

Climate and Disaster  
Resilient Transport in Small  
Island Developing States:  
*A Call for Action*

2017

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## Acronyms

AMS	Asset Management System
CCRIF	Caribbean Catastrophe Risk Insurance Facility
CERC	Contingency Emergency Response Component
CMB	Concrete masonry block
COP23	23rd Session of the Conference of the Parties to the UNFCCC
CRRS	Climate Resilient Road Strategy
CVA	Climate Vulnerability Assessment
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	Greenhouse Gases
GIS	Geographic Information Systems
GP SURR	Social, Urban, Rural, Resilience Global Practice
GRS	Geosynthetic Reinforced Soil
GSC	Geosynthetic Container
HDPE	High-density polyethylene
ICT	Information and Communication Technologies
IPCC	Intergovernmental Panel on Climate Change
MoI	Ministry of Infrastructure
MoPWP	Ministry of Public Works and Ports
NDC	Nationally Determined Contribution
O&M	Operation and Maintenance
PAIP	Pacific Aviation Investment Project
PCRAFI	Pacific Catastrophe Risk Assessment and Financing Initiative
PDOT	Provincial Department of Transport
PIC	Pacific Island Countries
PPCR	Pilot Program for Climate Resilience
PPP	Purchasing Power Parity
PRIF	Pacific Region Infrastructure Facility
RRM	Routine Road Maintenance
RTP3	Third Rural Transport Project
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
SVG	Saint Vincent and the Grenadines
T&I GP	Transport and ICT Global Practice
TAM	Transport Asset Management
TvAIP	Tuvalu Aviation Investment Project
UNFCCC	United Nations Framework Convention on Climate Change
VA	Vulnerability Assessment

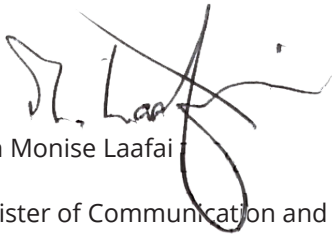
## Foreword

As a small, low-lying country in the Pacific, Tuvalu has already been significantly impacted by natural disasters and climate change. Strengthening Tuvalu's resilience in all its sectors is crucial for the country to sustain its limited natural resources and to develop a sustainable economy that can support its people.

Due to its size, remoteness, and susceptibility to natural disasters, Tuvalu has already had to look at innovative and practical solutions to ensure its resilience. Buildings, for example, have to serve multiple purposes, such as in the case of the new airport terminal that has been designed to include one of the largest underground water cisterns in the country to mitigate the impacts of frequent droughts. As described in this report, Tuvalu is also testing the use of geocell pavements using coral and seawater to ensure that we can build robust and resilient concrete roads in Funafuti and in the outer islands. These are just some of the fundamental innovations that Tuvalu has been pioneering in its attempt to manage the high risks imposed by the changing climate.

Despite Tuvalu's effort to reduce its exposure to these hazards, it remains vulnerable to the impacts of climate change, which threaten the livelihood sectors that are of importance to the sustainability of Tuvalu's growth - economically, environmentally and socially.

Therefore, the report "A Call for Action: Climate and Disaster Resilient Road Asset Management in Small Island Developing States", which focuses on investments for resilient transport systems as a way to reduce vulnerability to climate change impacts, is greatly supported by Tuvalu as it not only opens up ways to address our current situation facing climate change impacts, but also directly contributes to the accomplishment of Tuvalu's key strategic goals as expressed in the Tuvalu National Strategy for Sustainable Development Plan "*Te Kakeega III*".



Hon Monise Laafai

Minister of Communication and Transport  
Government of Tuvalu  
Vaiaku, Funafuti  
Tuvalu

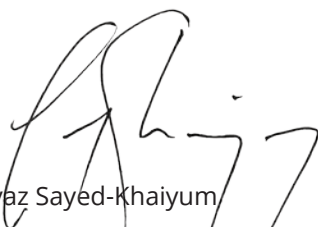
As a Small Island Developing State (SIDS), Fiji is no stranger to the impacts of climate change.

In February 2016, Fiji was ravaged by the destructive force of Category 5 Cyclone Winston, the strongest cyclone to ever make landfall in the Southern Hemisphere. In total, the cyclone claimed the lives of 44 of our people, damaged or destroyed 40,000 homes and hundreds of schools, and ravaged much of our nation's infrastructure and transport systems.

While certain risk factors are fixed, like Fiji's geographic location and size, we are actively working to identify and improve those things that are within our control-- including every aspect of our infrastructure. By enhancing our resilience and adaptive capacity, we are reducing our overall vulnerability to climate change impacts. One climate-vulnerable component that every nation has the power to change lies in our transport systems, and in Fiji, we are actively seeking out innovative ways to make our transportation sector more sustainable.

We welcome this timely report "Climate and Disaster Resilient Transport in Small Island Developing States: A Call for Action," as it makes the case for investments in resilient transport systems as a way to reduce vulnerability to climate change impacts. Importantly, this report also paves the way for improving access to much-needed international adaptation finance and harnessing innovation, enterprise, and investment to fast-track the development and deployment of climate solutions. We call on not only SIDS, but nations of all sizes, to focus on the development of sustainable transport; by doing so, the world can both curb carbon emissions and mitigate the aftermath of future extreme weather catastrophes.

Making the world's transport systems more sustainable will require global collaboration; by sharing our ideas, successes, and best practices, we will achieve results that will not only make a difference in the lives of our respective nations' citizens, but will collectively pave a path of sustainability and resilience for future generations of all countries. Building on the Fijian "Bula Spirit," which embodies the idea of inclusive, participatory, and transparent dialogue for informed decision making for the common good, this report rightly highlights the importance of developing local capacity, strengthening partnerships, and learning from each other. Only in this way can we succeed in meeting the needs of our people in the face of a changing climate.



Aiyaz Sayed-Khaiyum  
Attorney-General and Minister responsible for climate change  
Suva, Republic of Fiji

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Production of the report was managed by Maria Cordeiro, Sr Transport Specialist (T&I GP) and Frederico Pedroso, Disaster Risk Management Specialist (GP SURR), with the valuable assistance from Emiye Gebre Egziabher Deneke, Program Assistant (T&I GP). Main authors are Maria Cordeiro, Christopher R. Bennett, and Sean Michaels from the Transport and ICT GP; Frederico Pedroso and Marc Forni from GP SURR; and Julie Rozenberg from the GGSVP Chief Economist Office. Many authors also contributed to the case studies; their names are included with the case study descriptions. Tojo Ramanankirahina and Shruti Vijayakumar from T&I GP provided the information on the project in Cabo Verde.

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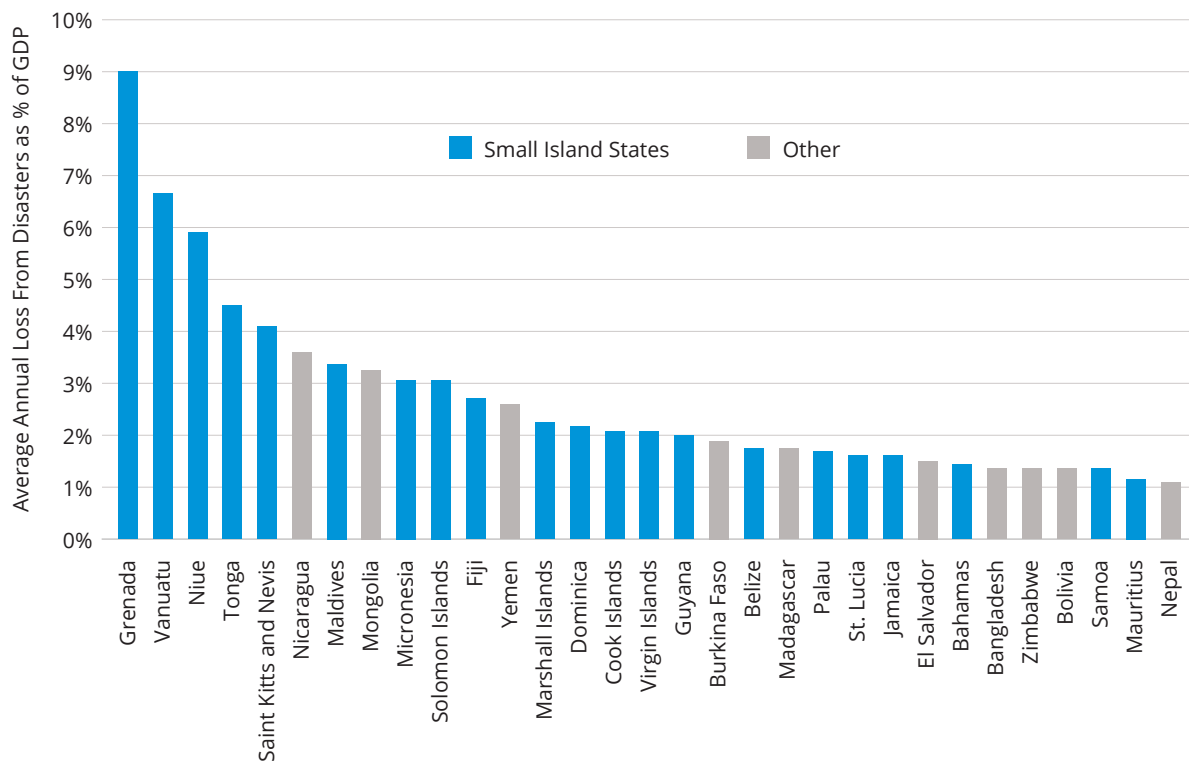


## Executive Summary

Small Island Developing States (SIDS) are a group of countries located across the world in the Caribbean, Pacific, Africa, and Indian Ocean regions. They are all small in size, sparsely populated and geographically isolated, and their small economies are typically based on tourism, fisheries, agriculture, and small-scale manufacturing activities.

SIDS are among the most exposed and vulnerable countries to natural disasters in the world, and climate change is expected to exacerbate future risks, threatening development progress. Because of their location, small size, and topography, SIDS are exposed to severe hazards, including cyclones, extreme winds, storms, earthquakes, tsunamis, and volcanic eruptions. Compared to other countries, SIDS also suffer very high economic losses when extreme events strike, with average annual losses ranging between 1 and 10 percent of gross domestic product (Figure 1). Climate change will not only exacerbate disaster risks, but also have long-term impacts such as sea level rise, changes in rainfall patterns, and more extreme temperatures, which also require adapted management.

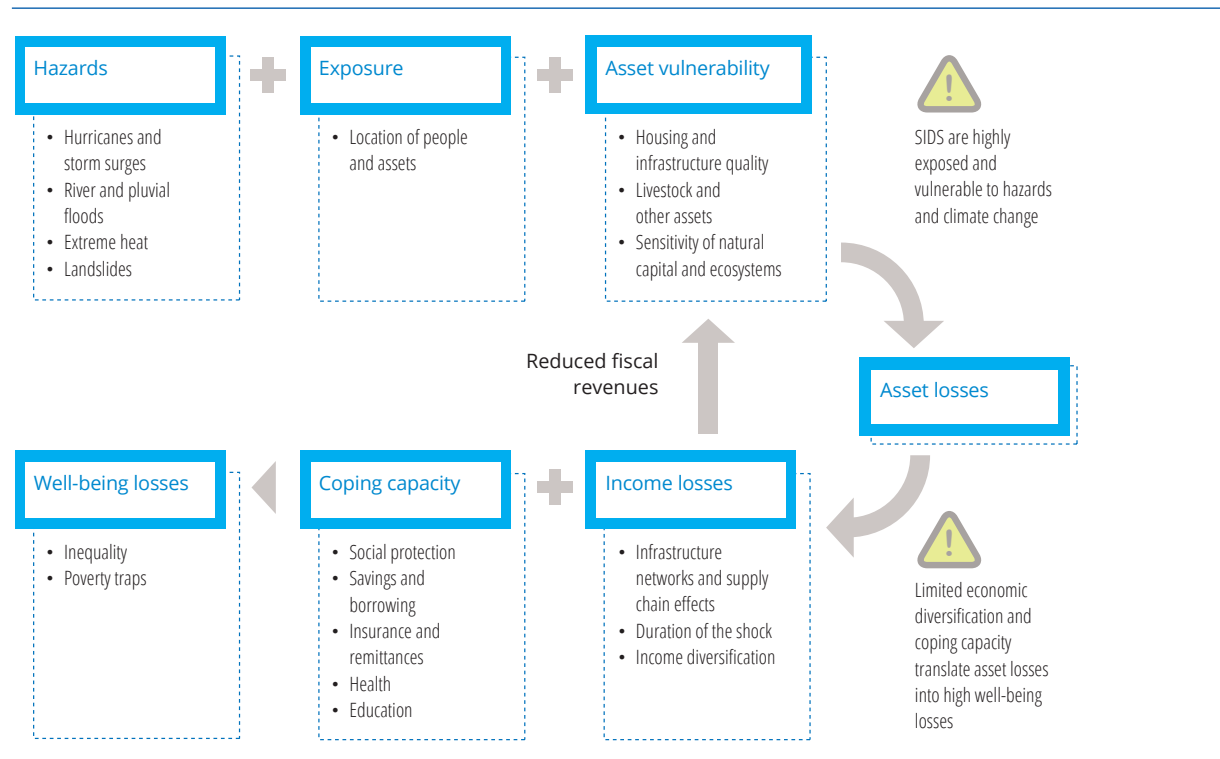
Figure 1. Average Annual Loss from Natural Disasters Relative to GDP



Source: World Bank Group 2014.

