy

As discussed above, selection of adaptation strategies should be based on an evaluation of the net costs and benefits of the strategies as well as consultation with stakeholders. Consider the implementation timing of each action in order to develop a multi-year implementation strategy. Some measures can be implemented quickly, while others will require more extensive planning and funding before they can be put in place. In addition, consider when the adaptation measure will yield benefits (USAID, 2014).

Identify specific next steps, responsible parties, and strategies for mainstreaming consideration of climate change into existing processes. Rather than creating an entirely new or parallel set of programmes and policies to address climate vulnerability, incorporate consideration of climate



impacts into existing decision-making to address uncertainties and imprecision in magnitude and timing of impacts. Mainstreaming leverages existing resources, requires minimal resources to implement, avoids the disruption that reorganization can create, and generates less opposition than creating new institutions (USAID, 2015a). Start by identifying existing relevant processes and decisions.

Example

The Adaptation Plan for the Port of Manzanillo recommends measures to be implemented by the port to reduce risks and take advantage of opportunities from climate change. The plan carefully considers Mexico's adaptation policy frameworks and outlines measures that align with policies and strategies at the federal, state, and municipal levels. The plan also indicates how adaptation measures can be integrated into the Port Master Plan and into other existing operational plans. The Adaptation Plan also includes a plan for engaging stakeholders to be involved in the implementation process (IDB, 2015b).

4.4 Capture funding for implementation

A variety of entities, including multilateral and bilateral organizations, development finance institutions, national development banks, international organizations and insurance facilities all provide funding for climate change adaptation efforts in developing countries. Once a strategy is in place, identify which sources of funding would be appropriate for implementing a given project or strategy. Figure 6 outlines some of the major sources for international adaptation financing in the form of loans and grants. Some of the most common funds are through the United Nations Framework Convention on Climate Change (UNFCCC). More information about these funds can be found under the Global Environmental Fund (GEF).

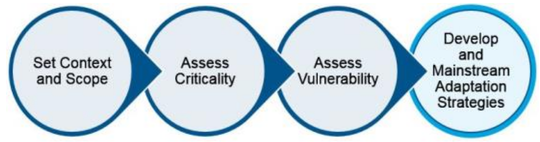
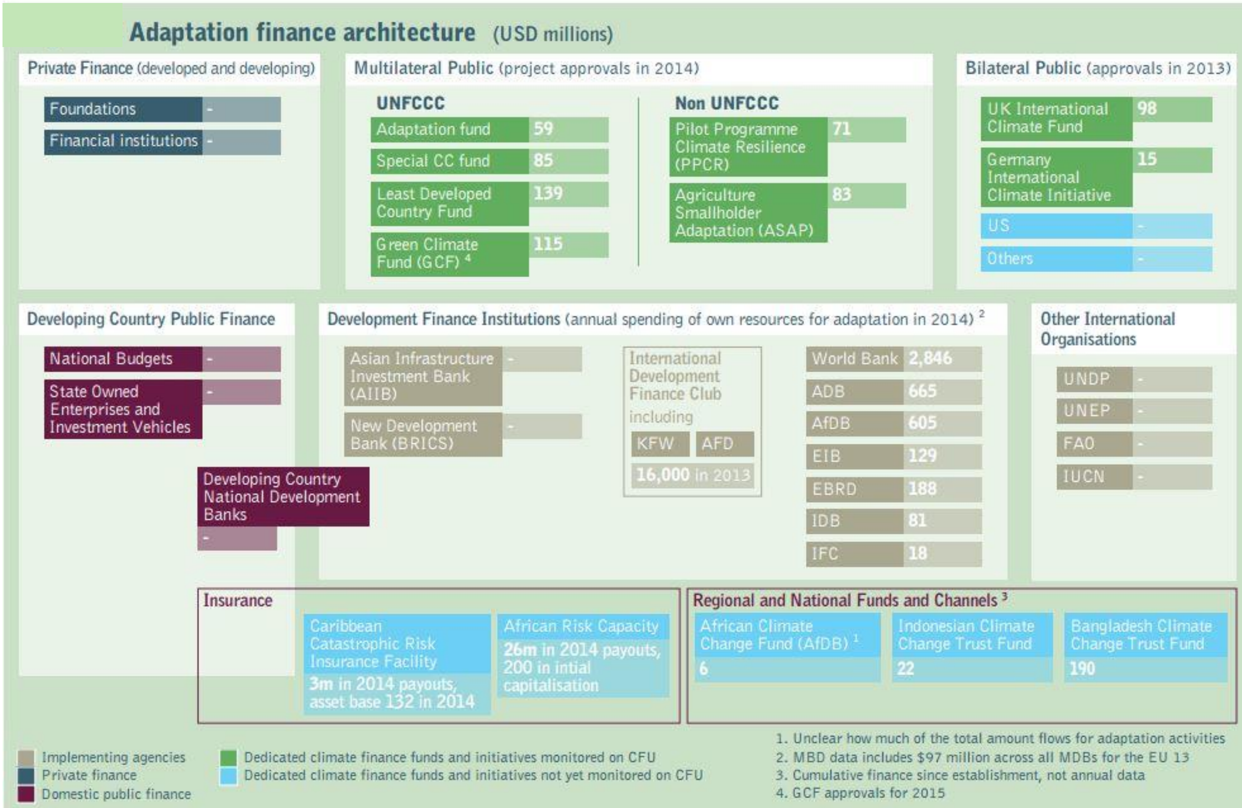
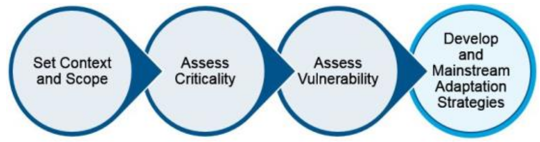


Figure 6. International adaptation finance architecture (Trujillo et al., 2015)



Available resources change relatively frequently. To keep abreast of the most updated lists of financing opportunities, there are a number of places to monitor and find sources that meet the needs of a given project.