In addition to economic losses, SIDS experience high social impacts from natural disasters. Weather related events affect many people, and social and psychological impacts of disaster events can remain long after they strike. Moreover, because of low socio-economic resilience, asset losses translate to great losses in income and well-being for SIDS. The small size of their populations affect institutional capacity, while limited economic activities constrain fiscal revenues, resulting in low ability to respond to disaster impacts. As shown in Figure 2, severe exposure to a range of hazards leads to asset losses, which—as a result of the limited economic diversification and low coping capacity—lead to losses in income and well-being.

Figure 2. Transport Asset Losses, Income Losses, and Well-being Losses



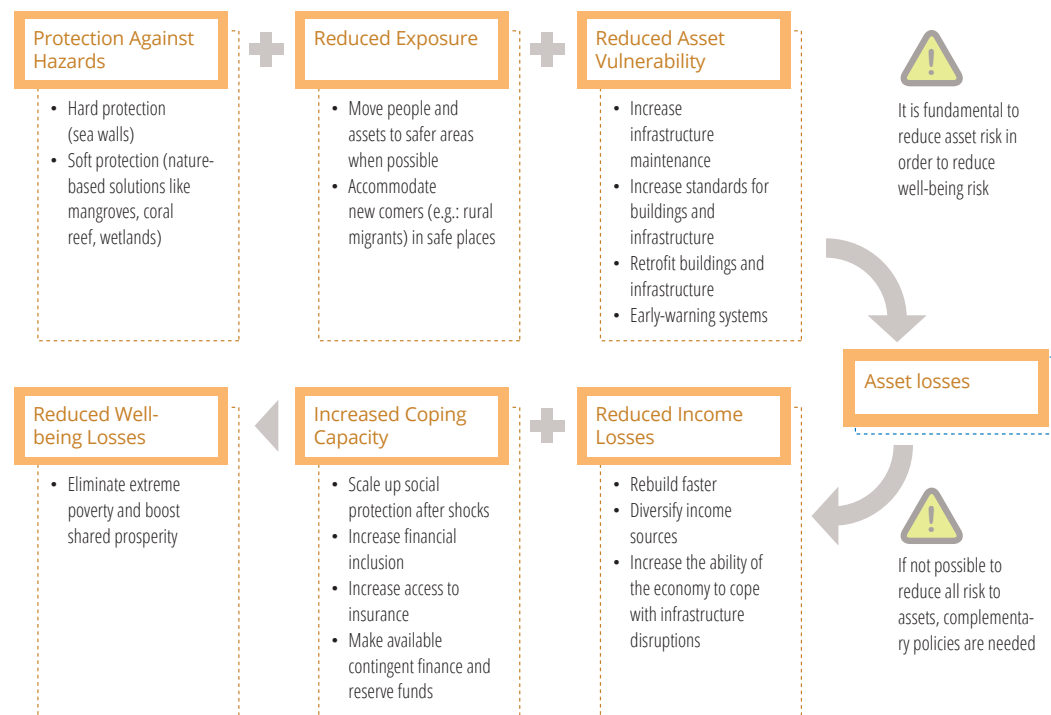
Source: Adapted from Hallegatte *et al.* 2017.

**The transport sector plays a central role in SIDS's vulnerability.** Transport assets represent a large share of public assets and government budgets. Road networks are often entirely financed by the government and international aid. In Fiji, for example, the Fiji Road Authority represents one third of the government budget. This means that when roads and bridges are damaged by floods or storms, governments bear the fiscal pressure to pay for the large costs of maintenance or reconstruction. In addition, transport networks in SIDS typically offer low redundancy due to limited physical space, small populations, and limited financial resources. There is often only one airport and one major port in an island, and these offer limited to no redundancy to the road network. Damage to transport infrastruc-

ture can affect accessibility to essential services such as schools and hospitals, and create business interruptions for the tourism, fishery, or agriculture sectors, exacerbating long-term economic losses.

**A range of policies and measures can enhance resilience for SIDS.** SIDS will need to adopt a diverse set of policies and measures to limit the impact of disasters and climate change and so reduce losses in assets, income, and well-being. Measures could include physical protection against hazards, early warning systems, improved infrastructure maintenance to reduce asset vulnerability, or rebuilding faster following an event (Figure 3). Against the less frequent but high impact events, SIDS could benefit from increased access to financial instruments such as risk-sharing facilities, contingent credit, or international aid to offset reduced tax revenues after disasters and be able to restore service along critical transport corridors.

**Figure 3. Policies and Measures to Reduce Asset, Income, and Well-being Losses from Natural Disasters**

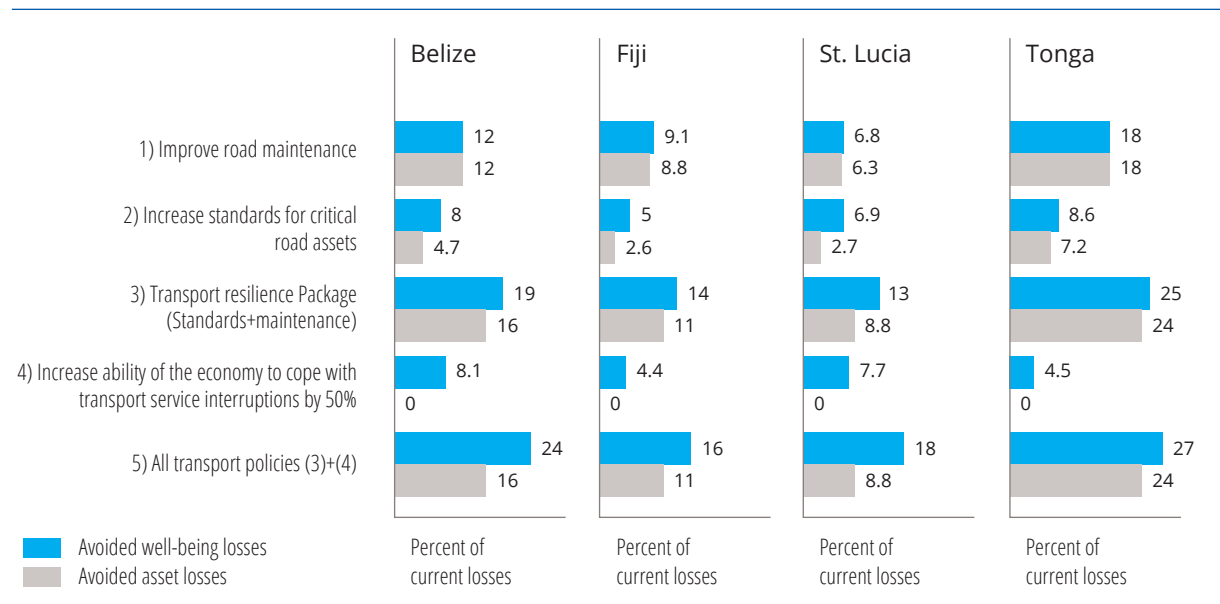


Source: Adapted from Hallegatte *et al.* 2017.

**Resilient transport policies can significantly reduce future losses in assets and well-being in SIDS.** In many SIDS, spending on transport infrastructure maintenance can prevent damage caused by frequent floods and storms, and thereby reduce user costs and repair needs. Appropriate transport asset management systems can save resources spent in rehabilitation and dedicate these to maintenance activities. Upgrading construction standards for critical bridges and culverts can reduce the impact from less frequent but higher impact events. This can sometimes be done at low cost thanks to new materials and

designs. Transport service disruptions can also be reduced by improving the resilience of supply chains with stocks and telecommuting, leading to positive impacts in the economy and social well-being. These policies together have shown to have the potential to reduce future asset losses by 8.8 to 24 percent and well-being losses by 16 to 27 percent across a sample of four SIDS (Figure 4).

**Figure 4. Comparison of Benefits of Several Resilient Transport Policies in Terms of Avoided Well-being Losses and Asset Losses**



Source: Authors' calculations using the Unbreakable model.

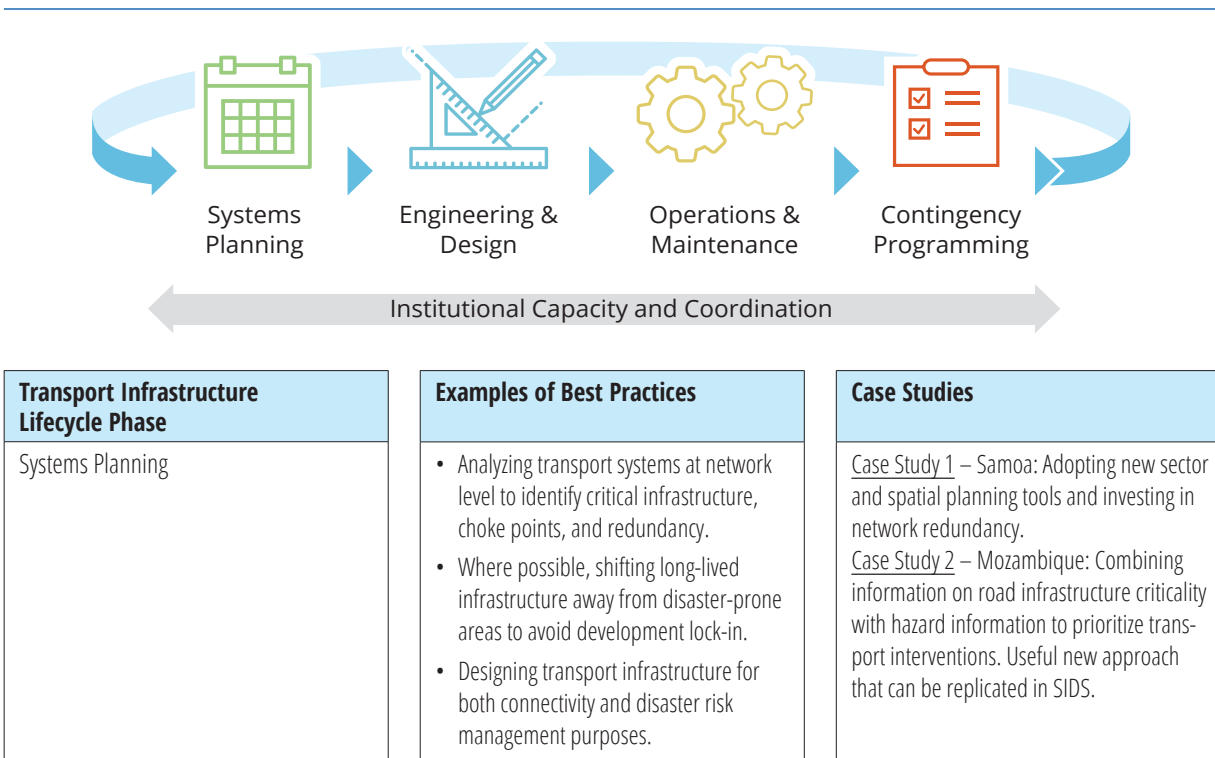
**To enhance the resilience of the transport sector, improved transport asset management systems are a priority in SIDS.** Transport asset management includes all strategic, financial, and technical aspects related to the management of transport assets across their lifecycle, and most SIDS have scope for improvement in this area. Surveys conducted in a sample of nine SIDS showed an overall low competency in transport asset management across SIDS in the Pacific and Caribbean Regions, though reported capabilities vary significantly among countries with Fiji and Grenada self-assessments expressing relatively higher levels of knowledge of transport assets and Tuvalu and Kiribati expressing lower levels of confidence in their current transport asset management systems. Given the importance of transport in the public asset base and the vulnerability of these assets to natural disasters, the SIDS transport agencies need asset management systems to understand the condition and criticality of assets to meet resilience needs. Moreover, asset management systems need to effectively incorporate climate change and natural disaster risks into decision-making processes. Finally, for asset management to be effective, it is key to have appropriate human resources capacity and incentives, inter-agency institutional protocols, and processes in place that enable informed decision making.



**Successful transport asset management must plan for “the unknown.”** On the local level, uncertainties exist related to the impacts of climate change, and this must be taken into account when integrating climate and disasters risk considerations in transport asset management systems. Uncertainties relate to the challenges of modeling complex climate systems, as well as uncertainty around policy actions and human behavior related to emission reductions or adoption of adaptation measures. In the case of SIDS, given their small size and the fact that they are surrounded by oceans, downscaling the changes in global climate to the country level leads to a wide range of potential local climate scenarios. To address the uncertainty around future climate change impacts, infrastructure needs to be designed to withstand a wide array of possible changes in climate conditions. In this context, it can also be useful to choose low regret design and engineering solutions that can withstand a variety of climate conditions. Another option is to increase the flexibility of investments, for example by choosing engineering designs that have a reduced lifetime or that are easy to retrofit in the future once additional information is known on the direction, magnitude, and speed of climate change and on the performance required.

**The transport infrastructure lifecycle provides an opportunity to integrate risks in a holistic and systematic manner.** The lifecycle approach (Figure 5) covers all aspects of transport asset management and provides a framework for integrating climate and disaster resilient transport interventions into decision making and implementation. Actions for example could involve mapping hazards, identifying highly vulnerable assets, understanding the magnitude of the consequences of asset failure, planning to prevent disruptions rather than only reacting after disasters, and building back better after events.

Figure 5. Transport Infrastructure Lifecycle



Transport Infrastructure Lifecycle Phase	Examples of Best Practices	Case Studies
Engineering and Design	<ul style="list-style-type: none"> <li>Using innovative materials.</li> <li>Upgrading design standards and specifications.</li> <li>Performing hazard and infrastructure-level vulnerability assessments.</li> </ul>	<p><a href="#">Case Study 3</a> - Tuvalu and Kiribati: Using local materials for coastal protection in coral atolls in the Pacific.</p> <p><a href="#">Case Study 4</a> - Sri Lanka: Using new technology for constructing bridges.</p>
Operations and Maintenance	<ul style="list-style-type: none"> <li>Inventorizing and mapping transport infrastructure assets using open and inter-operable technologies.</li> <li>Improving institutional, financial, and contractual arrangements for infrastructure maintenance.</li> <li>Mobilizing local communities in operations and maintenance of road assets using a gender inclusive approach.</li> <li>Improving capacity of service providers and awareness of users on how to best manage transport interruptions.</li> </ul>	<p><a href="#">Case Studies 6, 7 and 8</a> - Dominica, St. Lucia, and Belize: Using ICT to improve data collection and information systems on transport infrastructure and natural hazards.</p> <p><a href="#">Case Study 9</a> – Vietnam: Involving local women’s organizations in road maintenance in mountainous areas provides a best practice for replication in SIDS.</p> <p><a href="#">Case Study 10</a> - São Tomé and Príncipe: Building resilience through hazard and transport mapping, with communities involved with road maintenance.</p>
Contingency Programming	<ul style="list-style-type: none"> <li>Investing in emergency preparedness to meet local and regional evacuation, response, and recovery needs, and to prepare for relief distribution.</li> <li>Performing pre-qualification of goods and service providers for faster procurement post-disaster.</li> <li>Developing financial protection strategies, including disaster reserve funds, contingency budgets, and insurance programs to repair and replace public transport infrastructure components damaged by a climate-related disaster.</li> </ul>	<p><a href="#">Case Study 11</a> - Saint Vincent and the Grenadines and Dominica: Use of Contingency Emergency Response Component (CERC) allows a quick restoration of road connectivity following disaster events.</p> <p><a href="#">Case Study 12</a> - Tonga: Investments in emergency response systems and procurement regulations.</p>
Institutional Capacity and Cooperation	<ul style="list-style-type: none"> <li>Developing integrated government-wide objective setting and results monitoring for climate resilience to provide the required focus and incentives during implementation.</li> <li>Implementing alternative coordination mechanisms to facilitate cooperation across institutional mandates.</li> <li>Balancing capacity building with capacity supplementation to ensure long term sustainability of management systems.</li> </ul>	

**This report proposes solutions to integrate climate and disaster risk considerations in transport infrastructure lifecycle management and, in this way, enhance the resilience of transport systems.** The case studies presented in this report can be replicated by tailoring best practices to specific country contexts. Interventions can be made by lifecycle component, or integrated across the transport infrastructure lifecycle. In Tuvalu for instance, after Cyclone Pam in 2015 isolated the island, the Tuvalu Aviation Investment Project revised infrastructure design specifications to ensure resilience of the airport to future events, including also various measures to improve disaster preparedness and response ([Case Study 13](#)). In Cartagena, Colombia, a comprehensive climate risk assessment for the Muelles el Bosque Port was carried out to ensure reliable port operations despite future climate change related risks ([Case Study 14](#)). Although Colombia is not a SIDS, the climate risk assessment is a useful tool for assessing the exposure and vulnerability of ports in SIDS and in this way inform systems planning, engineering and design, operations and maintenance, and contingency programming.

**Finally, this report proposes a path forward for replicating best practices and deploying resilient transport infrastructure in SIDS.** Consisting of four components, the path leverages existing experiences in SIDS to coalesce and scale-up donor support to address financial gaps while reinforcing country systems and delivering scale with reduced administrative burden. Components of this path forward specifically address country-specific needs assessments and transition plans, implementation of resilience measures and transport asset management systems, avenues for local capacity building and knowledge exchange, and fundraising and reassessing capital needs for continued enhancement of transport systems resilience.

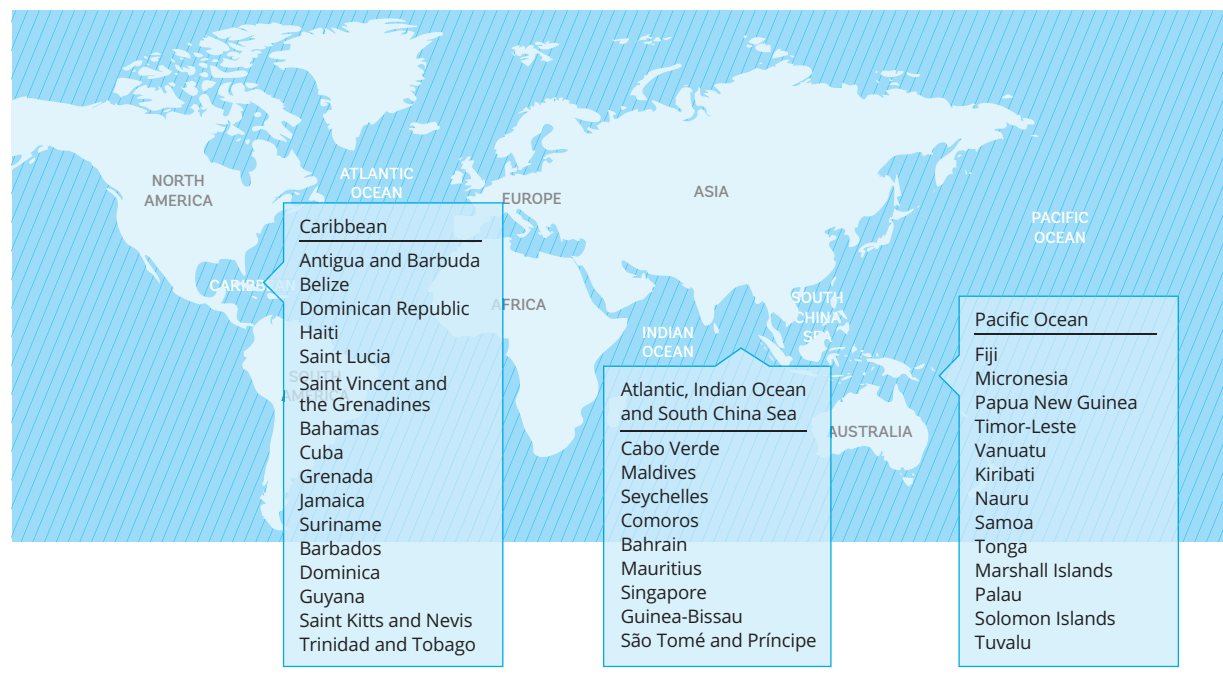
**A Call for Action: Enhancing climate and disaster resilience of transport systems in SIDS requires the support of the international development community.** Resilient transport systems generate many economic and social benefits and are a priority to deliver on sustainable development goals and climate nationally determined contributions of SIDS. Transport asset management systems that integrate disaster and climate risk considerations into the decision-making process reduce asset and well-being losses from natural disasters and climate change impacts and protect development progress in SIDS. Today, building on available knowledge and experiences around resilient transport in SIDS, engagement of the donor community is needed to support SIDS on their path toward disaster and climate resilient transport.

## Introduction

Small Island Developing States (SIDS) are a group of countries located across the world in the Caribbean, Pacific, Africa, and Indian Ocean regions. They are all small in size, sparsely populated, and geographically isolated (Figure 0.1), and their small economies are typically based on tourism, fisheries, agriculture, and small-scale manufacturing activities. The small populations on the islands bring only a limited domestic demand for goods and services, which reduces their attractiveness for international investments targeting local markets. As a result, some SIDS are heavily dependent on remittances from migrated population and international aid.

Most SIDS suffer significant economic losses from natural disasters. As shown in Figure 0.2, they are among a select number of countries with average annual disaster losses above 1 percent of Gross Domestic Product (GDP). In the Caribbean, average annual loss from tropical cyclones is estimated at US\$835 million; in the Pacific, this number is US\$178 million. A single event can have devastating impacts in the relative small economies of SIDS (CCRF; PCRAFI; and World Bank, 2016). In 2015 for example, Cyclone Pam caused estimated damages and losses in Vanuatu of US\$450 million, the equivalent of 64 percent of GDP (World Bank 2016a).

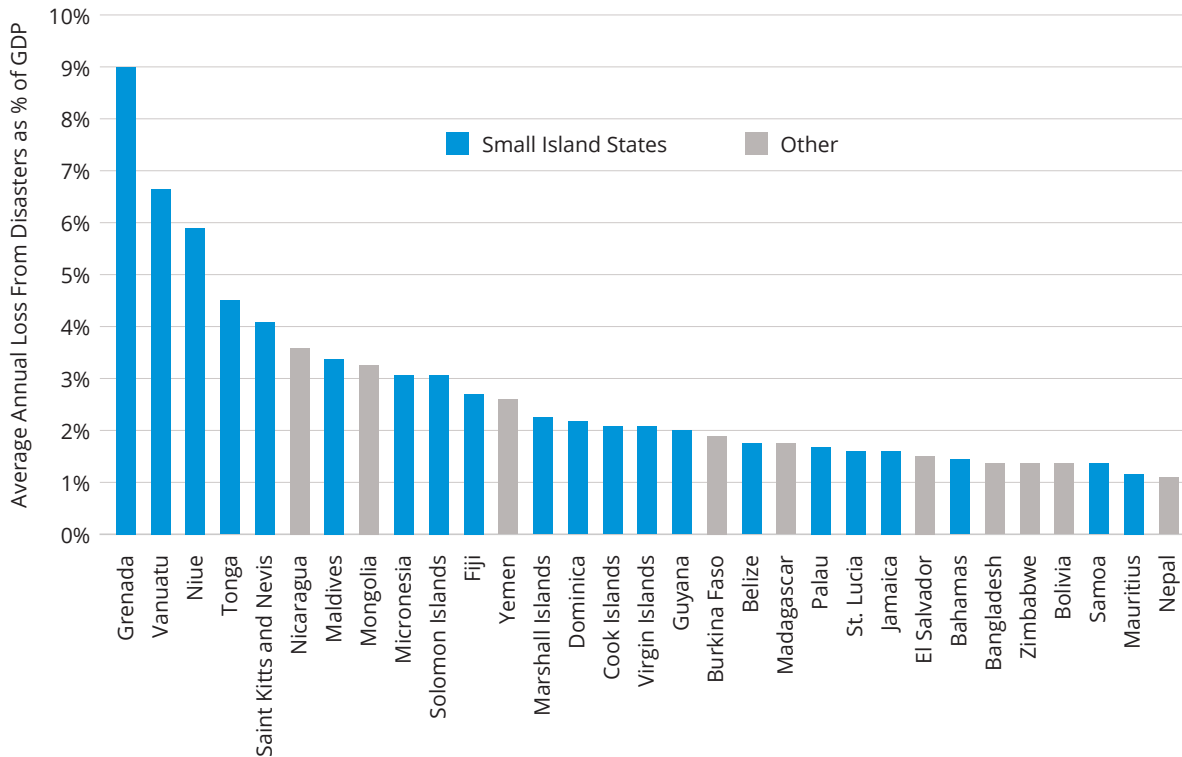
Figure 0.1. Map of Small Island Developing States by Region



Source: UNCTAD.