- EUROCLIMA maintains an updated list of principal sources of climate finance specific to Latin America, available on its website (EUROCLIMA, 2017). It also has a guide for climate financing in Latin America (European Commission, 2015).
- Caribbean Disaster Emergency Management Agency (CDEMA) website provides a list of available financing opportunities for community resilience and climate change adaptation in the Caribbean region (CDEMA, 2017).
- Organisation for Economic Co-operation and Development (OECD) Climate Fund Inventory provides a consolidated list of public climate funds with eligibility information (OECD, 2017).
- The Adaptation Programme and Financing Mechanism through the Pilot Program for Climate Resilience and Inter-American Development Bank has made US$17.5 million available to assist in mainstreaming climate change into development plans in the Caribbean.
- Caribbean Development Bank's Environment, Disaster, and Climate Change, Basic Needs Trust Fund (BNTF) provides a source of funding for disaster risk reduction, climate change mitigation, and climate change adaptation projects in the Caribbean (CDB, 2017).



4.5 Monitor and evaluate

Monitoring and evaluation are integral to the adaptation process to inform adaptive management over time (UNFCCC, 2016), particularly because adaptation strategies operate in a dynamic environment (5Cs, 2009).

Key components of an adaptation monitoring and evaluation framework include:

- Monitor the frequency of climate extremes over time (USAID, 2014)
- Establish performance measures to help ensure objectives are being met, and measure effectiveness of adaptation strategies over time (FHWA, 2015a; UNFCCC, 2016).
  - For ports and airports, performance measures may include:
    - On-time departures
    - Passenger throughput
    - Revenue generated
    - Facility closure duration
    - Time from beginning of weather event to dissemination of information to travelers
    - Frequency of flooding, operational shutdowns.
  - These performance measures need not be climate change-specific. In some cases, ports and airports may just need to recognize that climate change could affect their ability to meet existing performance measures (such as revenue or on-time statistics), and be sure they are able to measure the impact of extreme weather events on those outcomes.
- Project evaluations to identify effective evaluation approaches (UNFCCC, 2016)
- Working with existing data sources to track progress over time (UNFCCC, 2016).

Establish a monitoring and evaluation implementation plan to determine if actions are performing as designed and to identify the potential causes of poor performance (USAID, 2014).

Evaluation focuses on assessing the results of implementation to improve performance, ensure accountability, and promote learning. Consider the performance of the strategy under changing climate conditions. Distinguishing between the different reasons for poor performance such as a design flaw, substandard project implementation, or an unpredictable climate surprise could lead to different adjustments for improving project performance. Uncertainties about how climate will change and the need for adaptive management make it particularly important to give special consideration to implementation and evaluation in advance (USAID, 2014).

Frameworks for monitoring and evaluation of climate change adaptation are rapidly evolving, though the majority of the efforts are focused on the national level (Bours et al., 2014). For additional information, see Step 5 of the UKCIP AdaptME Toolkit at http://www.ukcip.org.uk/wizard/adaptme-toolkit/ (UKCIP, 2013).

V. Appendix

1. Key Terms

Unless otherwise noted, definitions are adapted from IPCC (2012)

Adaptation: In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.

Adaptive Capacity: The ability to take actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities from current climate extremes and long-term climate change.

Climate: Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. In various chapters in this report different averaging periods, such as a period of 20 years, are also used.

Climate change: A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate model: A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties. The climate system can be represented by models of varying complexity. Coupled Atmosphere-Ocean Global Climate Models (AOGCMs), also referred to as Atmosphere-Ocean General Circulation Models, provide a representation of the climate system that is near the most comprehensive end of the spectrum currently available. There is an evolution toward more complex models with interactive chemistry and biology. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal, and interannual climate predictions.

Climate projection: A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative-forcing scenario used, which are based on assumptions concerning, e.g., future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Component*: In this report, component refers to individual assets or components of a facility. For example, runways and terminals are components of an airport facility.

Criticality*: Criticality is the overall importance of an asset or system.

Criticality assessment*: An assessment to quantify or otherwise assess of the importance of an individual asset or system.

Criticality screening*: An assessment to screen for or identify the most critical assets or components of a system. To identify the most critical within a larger group of assets.

Downscaling: Downscaling is a method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses.

Emissions scenario: A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as technological change, demographic and socioeconomic development) and their key relationships. Concentration scenarios, derived from emissions scenarios, are used as input to a climate model to compute climate projections

Exposure: The extent to which an asset is subject to a climate hazard.

Facility*: Facility, in this report, refers to a port or airport, such as the facilities selected for assessment in the Jamaica and Saint Lucia case studies, like Port Castries and Hewanorra International Airport.

Hazard: The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.

Impacts: Effects on natural and human systems. In this report, the term ‘impacts’ is used to refer to the effects on natural and human systems of physical events, of disasters, and of climate change.

Mean sea level: Sea level measured by a tide gauge with respect to the land upon which it is situated. Mean sea level is normally defined as the average relative sea level over a period, such as a month or a year, long enough to average out transients such as waves and tides.

Projection: A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized, and are therefore subject to substantial uncertainty.

Resilience: The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.

Return period: An estimate of the average time interval between occurrences of an event (e.g., flood or extreme rainfall) of (or below/above) a defined size or intensity.

Risk: The probability of loss or damage from a hazard, as a function of the hazard's likelihood and consequence.

Sea level change: Changes in sea level, globally or locally, due to (i) changes in the shape of the ocean basins, (ii) changes in the total mass and distribution of water and land ice, (iii) changes in water density, and (iv) changes in ocean circulation. Sea level changes induced by changes in water density are called steric. Density changes induced by temperature changes only are called thermosteric, while density changes induced by salinity changes are called halosteric.

Sensitivity: The extent to which an asset or system will be positively or negatively affected if it is exposed to a climate hazard.

Uncertainty: An expression of the degree to which a value or relationship is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. Uncertainty may originate from many sources, such as quantifiable errors in the data, ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgment of a team of experts

Vulnerability: The propensity or predisposition to be adversely affected.