Figure 0.2. Average Annual Loss from Natural Disasters Relative to GDP



Source: World Bank Group 2014.

In addition to significant economic losses, SIDS suffer high social impacts from natural disasters. Between 1950 and 2011, extreme weather-related events in the Pacific islands region affected approximately 9.2 million people, causing 9,811 reported deaths. In Fiji, the social and psychological impacts of Tropical Cyclone Winston continue to be substantial a year and a half after the cyclone hit. One in five households across the country lost a significant share of their personal belongings and had their homes damaged or destroyed. Ensuring the safety of women and children throughout the reconstruction process continues to be a concern in some villages, with many staying in churches or with relatives while housing reconstruction is completed. (Government of Fiji 2017)

Across SIDS, the transport sector plays a crucial role both in building countries' resilience and in disaster response. The sector itself, however, is vulnerable to the impacts of natural disasters and climate change, and policies and measures must be explored and implemented to enhance the resilience of transport systems. Climate change is expected to cause local changes in average and extreme temperatures, as well as changes in rainfall patterns, duration, and intensity. The increase in global temperatures is expected to result in the melting of glaciers and in the thermal expansion of ocean water leading to sea-level-rise. These changes increase risks of riverine and coastal flooding, raise the risk of

landslides in mountainous areas, and affect the properties of transport infrastructure material. This in turn can damage or even destroy road, rail, port, and airport infrastructure. In addition to impacts on transport infrastructure, climate change can also cause disruptions in transport operations and logistics due to disruptions in transport services. Furthermore, climate change social and economic impacts can change levels and patterns for transport demand.

The goal of this report, “Climate and Disaster Resilient Transport in Small Island Developing States: A Call for Action” is to share with decision makers, international donors, and other interested parties, information about recent experiences enhancing the resilience of the transport sector in SIDS and, building on these best practices, present a path forward for SIDS to integrate climate and disaster risk considerations into their transport investments across the sector, including road networks, aviation and maritime transport.

To best present the case and a possible path for resilient transport in SIDS, the report consists of two parts. Part I focuses on the urgent needs as well as opportunities for SIDS to move toward disaster and climate resilient transport, in particular with the use of sound transport asset management systems that encompass the lifecycle of transport investments. Following an overview of the severe impacts of natural disasters and climate change in SIDS, which result in losses to assets, income, and well-being (Chapter 1), the report in Chapter 2 outlines the broad range of policies and measures available to SIDS to enhance resilience, highlighting the role for resilient transport in this context. Next, Chapter 3 provides practical examples—following the transport infrastructure lifecycle framework—that demonstrate how SIDS are currently moving toward disaster and climate resilient transport systems; the chapter references many case studies (included in Part II) to introduce existing and ongoing experiences. Finally, building on the first three chapters, Chapter 4 demonstrates a path to sustainably scaling up resilient transport systems across SIDS by leveraging existing experiences with new donor funds.

Complementing the first part, Part II includes fourteen case studies that present a range of best practice experiences in SIDS and selected other countries for building disaster and climate resilient transport systems. The examples, which describe the use of hazard mapping, vulnerability assessments, new construction materials, improved road transport management systems, community involvement in road maintenance, as well as complete life-cycle interventions for an airport, demonstrate the range of practical and existing solutions to strengthen resilience through targeted investments along the transport infrastructure life cycle.

Finally, this report does not stand alone but is part of a larger effort to grow the expertise and local capacity for resilient transport solutions in SIDS and introduce targeted solutions that address country needs. Following the introduction of this report at the 23rd Session of the Conference of the Parties (COP23) to the United Nations Framework Convention on Climate Change (UNFCCC), subsequent phases are intended to provide a platform for the international community to support SIDS in addressing the challenges they face from natural disasters and climate change in a holistic and robust manner, building on the path toward climate and disaster resilient transport presented in Chapter 4.

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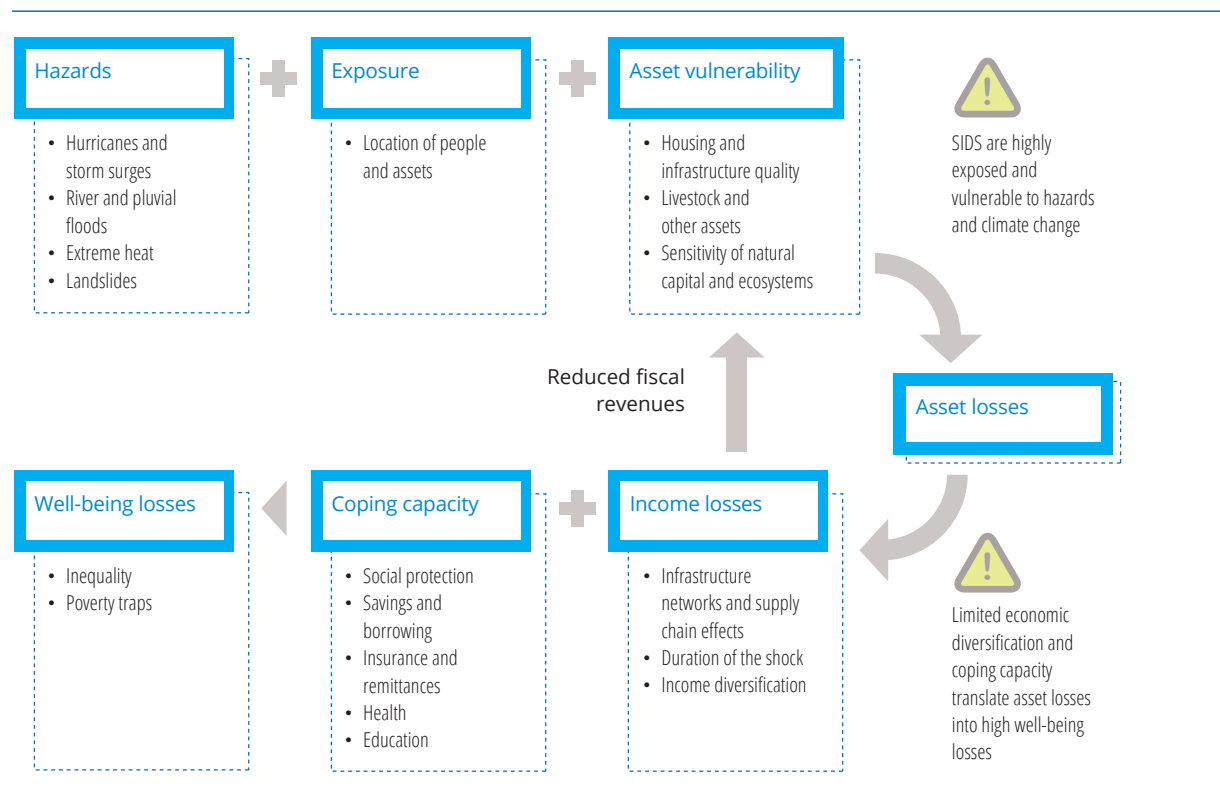
PART I. CLIMATE AND DISASTER RESILIENT TRANSPORT IN SMALL  
ISLAND DEVELOPING STATES: A CALL FOR ACTION

# Chapter 1. Unique Vulnerability of Small Island Developing States to Natural Disasters and Climate Change Impacts

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Natural disasters have devastating impacts in Small Island Developing States (SIDS), and climate change is increasing risks. As shown in Figure 1.1 and described in subsequent sections, the many types of hazards, the high exposure, and great asset vulnerability of SIDS can lead to significant asset losses that in turn, and as a result of limited economic diversification and low coping capacity, amount to high losses in well-being on the islands. In a negative feedback loop, the income losses stemming from the disasters lead to reduced fiscal revenues, which then again lead to deferred maintenance and increased asset vulnerability for the next event.

**Figure 1.1. Different Components of Asset Losses, Income Losses, and Well-being Losses**



Source: Adapted from Hallegatte *et al.* 2017.



## 1.1 High Exposure to Natural Hazards

The geographic location of SIDS in the Caribbean, Indian, Africa, and Pacific regions, along with their topography and geology, makes these countries highly exposed to a wide variety of natural hazards such as cyclones, extreme winds, storms, storm surges, earthquakes, tsunamis, and volcanic eruptions. In addition, the weather in SIDS is strongly influenced by monsoons and El Niño weather patterns that create high seasonal variability and bring alternating periods with drought or floods. For example, from 1981 to 2016—in just 35 years—no less than 27 Category 5 and 32 Category 4 tropical cyclones<sup>1</sup> have had a significant impact on SIDS in the Pacific (World Bank 2016a). In the Caribbean, recent hurricanes have led to devastating damages (Box 1.1).

### Box 1.1. Caribbean Nations: in the Frontline of Recurrent Disasters

Caribbean islands are highly exposed to natural hazards, especially heavy rain and hurricanes. The long history of disasters has brought the region to increasingly adopt disaster risk management and, more recently, include climate change risk considerations in their transport policies, investment prioritization, insurance schemes, among others.

Once again, the 2017 hurricane season demonstrated the devastation that extreme events can bring to the region and the clear need to invest and integrate both the disaster risk management and climate change adaptation (CCA) agendas to promote resilience in the Caribbean. Hurricanes Irma and Maria both led to deaths and massive devastation in numerous island countries in the Caribbean, including the Dominican Republic (displacement of 24,000 persons of which 10,701 stayed in official shelters and 13,415 stayed with family relatives) and Barbuda (95 percent of all houses were damaged by the storm, with 70 percent of all houses suffering severe damage). In Dominica, the entire island was affected with significant impacts for its economy. With no part of the island functioning, recovery is expected to be very challenging.

The 2017 very active hurricane season has brought many countries to a daunting challenge: How to be resilient to external shocks? The word “resilience” implies characteristics of both avoiding or limiting the impact of external events on the economy and society as well as being able to cope with human and economic shocks so normality can be restored in a timely manner. In this context, the transport sector plays a key role in emergency response and in restoring normality. Transport resilience is the first step, but the challenge goes beyond transport and will require an integrated approach to ensure critical lifelines and infrastructure survive in the aftermath of a disaster. As tweeted by Sir Richard Branson, “To recover, [the] Caribbean must take the leap from 20th century technology to 21st century innovation. [As such, we need to bring] together heads of state, international community & business leaders to create [a] Marshall Plan for [the] Caribbean.”

Source: World Bank and Sir Richard Branson Official Tweet, <https://www.virgin.com/richard-branson/creating-marshall-plan-caribbean>.

<sup>1</sup> A category 5 tropical cyclone has wind speeds of 252 km/h (157mph) or above; Category 4 tropical cyclones have winds between 209 and 251 km/h (130-156 mph).

Today, climate change is exacerbating risks. Climate change is increasing average ocean and land temperatures and changing the seasonality, intensity, and duration of rainfall. Sea levels are rising, accelerating coastal erosion, increasing saline intrusion, and heightening the impacts of “king tides” and storm surges in some countries. Sea level rise even threatens the existence of entire low-lying atoll island nations, such as Kiribati, Tuvalu, and the Marshall Islands (Table 1.1). In all SIDS, climate change is already adversely affecting agriculture, fisheries, coastal zones, water resources, health, and ecosystems, and thus economies.

**Table 1.1. Highest and Lowest Share of Population Living Less than 5 Meter above Sea Level**

Country	Population living within 5m above sea level
Maldives	100%
Tuvalu	100%
Marshall Islands	99%
Kiribati	95%
Suriname	68%
<b>Average</b>	<b>29%</b>
Mauritius	6%
Haiti	5%
Timor-Leste	4%
Dominican Republic	3%
Papua New Guinea	2%

Source: UN-OHRLLS, SIDS in Numbers 2013 and 2015.

The location of SIDS and their topography makes very large shares of these countries exposed to at least some hazards. In some SIDS, such as the atoll islands, it is difficult to find unoccupied safe lands where people could retreat when sea level rise brings increasingly more devastating storms. Uniquely, the small size of SIDS prevents spatial diversification, which means that 100 percent of the population can be affected by a single event.

Exposure is also increasing in most SIDS due to high population growth combined with poor coastal development and land use planning (World Bank 2016b). Infrastructure networks are often located in high risk areas (such as close to sea level and next to steep slopes), not built to high standards, and poorly maintained, which exacerbates their vulnerability (PIAC, 2013). In Fiji, about 10 percent of the national population (20 percent of the urban population) lives in more than 200 unplanned (and rapidly growing) urban and peri-urban informal settlements that are particularly exposed to coastal floods (Government of Fiji 2017).

## 1.2 Losses in Transport Assets and Well-being

The transport sector is widely recognized as a foundation for social and economic development; it also plays a key role in facilitating the response to natural disasters. The transport sector, and in particular the road network, is highly vulnerable to the impacts of climate change, generating high asset and well-being losses when damaged.

In SIDS, the road network is often a large part of the countries' infrastructure stock. In Belize for instance, the value of the road network represents 142 percent of the country's GDP, while power plants represent 14 percent of GDP and water supply and sanitation 25 percent. As a result, roads constitute 79 percent of infrastructure value (including energy, water and roads). In Jamaica and St. Vincent and the Grenadines, the estimate of road values is 36 percent of GDP, which is the lowest in the set (Table 1.2). In comparison, road networks in Bangladesh and Nepal represent only 12 percent of GDP, while this same share is 15 percent in Kenya and 34 percent in Mozambique.

**Table 1.2. Value of Infrastructure Stocks as a Percentage of GDP**

Countries	Transport (roads)	Power plants	Water supply and sanitation
Belize	142%	14%	25%
Dominica	82%	5%	19%
Fiji	64%	10%	18%
Haiti	121%	3%	16%
Jamaica	36%	6%	30%
Papua New Guinea	40%	5%	5%
Samoa	115%	6%	9%
São Tomé and Príncipe	93%	8%	19%
Solomon Islands	49%	2%	4%
St. Lucia	47%	2%	8%
St. Vincent and the Grenadines	36%	4%	13%
Tonga	145%	4%	8%

Source: World Bank calculations (see Rozenberg *et al.* 2017).

Road sectors also often represent a very large share of the government budget, especially for SIDS that do not rely heavily on international aid. While road transport in many countries can be partly financed by toll roads, SIDS face high challenges in attracting foreign direct investment and domestic private finance in road infrastructure. This means that maintenance, upgrading, and rehabilitation of road infrastructure typically rely on public funds and international aid. In contrast, airports, ports, and ICT assets can be financed by user fees and sometimes private sector investment.

In Fiji, for example, the Road Agency receives one third of the government budget (Fiji Budget 2017), while in Dominica the Ministry of Public Works and Ports represents 37 percent of total capital expenditures for 2017, most of which is for road rehabilitation (Dominica Budget address 2017/2018). In SIDS that are smaller or have a lower income, like Vanuatu and Tuvalu, all new roads are financed by international grants, with the government only financing maintenance. In all cases, the road sector represents the government's largest asset and thus a large liability in case of disasters.

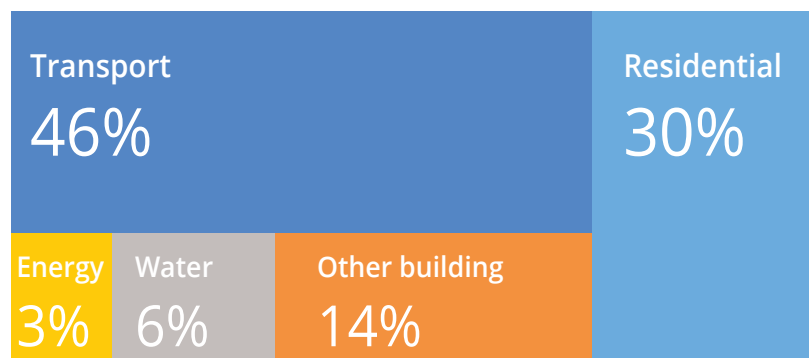
As shown in Table 1.3, when a disaster strikes, costs of damage to transport infrastructure are high. Transport assets are vulnerable to natural disasters, and climate change is amplifying these risks with more frequent disasters such as floods and storm surges, extreme heat, and salt water intrusions. Transport is often the most impacted infrastructure sector by extreme weather events like flooding and hurricanes, with damages representing a large percentage of total infrastructure damage costs. In Fiji, transport asset losses represent 46 percent of the country's total nonagricultural annual asset losses from hurricanes, earthquakes, tsunamis, and floods (Figure 1.2).

**Table 1.3. Examples of Infrastructure Damage Costs Associated with Extreme Weather Events in SIDS**

Countries	Weather event (Year)	Cost of damage to transport infrastructure (US\$, millions)	Percentage of total infrastructure damage costs
Belize	Hurricane Keith (2006)	40	51%
Fiji	Flooding (2009)	28.5	43%
Solomon Islands	Flooding (2014)	12	90%
Fiji	Cyclone Winston (2016)	63	61%

Source: Post Disaster Needs Assessments, GFDRR (<https://www.gfdr.org/post-disaster-needs-assessments>).

**Figure 1.2. Distribution of Nonagricultural Asset Losses due to Tropical Cyclones and Floods in Fiji**



Source: Government of Fiji 2017.

For all SIDS, given the share of road maintenance and reconstruction in government budgets, reconstruction costs aggravate fiscal pressure. In addition, the remoteness of the islands raises transportation costs for reconstruction material. This increases reconstruction costs, narrows fiscal space even more, and results in deferred maintenance and high vulnerability to future hazard events.

Finally, in addition to being expensive to repair after disaster events, disrupted transport networks can generate high socio-economic losses that affect the lives of people for years. Since most SIDS are served by transport networks that offer limited redundancy, transport disruptions or closures associated with natural disasters have significant effects on local economies and population well-being. Even a small loss in transport assets can lead to high service disruptions. During disasters, households and firms will lose more than just the value of their damaged assets if they are not able to go to work, school, or hospital because the transport network is disrupted. Similarly, agriculture production can be lost if it not brought to markets on time. Longer-term economic and social impacts can also occur if transport disruptions reduce the touristic attraction of the country.

In Vanuatu, in 2016, international air services were dramatically disrupted due to a deterioration in the condition of the runway at Bauerfield International Airport in Port Vila. The tourism industry, which represents one fifth of employment opportunities for women in Vanuatu (compared to one ninth for men), was severely impacted and some 700 jobs were lost (half of which were for women). Job losses and falling incomes can have significant impacts on people's well-being and long-term prospects, especially for the poorest who live close to subsistence levels.

### 1.3 Compounding Effect of Low Socio-economic Resilience in SIDS

As shown in Figure 1.1, asset losses from exposure to hazards lead to both income and well-being losses. The impact of asset losses, however, depends on a population or country's socio-economic resilience, which is the capacity of an economy to mitigate the impact of disaster-related asset losses on well-being, calculated as the relative value of asset losses to related well-being losses (Hallegatte *et al.* 2017). Well-being is the level of prosperity and standard of living of a country, referring to the utility gained through the consumption of goods and services.

By comparing well-being losses to asset losses, socio-economic resilience measures the vulnerability of an economy and the ability of the population to cope and recover from their income losses over time. Well-being losses at the country level depend on inequality, as the calculation of those well-being losses takes into account that a US\$1 loss for a poor person translates into more well-being losses than the same absolute loss for a richer person (Hallegatte *et al.* 2017 and Box 1.2).

### Box 1.2. Socio-economic Resilience and Well-being Losses in SIDS

Socio-economic resilience as used in this report was defined in the 2017, “Unbreakable: Building the resilience of the poor in the face of natural disaster” publication (Hallegatte et al. 2017) and is an indicator of a population’s ability to cope with and recover from disaster losses. It accounts for the fact that if a shock, such as a disaster event, triggers a reduction in income to an individual or family, the same reduction in income has very different implications for people at different income levels. While the well-off can reduce nonessential spending and use savings or borrowing to make up for the losses, poorer people may be forced to cut back on essential expenditures like food, housing, education, or health care.

To assess “well-being losses” caused by a disaster, analysis then must account for differences in coping capacity (for example, based on people’s access to savings or social protection) and also weigh more heavily any drops in consumption<sup>2</sup> when they affect poor people than when they affect richer individuals. Because disaster losses are not evenly distributed throughout the population and affect poor people disproportionately, in Fiji and Jamaica (where the socio-economic resilience is 56 percent), a US\$1 loss in assets due to a disaster has an impact on the population equivalent to a drop in national consumption by US\$1.8. Thus, in terms of well-being, a US\$250 million in average annual asset losses from tropical cyclones and floods is equivalent to a US\$446 million drop in annual consumption.

When compared with the 117 countries analyzed in the Unbreakable report, SIDS have a relatively low resilience, with all SIDS analyzed listing in the lower half.

Source: Based on Hallegatte *et al.* 2017.

Most SIDS have low socio-economic resilience when compared to a global sample of countries. Across the sample of SIDS presented in Table 1.4, the lowest socio-economic resilience is found in Haiti (21 percent). Inequalities and poverty in Haiti mean that its average annual asset losses of US\$255 million are equivalent to US\$1.2 billion in average annual well-being losses. Tonga has the highest socio-economic resilience among the SIDS listed in the table (67 percent), but this value is still significantly below that of the most resilient countries in the world, such as Denmark with a socio-economic resilience of 81 percent.

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<sup>2</sup> Consumption is the amount of goods and services that people buy, self-produce, or extract from their environment.

**Table 1.4. Average Annual Asset and Well-being Losses from Natural Disasters and Socio-economic Resilience in a Sample of SIDS**

Countries	Average annual asset losses (USD million 2011 PPP)	Average annual well-being losses (USD million 2011 PPP)	Socio-economic resilience
Belize	12	33	36%
Fiji	250	446	56%
Haiti	255	1,193	21%
Jamaica	153	271	56%
Papua New Guinea	32	55	57%
Solomon Islands	14	27	54%
St. Lucia	12	26	47%
Tonga	8	11	67%

Source: World Bank, based on Hallegatte *et al.* 2017.

Note: To quantify the socio-economic resilience of SIDS and the impacts of natural disasters on welfare, the model used in the Unbreakable Report (Hallegatte *et al.* 2017) was updated to include SIDS. The analysis considers the different ability of poor and nonpoor people to cope with asset losses by modeling the effects of asset losses on income (accounting for capital productivity and diversification of income sources) and consumption (accounting for savings, remittances and social protection, and post-disaster transfers). Consumption losses are translated into well-being losses, considering the different impacts of a \$1 loss for poor and nonpoor individuals. Well-being loss at the country level depends on the distribution of impacts within the population, but is expressed as the equivalent loss in national consumption.

The relatively low socio-economic resilience of SIDS can be explained by several factors. In SIDS, the low redundancy of infrastructure networks makes the economy particularly vulnerable to disruptions of transport, energy, or critical water assets. In Fiji for example, a 100-year flood that would damage about 30 percent of the infrastructure could reduce road transport service by almost 65 percent and exacerbate economic losses (Government of Fiji 2017).

The small size of SIDS and lack of economic diversification (many SIDS rely heavily on tourism, fisheries, and agriculture) also mean that when one disaster strikes, a large share of the economy is affected, reducing the country's ability to respond and rebuild quickly (Noy and Nualsri 2011). Ouattara and Strobl (2013) find that when SIDS in the Caribbean are affected by a hurricane, their governments must increase their short-term debt to finance deepened fiscal deficits.

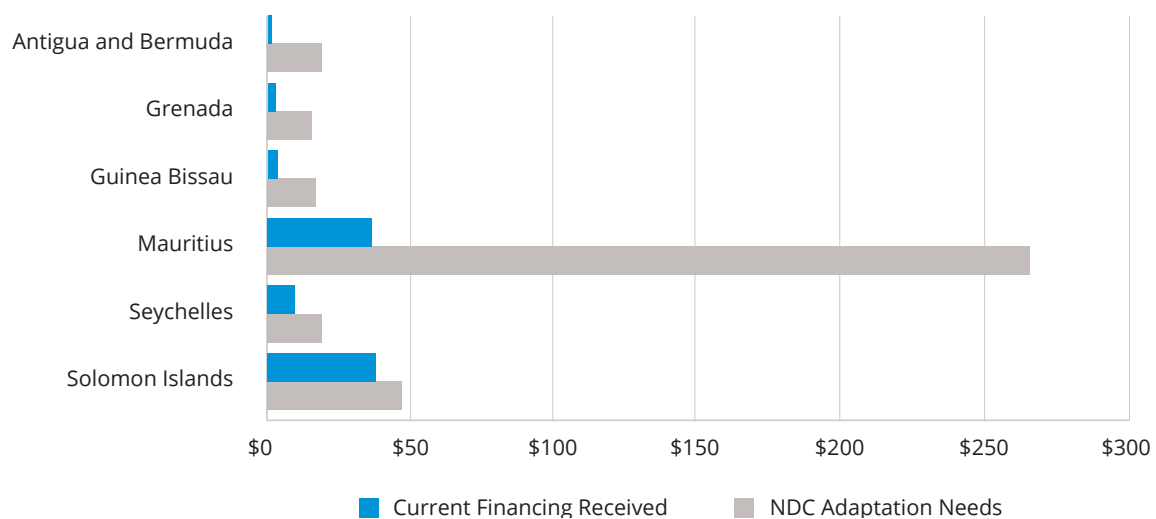
Moreover, financial services are not well developed in some SIDS. In Papua New Guinea for example, only 14 percent of the population has access to financial services, meaning that the rest of the population does not have savings in a financial institution or access to loans to rebuild after a disaster. In Haiti, only 4 percent of the bottom 20 percent has access to financial services, while for the top 80 percent 13 percent has access. Inequality is also high in some SIDS (in Haiti for example the Gini coefficient was above 60 in 2012<sup>3</sup>), and poor people are more vulnerable to disasters than the rest of the population.