*Definition for the purpose of this report

2. Example Stakeholder Tracking Table

Table 17. Example stakeholder tracking table

Organization	Name	Role	Phone	Email	Engage in:			
					Context and Scoping	Criticality Assessment	Vulnerability Assessment	Adaptation Planning

3. Climate Change Vulnerability Assessment Data Needs and Priorities

Table 18. Summary of climate change vulnerability assessment information needs and priorities

Priority	Category	Data Needed	Description	Assessment Step	Source
Highest	Climate data	Historical weather conditions	E.g., monthly average temperature and precipitation	Exposure	National government (e.g., Met Service)
Highest	Climate data	Tidal surface elevation	Average mean higher-high water at as many points as possible across the country	Exposure	National government (e.g., Met Service)
Highest	Climate data	Climate change projections	Averages (e.g., average annual or monthly temperature, precipitation), Extremes (e.g., number of days above today's 95^{th} per centile temperature or precipitation), estimated future sea level rise	Exposure	Local/regional universities, Intergovernmental Panel on Climate Change, etc.
Highest	Facility data	Transport facility location and spatial attributes (GIS)	Name, Location, Elevation, Spatial extent, replacement value, annual maintenance cost	Exposure	Facility owner/ operator
Highest	Facility data	Facility elevation (GIS)	Highest-possible resolution elevation data for the facility	Exposure	Facility owner/ operator
Highest	Facility data	Facility operations data	e.g., Volume of passengers, number of enplanements and deplanements, type and	Criticality	Facility owner/ operator

Priority	Category	Data Needed	Description	Assessment Step	Source
			volume of commodities, number of vessels, value of goods		
Highest	Facility data	Critical facility components	e.g., Number and locations of runways, control towers, and terminals in airports	Exposure	Facility owner/ operator
Highest	Facility data	Inland connectivity infrastructure	e.g., Type, location, and condition of roads and rail used to access facility (in GIS, ideally)	Sensitivity	Facility owner/ operator
Highest	Facility data	Vessel statistics	Type and size	Criticality	Facility owner/ operator
Highest	Historical weather data	Historical significant weather events	List of event names, descriptions, and dates	Sensitivity	Facility owner/ operator
Highest	Historical economic data	Past facility disruptions due to weather	Date and duration of closure, type of weather event	Sensitivity	Facility owner/ operator
Highest	Historical operations data	Data on thresholds describing when operations are disrupted	Criteria for determining if service is stopped, description of weather sensitivity thresholds (e.g., port experiences X impacts at Y ft. of storm surge)	Sensitivity	Facility owner/ operator
Highest	Historical economic data	Economic implications of disruptions	e.g., Revenue lost due to disruption	Sensitivity	Facility owner/ operator
Highest	Historical economic data	Repair and replacement cost	Cost of repairs and replacements necessitated by damage due to historic weather events	Criticality	Facility owner/ operator
Highest	Other	Elevation (GIS)	Highest-possible resolution elevation data for the country	Exposure	National government
Tier 2	Facility data	Master plan for facilities	Planned port developments, market forecasting, strategic objectives	Criticality	Facility owner/ operator
Tier 2	Facility data	Facility employment statistics	Number and types of employees	Criticality	Facility owner/ operator
Tier 2	Facility data	Critical facility equipment and damage information	Types of equipment are located at each facility, replacement cost of equipment	Criticality	Facility owner/ operator

Priority	Category	Data Needed	Description	Assessment Step	Source
Tier 2	Facility data	Company/tenant information	Size, number, and types of companies operating at the facility	Context	Facility owner/ operator
Tier 2	Facility data	Trading partners and competition	Location and trade flows	Context	Facility owner/ operator
Tier 2	Facility data	Annual or five-year capital program		Context	Facility owner/ operator
Tier 2	Facility data	Strategic business and operations plans		Context	Facility owner/ operator
Tier 2	Facility data	Facility Revenues	Maintenance and operating costs, revenues	Criticality	Facility owner/ operator
Tier 2	Facility data	Economic contributions of facility	e.g., Tourism dollars accounted for, number of visits	Criticality	Facility owner/ operator
Tier 2	Facility data	Health/Safety implications of facility	Role of facility in hurricane evacuation, hospital/healthcare access, access to major employment centers	Criticality	Facility owner/ operator
Tier 3	Facility data	Electricity generation	Location and type	Sensitivity	Facility owner/ operator
Tier 3	Facility data	Potable water	Source	Sensitivity	Facility owner/ operator
Tier 3	Facility data	Sanitation facilities		Sensitivity	Facility owner/ operator
Tier 3	Transport System Data	Pre-existing stressors to transport system	Aging infrastructure, land use change, population growth, port and airport usage rates, economic shocks, crime, pollution, and enforcement of regulations	Context	National Government/ Development Organizations/ Universities
Tier 3	Development Needs	National-level strategies; related work; main players responsible for adaptation	e.g., National Communications to the United Nations Framework Convention on Climate Change	Context	National Government/ Development Organizations/ Neighboring Countries

4. Summary of Caribbean Climate Change Data

Table 19. Climate data sources available in the Caribbean

Name	URL	Variables	Time Period	Temporal Resolution	Models	Scenario(s)	Spatial Resolution
Caribbean Community Climate Change Centre (5Cs) Regional Clearinghouse* – RCM	http://clearinghouse.caribbeanclimate.bz/?db_type=Climate%20Model&country=&collection=V501&s=&sector=&topic=	Available soil moisture content in root zone, convective rainfall rate, evaporation rate from canopy, large scale rainfall rate, max temperature, minimum temperature, humidity, etc.	1961-2100	Daily	ECHAM5	A1B	25 km
Caribbean Community Climate Change Centre (5Cs) Regional Clearinghouse – HadCM32 GCM ensemble	http://clearinghouse.caribbeanclimate.bz/?db_type=Climate%20Model&country=&collection=V501&s=&sector=&topic=	Change in annual mean temperature, Change in total precipitation rate (mm/day), Change in mean surface temperature, Change in relative humidity, Change in wind speed at 10 m (m/s)	2010-2069	Daily	HadCM3 (aexsc), HadCM3Q3 (aexsa), HadCM3Q11 (aexsm), HadCM3Q14 (aexsl), HadCM3Q0 (aenwh), HadCM3Q10 (aexsk)	A1B	25 km
5Cs Regional Clearinghouse – ECHAM4 50 km	http://clearinghouse.caribbeanclimate.bz/?db_type=Climate%20Model&country=&collection=V501&s=&sector=&topic=	Change in annual mean temperature, Change in total precipitation rate (mm/day), Change in mean surface temperature, Change in relative humidity, Change in wind speed at 10 m (m/s)	1990-2100	Daily	ECHAM4	A2, B2	50 km