<sup>3</sup> <http://iresearch.worldbank.org/PovcalNet>



Further contributing to the low socio-economic resilience of SIDS is their limited access to funds. In general, SIDS operate under a constrained fiscal envelope, and many have high long-term debt resulting in very low levels of readiness to address future shocks and the impacts of climate change. Many SIDS also have limited access to concessional finance, which further limits their capacity to invest in climate risks reduction. The investments needed for resilience in SIDS, as expressed in their Nationally Determined Contributions (NDCs), far exceed current financing received for resilience (Figure 1.3).

**Figure 1.3. Investment Needs in Adaptation against Current Financing for Selected SIDS (US\$ million/year)**



Source: SISRI Database and National NDCs; World Bank 2016a.

Note: Investment needs are expressed as nationally determined contributions (NDC) against current annual financing for climate and disaster resilience.

Overall international funding sources are also fragmented, raising transaction costs and putting pressure on limited local institutional capacity. SIDS receive funding through more than 26 bilateral donors and 12 multilateral agencies, and SIDS in the Pacific frequently manage more than 10 projects, each diluting national capacity for implementation and often resulting in duplication and high transaction costs (World Bank 2016a).

Finally, SIDS's socio-economic resilience is hindered through its lack of institutional capacity to efficiently respond to disasters, as their small populations and few in-country education facilities only produce a limited workforce with few adequate specializations. Lack of opportunities also sees many of the best educated emigrating. In terms of addressing climate and disaster risk and vulnerability in the transport sector, three specific and systematic capacity challenges need immediate attention.

- **Challenge 1: Narrow and shallow institutional structures.** With small populations, SIDS typically run small institutions with limited structural breadth and depth. In many Pacific island countries, a ministry of transport (or infrastructure, works, or relevant state-owned enterprise) may often employ only about a handful of staff for an entire transport sub-sector such as roads, maritime, or aviation, making it unfeasible to have specialized units focused on areas related to climate resilience. Land transport authorities and marine or aviation divisions are often staffed by generalists and a limited number of staff with a technical background to carry out project management, policy formulation, and engineering, with very few if any of these positions dedicated or with a focus on climate resilience. These capacity limitations also make it difficult to effectively supervise activities by consultants and contractors.
- **Challenge 2: Weak enabling environment and limited planning tools.** Many SIDS lack climate resilient transport policies or standards. While some are taking steps to develop them, institutional oversight for enhancing climate resilient transport is generally not well-defined in SIDS' legislative frameworks, resulting in inter-agency confusion and relatively slow implementation. In addition, many transport institutions do not have climate resilient planning tools for staff to identify and prioritize vulnerable transport network assets and take the systematic measures that are needed to enhance resilience. The few institutions that do are typically funded by donors, with work carried out by donors or international consultants. Tools also need to be updated regularly, as vulnerabilities and priorities change, but governments generally do not plan for the recurrent funding that would be required, which again means donors are needed to fill the gap.
- **Challenge 3: Lack of government funding to maintain climate resilient capacity building.** Transport professionals in SIDS often do not have backgrounds in climate resilience, and many require on the job learning or formal training to ascertain base competence in this area. This training, however, is not typically included in government budgets and if provided often relies on donor support. To ensure skills retention, on the job learning and training must also be provided periodically, especially in the transport institutions of SIDS that suffer from significant attrition as many highly-trained or qualified people leave for higher-paying jobs in the private sector or overseas.

Overall, as a result of their high asset vulnerability (due to the many hazards and high exposure) and large well-being losses when assets are damaged, SIDS must act on many fronts to meet future development goals in a sustainable and resilient manner. This will require well-managed public finances and significant investment capacity in infrastructure, particularly in transport asset management systems. Furthermore, in atoll islands like Kiribati, the Marshall Islands, and Tuvalu, climate change even poses difficult questions about the feasibility of long-term development plans. (Box 1.3.)

### Box 1.3. Long-term Trade-offs for Atoll Nations

With their highest point of elevation only a few meters above sea level, the atoll nations of Kiribati, the Marshall Islands, and Tuvalu are particularly vulnerable to sea level rise. Without adaptation, the rising sea level will reduce the islands' available habitable surface over time, leading to a very high displacement of people. At Majuro Atoll in the Marshall Islands, for example, a 50 centimeter rise in sea level (a conservative projection for 2080) may mean the disappearance of 80 percent of its land area (Asian Development Bank 2013).

In addition, sea level rise and the deterioration of coral reefs, due to ocean temperature increase and acidification, significantly increases the risk of storm surges. Storm surges and salt water intrusion threaten fresh water supply and agriculture production, while the disappearance of the reefs weakens the marine ecosystems that populations depend on. Future vulnerability is also exacerbated by high population growth. From 1995-2010 in South Tarawa in Kiribati, yearly population growth was 3.9 percent (Government of Kiribati 2011).

The DIVA model (Hinkel and Klein 2009), a widely used model to assess consequences of sea-level rise, estimates that the cost of coastal protection in Kiribati (with seawalls and beach nourishment) could be between US\$13 and 42 million per year in the 2020s and between US\$17 and 54 million per year in the 2040s, depending on sea level rise. This estimate assumes that populations and economic activities continue to settle and grow in the same areas as today, thus without active land use planning to regroup them in smaller protected zones. Considering residual risk, the cost of coastal adaptation in this scenario could be between 4 and 11 percent of Kiribati's GDP in the 2040s, which is up to one third of the government's revenue.

Some people in Kiribati believe it may already be too late to save their nation from the effects of sea level rise and increased frequency of king tides. Former President Anote Tong spoke of the need to ensure "migration with dignity" for the country's population of about 110,000 people. For Tuvalu, migration as a result of climate change is seen as an option of last resort (McNamara and Gibson 2009). Similarly, the vast majority of Tuvaluans do not view this as a major reason for concern and are not, yet, preparing to migrate because of climate change (Mortreux and Barnett 2009).

The decision to relocate to another country is a difficult one to make. But if international finance does not match the investment needs for climate resilience, if protection is unfeasible in technical terms, or if it creates unacceptable risks in case of protection failure, a progressive relocation may need to be considered. The objective could then be to maintain desirable living conditions for a few decades for a declining number of people, as the population is progressively relocated. There are political issues associated with this (Wyett 2014), and it requires buying land elsewhere (as did Kiribati by buying land in Fiji), but this option is less costly than a last-minute abandonment with huge emergency assistance.

Source: Based on World Bank 2016b.



PART I. CLIMATE AND DISASTER RESILIENT TRANSPORT IN SMALL  
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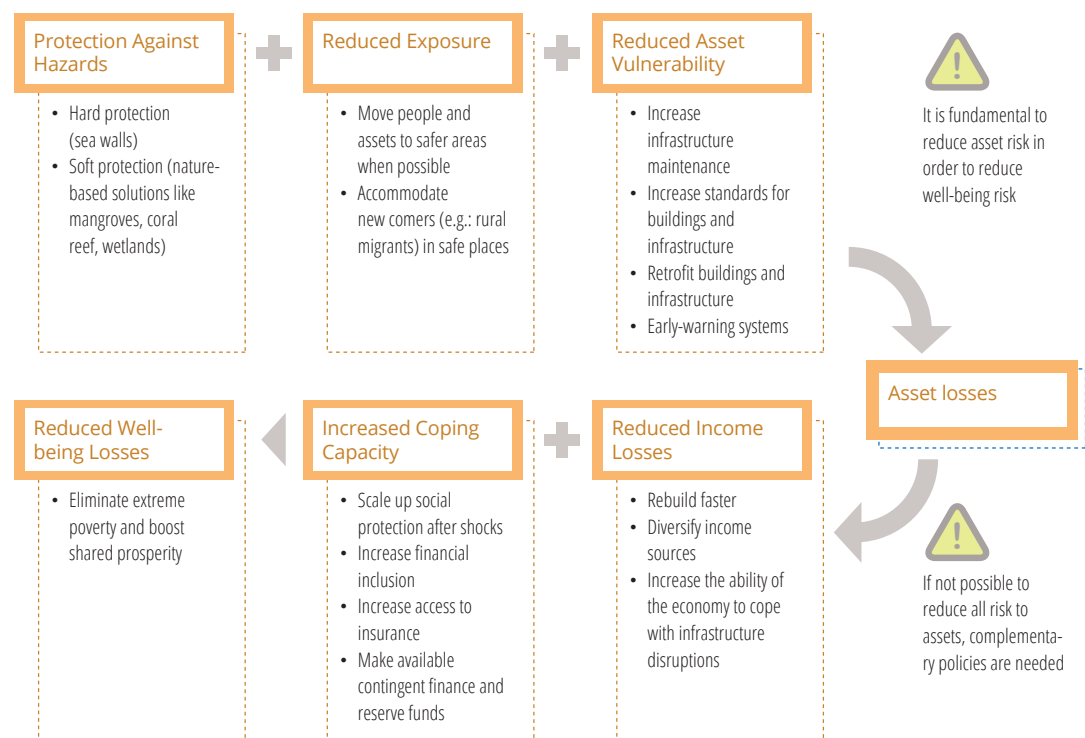
## Chapter 2. Range of Policies and Measures to Enhance Resilience



Given the scale of the challenges presented by natural disasters and climate change, SIDS will need to adopt a diverse set of policies and measures to limit their impacts and alleviate the likely increase in losses in assets, income, and well-being that will result from them. Figure 2.1, against the same components used in Figure 1.1, shows the broad range of policies and measures available to enhance resilience to climate and natural disasters impacts, such as for example providing physical protection against hazards, reducing asset exposure and vulnerability, building back faster after disaster, and developing capacity to recover after an event.

The next three sections describe these measures and policies, showing relative benefits for countries based on an analytical framework to measure reductions in asset losses, income losses, and well-being losses based on these interventions. Among all options, model findings point to the key role of resilient transport policies to enhance resilience and reduce losses in SIDS, underscoring the general need for investment and capacity building in this area.

**Figure 2.1. Policies and Measures to Reduce Asset, Income, and Well-being Losses from Natural Disasters**



Source: Adapted from Hallegatte *et al.* 2017.

## 2.1 Measures to Reduce Asset Losses

To limit asset losses, policies and measures can be used to reduce either the exposure of assets to hazards or the vulnerability of those assets. For the former, reducing exposure, suitable measures include investing in stronger protective infrastructure, such as seawalls and appropriate drainage systems, or applying “softer” methods such as beach nourishment, coral reefs protection, and mangrove preservation. In addition, the exposure of assets to hazards can be reduced through the integration of climate and natural disasters risk considerations in land-use planning to prevent people from settling in areas that are too expensive to protect and avoid the location of critical transport infrastructure in hazardous areas.

Next, to lower the vulnerability of assets to impacts of natural disasters and climate change, options include increasing design standards, retrofitting existing assets, and improving the maintenance of the asset base. Early-warning systems, which rest on a well-functioning ICT infrastructure network, are also very efficient at reducing asset losses by giving people the time to move valuable assets, including vehicles, to safe places. In sectors other than transport, asset losses might be protected in different ways. In the agriculture sector, for example, the use of higher-yielding and more climate-resistant crop varieties and livestock breeds can make agriculture production more resilient to climate shocks.

### *Reducing Asset Losses in the Transport Sector through Transport Asset Management Systems*

Sound transport asset management systems play an important role in reducing the vulnerability of transport infrastructure. Transport asset management systems cover the planning, operation, maintenance, upgrading, and expansion of physical assets throughout their life cycle to ensure an acceptable level of service (see also Chapter 3). As such, they help transport agencies understand the condition and criticality of assets, prioritize interventions, and effectively incorporate climate change and natural disaster risks into decision-making processes, which improves transport resilience and reduces costs through preventive maintenance and upgrading of critical structures. Importantly, for asset management to be effective, stakeholder commitment, effective institutions, and adequate resources are key.