Name	URL	Variables	Time Period	Temporal Resolution	Models	Scenario(s)	Spatial Resolution
5Cs Regional Clearinghouse – HadAM3P 50 km	http://clearinghouse.caribbeanclimate.bz/?db_type=Climate%20Model&country=&collection=V501&s=&sector=&topic=	Change in annual mean temperature, Change in total precipitation rate (mm/day), Change in mean surface temperature, Change in relative humidity, Change in wind speed at 10 m (m/s)	2010-2069	Daily	HadAM3P	A2, B2	50 km
CARIBSAVE Climate Change Risk Atlas	http://www.caribbeanclimate.bz/?s=CARIBSAVE+Climate+Change+Risk+Atlas	Mean temperature, total precipitation, wind speed, relative humidity, sunshine hours, sea surface temperatures, frequency of hot days, frequency of hot nights, frequency of cold days, frequency of cold nights, per centage of rainfall falling in heavy events, maximum 1-day rainfall, maximum 5-day rainfall	2020s, 2050s, 2080s (rel. to 1970-1999)	Seasonal and Annual	Ensemble of 15 General Circulation Models (GCMs) and PRECIS Regional Climate Model (RCM) driven by ECHAM4 and HadCM3	GCMs: A2, A1B, B1 RCM: A2	GCMs: 2.5 degrees RCM: unknown
IDB Climate Change Projections in Latin America and the Caribbean: Review of Existing Regional Climate Models' Outputs	https://publications.iadb.org/handle/11319/7746?locale-attribute=en	Temperature: Change in days > 29.5°C, days > 35°C, and days > 41°C Precipitation: Change in return interval of today's 20-, 30-, 50-, 100-, and 300-year events Sea level rise	Baseline: 1986–2005 Future: 2040, 2070	Annual	38 GCMs (see report)	RCP6, RCP8.5	0.5 degrees

*Additional datasets are under development and will be posted on the 5Cs Regional Clearinghouse once available (Trotz, 2017)

5. Understanding Sea Level Rise

What is happening now?

Sea levels rise because warmer temperatures cause water molecules in the ocean to expand (thermal expansion), glaciers and ice caps to melt, and continental ice sheets to melt and flow into the ocean. Since 1880, global mean sea level (GMSL) has risen by 21-24 cm, with a third of that occurring since 1993 (NOAA, 2017; Church and White, 2011; Hay et al., 2015). Measurements of sea level in the past few decades and reconstructions into the past demonstrate that global mean sea levels have risen at an increasing rate, from around 1.7 mm/year in the early part of the 20th century to 3.2 mm/year between 1993 and 2010 (IPCC, 2014a). Sea level measurements and historical reconstructions come from altimeters (satellite data) and tide gauges. Since 1993, the two have aligned, both reporting annual sea level rise of around 3-3.4 mm/year (NOAA, 2017). This rate is faster than scientists imagined and show that GMSL rise since 1900 has been at a faster rate than any comparable period in the last 2800 years (Kopp et al. 2016).

Where do sea level rise projections come from?

Based on historical sea level rise trends and projections of future climatic conditions, scientists create projections of potential future sea level scenarios. Projections are not predictions of actual sea level rise because no one knows exactly how the ocean will respond. Instead, projections are a range of plausible outcomes based on the best scientific information. Their purpose is to aid decision makers in planning for an uncertain future. These projections may consider the impacts of ice-sheet dynamics, land subsidence, and greenhouse gas emissions scenarios with corresponding temperature changes on sea level.

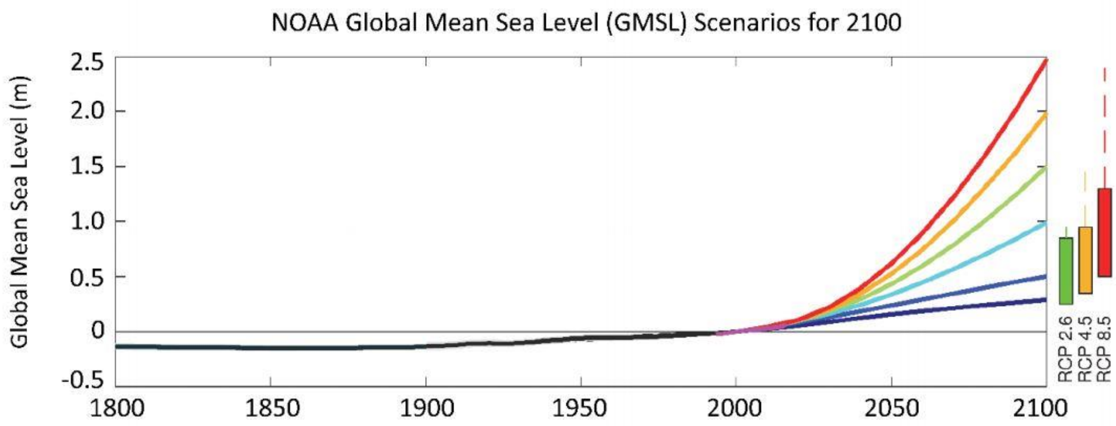
Sea level rise occurs because of a number of factors, primarily thermal expansion due to rising temperatures and ice melt from land-based glaciers and ice sheets. Previously, scientists underestimated the extent of land-ice melt from the continental ice sheets of Greenland and Antarctica. Improved modelling of these land-ice contributions has increased global sea level rise projections beyond what they were previously (IPCC, 2014a; DeConto and Pollard, 2016). Continental ice sheets are miles thick and supported by land. As they melt, the water from the ice will enter the ocean. For thousands and millions of years, this ice has been stored in these large glaciers and, once they pass a particular threshold, this unprecedented level of melt is irreversible. Thus, as scientists have taken these dynamics into account, projections of future sea level rise out to 2100 have changed. See Table 20.

Table 20. Evolution of global sea level rise projections

Year	Study	2100 Global Mean Sea Level Rise Projections
2001	IPCC, 2001	0.09 – 0.88 m
2007	IPCC, 2007	0.18 – 0.59 m
2014	IPCC, 2014a	0.52 – 0.98 m
2017	NOAA, 2017	0.3 – 2.5 m

The 2017 NOAA Technical Report on Sea Level provides evidence of the most up-to-date science and methodologies on sea level rise from the literature. The GMSL projections range from 0.3 m - 2.5 m by 2100 and involve probabilistic modelling that accounts for different greenhouse gas emissions scenarios and temperature changes (see Figure 7). **The most recent projections find support a plausible GMSL rise of 2.0-2.7 meters by 2100.**

Figure 7. Global mean sea level rise projections (NOAA, 2017)



This study's six representative GMSL rise scenarios for 2100 (6 colored lines) relative to historical geological, tide gauge and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines; as in Figure 3a) and central 90% conditional probability ranges (colored boxes) of RCP-based GMSL projections of recent studies (Church et al., 2013a; Kopp et al., 2014; 2016a; Slangen et al., 2014; Grinsted et al., 2015; Mengel et al., 2016). These central 90% probability ranges are augmented (dashed lines) by the difference between the median Antarctic contribution of Kopp et al. (2014) probabilistic GMSL/RSL study and the median Antarctic projections of DeConto and Pollard (2016), which have not yet been incorporated into a probabilistic assessment of future GMSL. (A labeling error in the x-axis was corrected on January 30, 2017).

How do global sea level rise projections translate to local sea level rise projections?

Sea level rise will not be uniform across the globe. Some areas will experience more than others because of gravitational pull. Antarctica pulls water towards it because of its great mass and as that is lost, seas will push back to the north. NOAA's GMSL model has been used to create regional sea level rise projections for the U.S. and Caribbean. Regional sea level rise depends on various factors that impact the relative land-sea levels, including oceanographic circulation, gravitational forces, subsidence, and differences in topography, groundwater and fossil fuel withdrawals (NOAA, 2017). Based on these projections, the east coast of the U.S. and the Caribbean will experience higher than average sea level rise compared to the rest of the world (NOAA, 2017).

Thus, when considering the estimations of sea level rise, it is wise to find region-specific data that will capture the specific impacts to a particular region of the world rather than taking a global average. As the time and resources allow, working with climate science and coastal experts may be beneficial for finding and analyzing relevant data and turning it into actionable adaptation plans.

How do I choose a sea level rise scenario?

For decision makers, it can be difficult to determine which projections to use and how to make decisions when the future conditions are uncertain. The level of detail and projections used may depend on the type of project being executed. For each project, managers should understand the goals, problems, and specific circumstances of the decision, including the timeframe for the project, who will be affected by sea level rise, are there thresholds in the human or natural systems, and specific details of the coastal system and location vulnerability (NOAA, 2017). These questions may reveal the need for a “stress test” or vulnerability assessment to determine the risks sea level rise poses (NOAA, 2017). Overall, failure to account for sea level rise events, even those that are low-probability, high-consequence can make projects susceptible to future risks. It is often best to base decisions on the worst-case scenarios (NOAA, 2017).

The most up-to-date information indicates that the low-end scenario by 2100 should be updated to 0.3 m by 2100 because satellite altimeters and tide gauges have measured sea level rise at over 3 mm/year for close to 30 years (NOAA, 2017). This lowest RCP scenario is unlikely achievable given that it would require net-zero greenhouse gas emissions (NOAA, 2017). Given the mounting evidence that ice loss from the Antarctic and Greenlandic ice sheets is increasing, there is more emphasis on considering the worst-case scenarios, in the range of 2.0 m to 2.7 m (NOAA, 2017). This upper limit of GMSL rise is critical for infrastructure with a long lifespan (NOAA, 2017). In order to design specifications that consider sea level projections, managers should consider what the plausible upper-bound or worst-case scenario would be for their particular location. Over a long-term project, the likelihood of this level of event should not be underestimated. It is likely that a low GMSL scenario would have 94% to 100% likelihood of being exceeded under a high or low RCP emissions scenario, whereas extreme high projections have a 0.05% to 0.1% chance of exceedance (NOAA, 2017). Use a central estimate or mid-range scenario as a baseline for short-term planning but continue to use the upper-bound as a standard for planning (NOAA, 2017). Most robust and risk-based decision-making would plan according to a scientifically plausible, worst-case scenario (NOAA, 2017).

As mentioned earlier, these projections are not stagnant. As the scientific community continues to improve their modelling techniques, gather more observational data, better understand ice sheet dynamics, and develop a deeper understanding of the feedback mechanisms that result from climate change, the projections of sea level rise will become more refined. Furthermore, these scenarios only account for changes until 2100. Depending on how the climate and greenhouse gas emissions change during that timeframe, the path for sea level rise might change dramatically. For this reason, it is important for decision makers to plan for uncertainty and practice “adaptive management”. Adaptive management strategies involve flexible plans that can be modified as new information becomes available.

6. Example Port and Airport Vulnerability Assessments

Several organizations have completed vulnerability assessments of transport infrastructure to climate change. These assessments have occurred at all levels, including national, regional, local, and facility level.

For example, a seminal assessment conducted in the United States is the Gulf Coast Study, which assessed the potential impacts of climate change on the transport sector across a region in the southern United States.