The importance of transport asset management was highlighted by the 2013 report, “Challenging the Build-Neglect-Rebuild Paradigm” (PIAC, 2013), which reviewed infrastructure maintenance in the Pacific Island Countries (PICs) across a range of sectors. The report noted that the failure to manage and maintain existing infrastructure assets in PICs had resulted in a large infrastructure “debt,” representing the gap between what had and should have been spent on infrastructure. Specifically, the report noted that the lack of preventative maintenance had led to the premature deterioration of infrastructure. This not only negatively impacted lives in the countries involved, it also was very costly. As described in the report, “every dollar of routine maintenance that is deferred will end up costing \$5 in repairs, or ultimately, \$25 in rehabilitation or replacement as the asset declines overtime.”

With climate change leading to increased risk of disasters, this situation for PICs and other SIDS will only get worse in the absence of effective infrastructure asset management. Solutions, however, are available, such as mobile tools to effectively monitor asset condition over time or mechanisms to

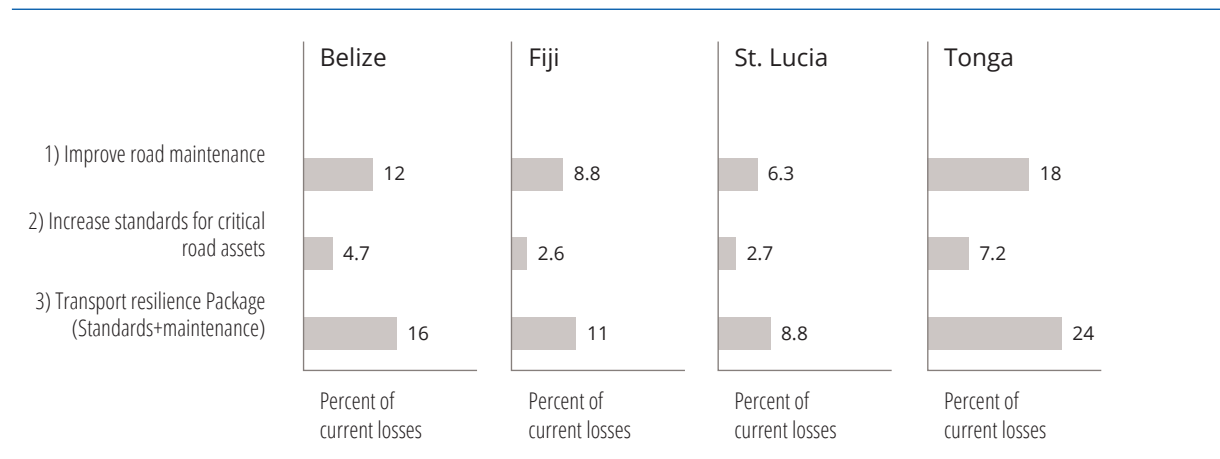
identify the most vulnerable infrastructure elements and prioritize investments. Significant technological progress in recent years offers low-cost opportunities for mapping transport networks and natural hazards, while new technologies and construction techniques can provide cost-effective long-term solutions. These solutions and others are presented in Chapter 3 and Part II of this report.

### *Benefits of Investments in Resilient Transport Policies to Reduce Asset Losses*

As mentioned above, transport asset management systems not only bring benefits such as improved service levels and reduced costs for maintenance. They also generate benefits from a resilience perspective in terms of reduced transport asset and economic losses following natural disasters. To assess these benefits, the Unbreakable model (Hallegatte *et al.* 2017, see also section 1.3) was combined with a transport model (Box 2.1 and Rozenberg *et al.* 2017). The Unbreakable model does not consider the cost or feasibility of policies, but indicates their relative importance in terms of reducing asset losses and well-being losses (see section 2.3), and thus improving resilience.

Based on the model findings, the benefits of three specific transport measures—improved road maintenance, increased standards for critical road assets, and both combined—that can increase the resilience of transport networks in SIDS are presented in Figure 2.2 for Belize, Fiji, St. Lucia and Tonga.

**Figure 2.2. Reduction of Asset Losses Due to Resilient Transport Policies**



Source: Authors' calculations using the Unbreakable model.

Note: Results were produced with the Unbreakable model described in Box 2.1. It is assumed that road asset maintenance removes all asset losses due to flood events with a return period of 20 years or less. Based on the results of an analysis for Fiji (see Box 2.2), it is assumed that the standard upgrade of critical assets reduces asset losses by 20 percent.

The first measure in Figure 2.2, improve road maintenance, reduces asset losses that are linked to frequent events (such as floods that happen every five to twenty years) by making assets more resistant to heavy rainfall and small floods. As shown in the figure, regular maintenance can also have high



economic benefits in the presence of natural hazards and climate impacts as it can reduce asset losses by 6.3 percent (St. Lucia) to 18 percent (Tonga) in the sample of SIDS analyzed. Road maintenance can also reduce costs for users (for example for vehicle repairs or increased fuel consumption linked to driving on damaged roads) and prevent the need for reduced speed and detours, thus further reducing income losses and well-being losses. For SIDS without the fiscal space to increase spending in road maintenance, road asset management systems can help prioritize maintenance expenditure by giving the road authorities information on the condition of their assets and their exposure to natural hazards. For SIDS who could increase maintenance spending, road asset management systems can provide the economic justification for an increased maintenance budget.

Results for the second measure, increase standards for critical road assets (such as bridges and culverts), show possible reductions in asset losses and thus disruptions linked to less frequent but more harmful events, such as storms and floods that happen every fifty to a hundred years. Critical structures are those that lead to high service losses if they are damaged. By making the network more resistant to extreme events in strategic places, asset losses are reduced and major transport service losses can be avoided, in turn reducing losses in income and well-being. As described in Box 2.3 and further addressed in Chapter 3 and Part II, recent advances in construction technology mean that higher standards and more climate resilience can be achieved at lower costs.

Finally, by combining the two policies—improve road maintenance and increase standards for critical road assets—the measures have the potential to significantly reduce asset losses in the set of SIDS analyzed here. In Belize and Tonga, for example, asset losses could be reduced by as much as 16 percent and 24 percent, respectively (Figure 2.2). Box 2.2 reports on the findings of an analysis of the value of resilient transport investments in Fiji.

#### **Box 2.1. Inclusion of SIDS and Transport Losses in the Unbreakable Model**

The “Unbreakable model,” developed for the 2017, “Unbreakable: Building the resilience of the poor in the face of natural disaster” publication (Hallegatte *et al.* 2017) and fully described in Vogt-Schilb *et al.* (2016), is work-in-progress combining data on natural hazards, population and asset location, asset vulnerability, and socio-economic characteristics. In addition, the model combines insights from natural and social sciences, to assess how natural disasters affect well-being, measured using a social welfare function (welfare is the metric used by economists to measure well-being). The model and the data used for Hallegatte *et al.* 2017 are available online.

In the Unbreakable publication, the model is applied to 117 countries for which data was available on global public databases. The analysis, however, did not include any SIDS. To use the model for the current report, data has been collected for a sample of eight SIDS, and the model was modified to specifically account for transport infrastructure losses and transport service losses.

To account for transport infrastructure losses, transport assets are simply distinguished from the other assets, while the same vulnerability is applied to all. For transport service losses, the produc-

tion function (only in the event of a shock) was modified, assuming that when a transport service loss occurs, this loss impacts the country's income (see Rozenberg *et al.* 2017 for details). For all countries but Fiji (for which service loss data was available), service losses are assumed to be proportional to the infrastructure losses. This is a conservative assumption, especially for small countries in which the road network has even less redundancy than in Fiji. (Note that in the Unbreakable model, asset losses come from UN-ISDR (2015), which means they come from different flood maps than the ones used in the Fiji model described in Box 2.2.)

Using the model, two kinds of measures were tested: improved maintenance that reduces losses due to frequent but low-impact disasters, and upgraded standards for critical bridges and culverts to reduce service losses in case of rare but high-impact events. For this second measure, and based on results for Fiji (see Box 2.2), it is assumed that road damage can be reduced by 20 percent and service loss by 35 percent through a standard upgrade of critical assets.

### Box 2.2. The Value of Resilient Transport Investments in Fiji

To assess the cost of natural disasters on Fiji's transport network and identify the best investments for improving transport resilience, a transport network model was developed and combined with flood maps for different return period events.

The model of the transport network was built using the Fiji Road Authority asset database. The main cities were selected as origin-destination (OD) pairs, and a gravity model was used to estimate traffic between each OD pair. The model was calibrated using data from the Fiji National Transport Planning Database. The transport network was then overlaid with flood maps corresponding to different return period events, from 5 to 1000 years. For each flood map, the repair cost associated with the damaged infrastructure was calculated, as well as the increase in road user costs due to detours and isolated trips (trips that can no longer be completed). For these calculations, two different assumptions were used on the condition of infrastructure, resulting in a lower (for better condition infrastructure) and a higher value of asset damage and transport losses for each flood event return period. Results for the two main islands in Fiji, Viti Levu and Vanua Levu, are presented in Table B2.2.1.

**Table B2.2.1. Transport-related Economic Losses from Pluvial Flood Events**

Flood event return period (years)	Viti Levu		Vanua Levu	
	Asset damage (repair cost as percentage of total assets value)	Transport service loss during the year of the event	Asset damage (repair cost as percentage of total assets value)	Transport service loss during the year of the event
5	0-1%	0%	0%	0%
20	0-1%	1-4%	0-1%	2-5%
100	10-24%	65%	5-26%	45%
1000	45-47%	66%	27-55%	51%

Note: Value ranges represent results from high and low scenarios depending on assumptions on the condition of the transport infrastructure. When conditions are worse, damages and losses are higher.

The Fiji Road Authority (FRA) has already identified many structures as priorities for rehabilitation because of the lack of maintenance they have received in recent years. The investment and capital expenditure needs for this have been estimated at F\$4.7 billion, of which most (F\$3.1 billion) is already planned. Most of these investments are to renew and strengthen existing roads and bridges (including culverts, crossings, and footbridges) so they can better serve users in normal time as well as cope with floods (Rozenberg *et al.* 2017). Using the transport network model, it was estimated that these investments could reduce infrastructure damage (and thus emergency repair costs) by 52 percent and transport service loss by 35 percent. This is a resilience co-benefit of about F\$160 million per year for these rehabilitation investments.

The model was also used to identify a small set of investments that could reduce asset and service losses at a small cost. This set of investments will only cost F\$360 million and can reduce transport services losses by 22 percent and save Fiji F\$90 million per year. The total benefits are lower than FRA's rehabilitation priority list, but the investments are much more efficient in terms of resilience: the rate of return of this set of investments is 25 percent.

Source: Rozenberg *et al.* 2017.

### Box 2.3. New Technologies to Meet Higher Standards at Lower Costs

Advances in construction technology mean that lower-cost approaches need not sacrifice performance. In fact, some low-cost technologies perform better than traditional approaches, with advanced materials and methods making for infrastructure that is both less expensive and more climate resilient. Two examples of this can be found for bridges, which are often critical links in the transport network.

The first example involves the introduction of Geosynthetic Reinforced Soil (GRS) abutments. While traditional piled abutment foundations are required in some geotechnical situations, where feasible new GRS abutments offer a significantly lower-cost solution (30 percent in Sri Lanka) that is also more seismically resilient and faster to construct from locally available materials (see also Case Study 4).

A second example for bridges is the use of modular bridge solutions that encase the deck structure of the bridge in stainless steel. This approach results in a significantly longer design life of up to 100 years with associated lower maintenance costs, a performance well beyond that which can be achieved at a reasonable cost with traditional in-situ reinforced concrete. Construction costs are also lower because standardized formwork (including reinforcing) can be delivered to the site in a container, with deck casting done in a single pour, as opposed to the longer times and complex formwork needed for traditional in-situ structures.

## 2.2 Measures to Reduce Losses in Income and Well-being

While reducing asset-losses is essential, future asset risks in SIDS cannot be eliminated completely. Flood protection, for example, can fail in the face of exceptional tsunamis or storm surges, and cyclones can wreak massive devastation even with the strictest building norms. In addition, the uncertain effects of climate change make it more likely that some hazards will overwhelm protection infrastructure or hit where they are not expected. SIDS have no choice but to become better equipped to cope with asset losses, focusing also on reducing losses in income and well-being losses following a disaster. To reduce income losses post-disaster event, several policies and measures are available. They include measures for re-building faster and better following the disaster, or limiting the dependency of the economy on vulnerable infrastructure. The later can for example be accomplished by adopting a telecommuting strategy for companies or maintaining stocks of emergency relief supplies in warehouses that will remain accessible during an event, along with logistical and operational capabilities to distribute the supplies.