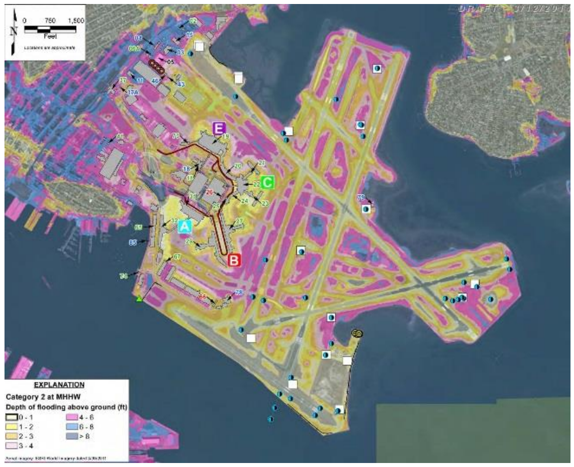
6.1 National and regional assessments

- **U.S. Department of Transportation, Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study** – The study used historical trends and future climate projections to examine the potential effects of climate change on all major transport modes within the U.S. central Gulf Coast Region. Key findings included: (1) warming temperatures are likely to increase the costs of transport construction, maintenance, and operations; (2) More frequent extreme precipitation events may disrupt transport networks with flooding and visibility problems; (3) relative sea level rise will make much of the existing infrastructure more prone to frequent or permanent inundation – 27 percent of the major roads, 9 percent of the rail lines, and 72 percent of the ports are built on land at or below 122 cm (4 feet) in elevation; (4) Increased storm intensity may lead to increased service disruption and infrastructure damage (CCSP, 2008).
- **Belize Climate Resilient Infrastructure Project** – The project evaluated flood susceptibility using an indicator-based approach, carried out through field visits and qualitative methods. Detailed flood hazard analysis was not possible because hydro-meteorological, topography, and bathymetry data were not available, Instead, the study used two criteria: flooding at stream crossing and indications of river floods (e.g., flood records) (World Bank, 2014).

6.2 Airport facility-level assessments

- **Massachusetts Port Authority, Boston Logan International Airport** – Massport used high-resolution LiDAR elevation data to map potential inundation at the airport under a series of hurricane and sea level rise scenarios (see Figure 8). These scenarios include Category 2 or 3 hurricanes and mean higher high water (Massport, 2016a).

Figure 8. Inundation mapping at Boston Logan International Airport (Massport, 2016a)



- **Heathrow Airport, London: Climate Change Adaptation Reporting Power Report** – This study considers assets owned by Heathrow Airport Limited and uses a comprehensive risk assessment of climate related risks to the direct and indirect operations of Heathrow. risk assessment approach has been developed to address risks in the short (to 2020) and medium to long term (2040/50), alternative future scenarios of climate change, the implications of critical thresholds and uncertainty in core data used. To maximise the accessibility of the findings of this study to airport staff; to put the risks into the context of day to day risk management activities; and to allow comparison of the risks associated with climate change to other risks on risk registers for the airport, the results of this assessment have been expressed in terms of the language, objectives and processes currently used at Heathrow for risk management where they are appropriate (Heathrow Airport Limited, 2011).
- **Airport Climate Risk Operational Screening (ACROS) Tool** – Developed by the United States' Airport Cooperative Research Program (ACRP), ACROS provides a way for airports to perform a high-level climate change vulnerability screen, across climate hazards, airport assets, and operational activities. The tool relies on relatively low resolution GCM data and simple climate variables, such as the number of days greater than 90°F (32.2°C) and the number of days with rainfall greater than 0.8 inches (20.3 mm). It then provides a default vulnerability rating of each asset (e.g., runways, apron, navigation aids, gates) for each hazard on a simple scale of 1 to 3 to help airports identify what assets or operations at the airport are most at risk to climate changes (ACRP, 2015).

6.3 Port facility-level assessments

- **Port Avatiu, Rarotonga, Cook Islands: Climate Risk Assessment for Ports and Connected Infrastructure** – This project conducted a qualitative "first pass" vulnerability assessment using surveys of key port stakeholders to assess the historical frequency and severity of climate-related weather events. This study also focused on the relationship between the port and other interconnected infrastructure (e.g., water, energy) (Cox et al., 2013).

- **Port Kembla, Australia: Mapping Vulnerability to Sea-Level Rise** – This project develops a 3D model to assess the vulnerability of ports by determining the impact of sea level rise on assets. Key operational assets were first identified and geo-referenced on a high-resolution digital terrain model. The spatial model provides an innovative, flexible and visual representation of sea-level rise under different climate projections with the capability of mapping vulnerability of port assets relative to their location. The visual outputs provide the capacity to develop evidence-based adaptation strategies to adjust or retreat to respond to the risk of sea-level rise and related flooding (Chhetri et al., 2014).
- **Muelles el Bosque, Colombia: Climate Risk and Business (Ports)** – This report used projections from 10 General Circulation Models for three emissions scenarios to capture the range of uncertainty. The report assesses climate change risks to the assets and activities on which a port's commercial success relies, including: trade levels and patterns, navigation and ship berthing, goods handing inside ports, movements of goods, vehicles, and people, goods storage in ports, and inland transport beyond ports' fence lines (IFC, 2011).
- **Port of Manzanillo, Mexico: Climate Risk Management** – This study applied the UK Climate Impacts Programme framework, a widely cited approach that has been used as the theoretical foundation of many subsequent conceptual frameworks. The study carries out financial analysis in three stages: baseline case, climate change cases, and climate change with adaptation cases. The study takes into account the latest climate change policy developments established at the federal, state and municipal level in Mexico to ensure that adaptation actions at the port are in alignment with policy instruments that already exist in the country (IDB, 2015b).
- **Port of Rotterdam, Netherlands** – The Rotterdam Climate Proof Programme developed a comprehensive climate adaptation strategy and vulnerability assessment that identified bottlenecks and potential vulnerable areas citywide (Rotterdam Climate Initiative, 2015).
- **Port of San Diego, California, USA** – The Port of San Diego completed a risk evaluation to consider the likelihood and consequence of different climate change impacts on a qualitative scale (e.g., low, medium, high, very high). These ratings were determined through stakeholder input (Becker et al., 2013, citing Messner and Moran, 2013).
- **Considering Climate Change: A Survey of Global Seaport Administrators** – A 2011 survey of port authorities around the world found that many respondents were considering, or at least discussing, climate change impacts. Sea level rise was the chief concern among respondents. Most ports plan on a 5-10-year horizon and the majority are planning for some level of expansion of their facilities. Those with planned projects indicated that most plans were for more terminals and berths or for land acquisition. Only three ports surveyed (3.2%) planned to build only protective structures. Globally, port planning practices do not yet address climate change and the resulting storm impacts, even though port managers recognize adapting to climate change as an emerging challenge (Becker et al., 2011).

6.4 Take-aways

The most detailed vulnerability assessments rely on high resolution LiDAR or other elevation data and advanced storm surge and/or wave modeling. However, several projects have developed actionable information without access to this data, which can be expensive and difficult to acquire. Additionally, the results of several assessments have been expressed in terms of the language, objectives, and processes currently used at the facility for risk management.

For this reason, we recommend that Caribbean SIDS pursue LiDAR data collection, while beginning to understand and address vulnerabilities through the framework described herein. See Section III, Lessons Learned and Recommendations.

7. Beach Erosion and Retreat Analysis Methodology

The Saint Lucia case study included an analysis of beach erosion and retreat. This appendix provides an overview of the methodology. Further details on the methodology can be found in UNCTAD (2017) and in Monioudi et. al (2017).

7.1 Methodology Overview

In the Saint Lucia case study, the approach to assess direct impacts of climate variability and change on the coastal transport infrastructure assets (i.e. the two ports and two airports) consisted of the following:

(1) Assessment of the direct impacts on coastal infrastructure through modelling of the flood/inundation due to extreme sea levels (ESLs) under the present and future climate.
(2) Assessment of direct impacts on coastal transport infrastructure using the thresholds method.
(3) Assessment of the indirect impacts on coastal infrastructure, viz. impacts on beach carrying capacity. Transport is a demand-driven industry. As international air passenger transport in St Lucia is almost entirely depending on tourism, the climate variability and change impacts on tourism were also analysed.

The thresholds method (2) is explained in Section 3.1. The remainder of this appendix focuses on the assessment of the indirect impacts of sea level rise on beach carrying capacity (3).

7.2 Input data

The input data for the application of this approach are the following:

7.2.1 Beach characteristics database

The geo-spatial characteristics of the "dry" beaches can be obtained, using images and other optical information, available in the Google Earth Pro application (UNCTAD, 2017). This included the geo-spatial characteristics of "dry" beaches. In this study, "dry" beaches were defined as the low-lying coastal sedimentary bodies bounded on their landward side by either natural boundaries (vegetated dunes and/or cliffs) or permanent artificial structures (e.g. coastal embankments, seawalls, roads, and buildings) and on their seaward side by the shoreline, i.e. the median line of the foaming swash zone shown on the imagery.

The lateral extent of individual beaches was delimited by natural barriers, such as rock promontories. Tiny beaches (length less than 50 m) were not included in the data set. Beaches were digitized as polygons. There has been no geo-rectification, as the aim of the exercise has not been to provide definitive locations and elevations of beach features, but to extract/record (horizontal) geo-spatial characteristics.

In addition to beach dimensions, other relevant information was recorded/codified, including: the presence of (a) natural features, such as river mouths, vegetation and (b) artificial features such as coastal protection schemes and backshore infrastructure/assets.

7.2.2 Environmental forcing

This methodology is suitable for large scale applications thus the input data of the models are not based on in situ measurements. The models are set up using a plausible range of environmental conditions. As initial bathymetry linear profiles are considered with different profile slopes. The lack of accurate bathymetry data may introduce some uncertainty. However, validation of the models against physical experiments in GWK in Germany showed that the results of the models set with the equivalent linear profile were reasonably close to those of the physical experiments (Monioudi et al. 2017). In Saint Lucia case study (UNCTAD, 2017) 5 different profile slopes (bed slopes of 1/10, 1/15, 1/20, 1/25 and 1/30) were examined. The wave forcing was provided though the analysis of ERA-INTERIM wave data (1979-2015) and it was found that significant wave heights in St Lucia ranged between 1 - 4 m. Experiments were carried out using various plausible wave conditions, i.e. waves with offshore heights (Hs) of 1, 1.5, 2, 3 and 4 m and periods (T) of 4, 5, 6, 7 and 8 s. With regard to the sediment texture, descriptive information (e.g. sand, gravel) was collected from the available photos on the Google Earth Pro application and other available information from the very little relevant literature available. Most beaches were found to be composed of sandy sediments, so a range of d_{50} values between 0.2 - 1 mm was used (d_{50} of 0.2, 0.33, 0.50, 0.80, 1 mm).

Table 1. Data used

Data	Source	Publicly Available?	Expertise Needed?	Software/Other Resources Needed?
Beach location and width	*Manually digitized from Google Earth*	*Yes*	*None*	*Google Earth Pro, Arc GIS*
Beach slope	*Plausible range of beach slopes*	*No*	*None*	*None*
Wave conditions	*Plausible range of wave conditions based on ERA-INTERIM wave data (1979-2015)*	*Yes*	*Manipulation of NetCDF Data*	*Software for Manipulating or Displaying NetCDF Data*
Median sediment size D_{50}	*Optical information from Google Earth and other available information collated from scientific literature/reports*	*Yes*	*None*	*None*
Mean Sea Level Rise Projections	*Integrated Climate Data Center - ICDC*	*Yes*	*None*	*None*
Total Water Levels Projections	*Joint Research Centre (JRC)*	*Yes?*	*Manipulation of NetCDF Data*	*Software for Manipulating or Displaying NetCDF Data*

7.2.3 Sea level projections

MSLR and episodic extremes (due to the combined effect of storm surges and wave set up) projections from literature and available databases are used. In the Saint Lucia case study recent MSLR projections for (i) southern assets (Hewanorra Airport and Port Vieux Fort (13.5° N, 60.5°W)) and (ii) northern assets (George F.L. Charles Airport and Port Castries (14.5° N, 60.5° W)) were used (Integrated Climate Data Center - ICDC, Church et al., 2013). Under RCP 4.5 and RCP 8.5 scenarios sea level rise is projected to be (i) 0.185 m and 0.19 respectively for the year 2040; and (ii) 0.56 m and 1.2 m respectively for the year 2100. Projections of episodic extremes for (i) south ports and (ii) North ports were provided from the Joint Research Centre (JRC).

7.3 Outputs

This approach outputs the following:

- Potential ranges of beach retreat/erosion and temporary inundation/flooding
- Ranges of decreases in 'dry' beach widths projected through the comparison between the ranges of beach retreat/erosion (*S*) and the maximum widths of the Saint Lucia beaches
- Ranges in beach temporary inundation/flooding
- Numbers and percentages of beaches where backshore infrastructure/assets are projected to be affected by beach retreat/erosion and flooding

The results for Saint Lucia and the detailed analysis methodology are provided in UNCTAD (2017).

7.4 Special expertise needed to apply the methodology

A toolbox is constructed in order to simplify the developed approach. The toolbox is provided as a Guide User Interface (GUI) suite, is user- friendly, fast and requires no great expertise for its operation. This tool can bridge the gap between coastal scientists/engineers and coastal managers and stakeholders and can be used in building capacities in coastal regions with scarcity in human resources and little relevant expertise.

It must be noted that use of the toolbox may reduce flexibility in the use of the models; for full control in the use of the models, experience in morphodynamic modeling and scientific programming is needed. Nevertheless, it can be used easily for a first assessment of the beach erosion risk. The toolbox is provided together with a detailed manual.

7.5 Benefits

The present approach provides reasonable assessments of potential ranges of beach retreat under marine forcing (i.e. sea levels and waves) on the basis of (minimal) environmental information that can be obtained relatively easily. It provides ranges (maximum and minimum) of the horizontal excursion of cross-shore beach retreat/inundation, which could be then compared to the beach width that could be easily determined by remote-sensed imagery.

Beach erosion is amongst the first issues to consider when planning for the sustainable development of the coastal zone, particularly in areas where beaches function as natural 'armor' to valuable coastal infrastructure and assets and/or as significant environments of leisure. Assessments of the beach morphological evolution at different spatio-temporal scales are required, based on advanced numerical, analytical, and/or empirical models constructed and applied by experienced operators, set up/validated using appropriate field data and backed by expert analysis. However, such efforts are usually hampered by the (a) scarcity of relevant information in many coastal areas, and (b) dearth in the necessary human and financial resources (e.g. Parker et al., 2013); this is particularly true when assessments of beach erosion are carried out over larger spatial scales.

Existing methodologies/tools for rapid assessment of coastal/beach erosion due to MSLR and extreme events at large scales (e.g. Hinkel et al., 2010) have limitations stemming from (amongst others): (a) their requirements for coastal Digital Elevation Models (DEMs) of high resolution/accuracy; and (b) the generally limited consideration of major controls (e.g. hydrodynamics). At the same time, advanced modeling approaches (e.g. Vousdoukas et al., 2016) in addition to detailed environmental information commonly require experienced operators and high computation costs that may make them impractical to coastal planners/managers in SIDS (e.g. McLeod et al, 2010).

The present approach, which compares ranges of SLR induced beach retreat and flooding under different initial conditions and hydrodynamic forcing with beach maximum widths, is not limited by the resolution/accuracy of available coastal DEMs or the availability of detailed environmental information (e.g. Jiménez et al., 2012) and be used in areas with limited human resources. Nevertheless, there are also constraints. Projections are based on the assumption that beaches comprise inexhaustible sediment reservoirs, with no lateral sediment losses; cross-shore modeling obviously cannot resolve such issues. In addition, the approach is not designed to account for other erosion-controlling factors, such as: geological controls, coastal sedimentary budgets, and extreme event duration and sequencing (e.g. Corbella and Stretch, 2012); the presence of artificial beach protection schemes and/or protecting nearshore ecosystems (e.g. Peduzzi et al., 2013); and the effects of coastal use (e.g. Bi et al., 2013). However, the aim of the exercise is not to replace detailed modeling studies for individual beaches, but to provide ranges of beach erosion and flooding at a large scale.

7.6 Additional data or resource needs

Models displayed differential behavior for almost all tested conditions, showing as expected significant ranges of results due to the varying initial conditions and forcing used i.e. different bed slopes, sediment sizes and wave conditions. Generally, all model results have been found to be very sensitive to beach slope, which makes the beach slope the most responsible parameter for the wide range of the beach retreat results. The "high" predictions of that range reflect the calculations with mild beach slope (1/30), heavy wave conditions and fine beach material ("low" predictions are for the other ends). Then, high and low predictions are applied to each beach of St Lucia to drive the results, assuming that all beaches have either mild slope ("high" prediction) or steep slope ("low" prediction). The predictions can be improved if more information is available for the environmental conditions (especially for the beach slope) of each beach from previous studies or from literature, then this information can be used to narrow the envelope of the maximum and minimum retreat ranges through the interactive GUIs and apply a different range of beach retreat/inundation to each beach. If such information is not available, in situ measurements are required, which at large spatial scale are impractical to be performed, especially by coastal planners/managers.

7.7 Relationship between beach retreat and erosion, and transport infrastructure vulnerability

Transport is a demand-driven industry (see also the beginning of the document). So, whatever effects CV &C has on tourism will have also on the transportation demand. The tourist industry in St Lucia is based on the 3S model (Sea, Sand and Sun). A most critical component of 3S tourism is the availability of beaches that are environmentally and aesthetically sound and retain adequate carrying capacity (e.g. McArthur, 2015; Cisneros et al., 2016). Carrying capacity is defined as the “maximum number of people that may visit a tourism destination at the same time, without causing destruction of the physical, economic and socio-cultural environment and an unacceptable decrease in the quality of the visitor’ satisfaction” (WTO,1981). Beach erosion due to e.g. sea level rise might reduce significantly the carrying capacity and the quality of the beaches as environments of leisure. Therefore, beach erosion will reduce the attractiveness of the country to tourism, with severe (indirect) impacts on the major gateways of the international tourism, i.e. airports, and to a lesser extent, seaport).

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