To reduce well-being losses, SIDS must implement measures to increase their socio-economic resilience, giving people the means to recover and rebuild their asset stocks through scalable social protection, increased access to the financial system, and access to insurance for natural disasters. Scaling up social protection after a shock, however, is generally difficult for SIDS, as when disaster strikes, a large share of the economy is impacted and tax revenues are reduced.

To address contingent liabilities, various instruments have been developed and used in SIDS. Instruments include reserve funds, catastrophe bonds, regional risk sharing facilities, and contingent credit. An example of contingent credit is the World Bank Catastrophe Deferred Drawdown Options, a new financing instrument that allows countries eligible to borrow from the International Bank for Reconstruction and Development to access budget support in the immediate aftermath of a disaster. The Caribbean Catastrophe Risk Insurance Facility (CCRIF) and the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) both pool disaster risk across SIDS in their respective regions, providing participating governments with quick, short-term liquidity for financing responses and early recovery from major disasters. The application of the CERC is further discussed in Chapter 3 and Case Study 11 in Part II.

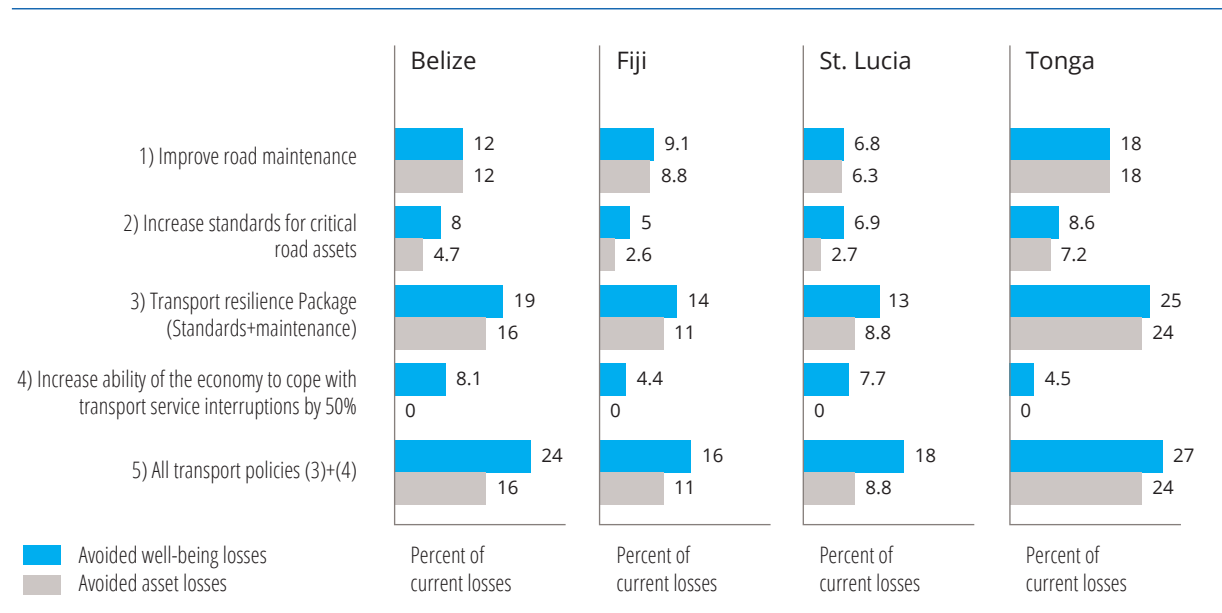
## 2.3 Well-being Benefits of Resilient Transport Policies

As described in section 2.1, improving road maintenance and increasing standards for critical road assets are important for reducing asset losses in SIDS; in addition, these measures also have the potential to significantly reduce income and well-being losses. As shown in Figure 2.3, well-being losses in Belize can be reduced by 19 percent and those in Tonga by 25 percent, based on the implementation of the combined package of measures.

However, the measures described in section 2.1 cannot protect the transport networks in SIDS from all events. Standards for road assets are often no higher than 20 years, and even if the standards of critical road assets are increased to cope with a 50-years event, the infrastructure is still vulnerable to less frequent—and larger impact—events.

To further reduce well-being losses, government authorities can aim to increase the ability of the economy to cope with transport service interruptions. Using the same model, a set of policies that increases by 50 percent the ability of the economy to cope with transport service losses was tested, meaning that half of the firms that would be affected are now able to keep producing because of the availability of stocks and better logistics, while also half of the workers who could not get to work in case of transport asset failure can now telecommute. While these policies have no impact on asset losses, they can reduce well-being losses by 4 to 8 percent depending on the country. Finally, when combining all transport policies, well-being losses can be reduced by 16 percent (in Fiji) to 27 percent in Tonga (Figure 2.3).

**Figure 2.3. Comparison of Benefits of Several Resilient Transport Policies in Terms of Avoided Well-being Losses and Asset Losses**

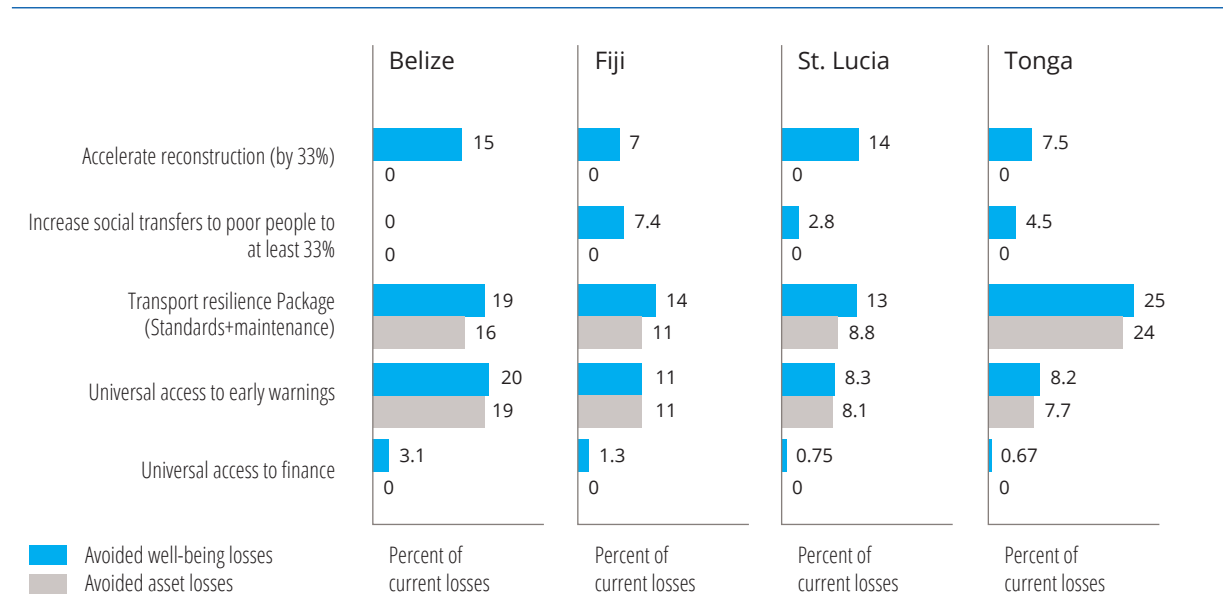


Source: Authors' calculations using the Unbreakable model (see Box 2.1).

Note: The sum of the benefits of the resilient transport package (3) and of the policies that reduce the dependence of the economy on transport services (4) is higher than the benefits when the two policies are combined in (5). This is because the benefits of (4) are reduced if the transport infrastructure becomes more resilient thanks to (3).

Finally, how do resilient transport policies compare with other types of policies? Using the same model, relative benefits of several policy measures for resilience were analyzed, including household access to finance, early warning systems, increased social transfers, accelerated construction post-disaster, and a transport resilience policy package. The results of the analysis again point to the importance of transport resilience in terms of avoiding asset and well-being losses. While for each individual country the most beneficial policy package may differ, across all SIDS, improving the resilience of the transport networks consistently ranks high both in terms of avoided asset losses and well-being losses (Figure 2.4).

**Figure 2.4. Comparison of Benefits of Transport and Other Policies in Terms of Avoided Well-being Losses and Asset Losses**



Source: Authors' calculations using the Unbreakable model.

This important role for resilient transport policies encompassed in road asset management systems, as shown by the model outcome, is not surprising, as investing in resilient transport infrastructure has many economic and social benefits. More resilient transport infrastructure directly helps avert asset losses from natural disasters and climate impacts, reducing required investments in reconstruction and rehabilitation. This in turn releases funds for maintenance, minimizing impacts from future events. Reduced transport disruptions further reduce business interruptions and mitigate the long-term social and economic impacts of natural disasters.



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PART I. CLIMATE AND DISASTER RESILIENT TRANSPORT IN SMALL  
ISLAND DEVELOPING STATES: A CALL FOR ACTION

## Chapter 3. Toward Disaster and Climate Resilient Transport Systems

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As described in the previous chapter, the integration of climate and disaster risk considerations in transport asset management is a key way to strengthen transport resilience, bringing high benefits across SIDS in terms of reduced losses in assets, income, and well-being. This chapter aims to demonstrate opportunities and practical measures for SIDS to achieve those benefits.

The chapter first presents a high-level overview of the status of transport asset management for a selection of SIDS (section 3.1), followed by a brief discussion on how to integrate climate change uncertainty with transport asset management (section 3.2). Section 3.3 then reports on examples of interventions deployed in SIDS, often with World Bank support, in integrating climate and disaster risks in transport asset management systems. This section, using an infrastructure lifecycle framework to categorize interventions, draws from all the case studies in Part II of this report to summarize engagement across regions and showcase best practices in SIDS and elsewhere with relevance for SIDS.

### 3.1 The Status of Transport Asset Management in SIDS

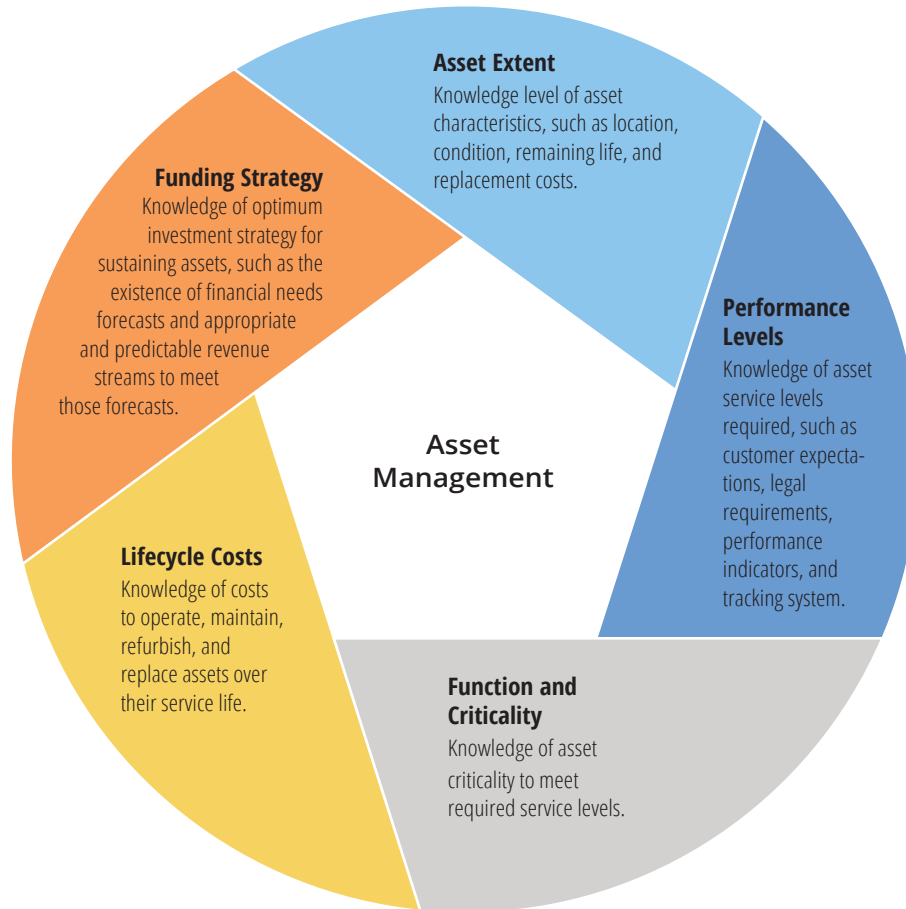
Generally speaking, transport asset management encompasses strategic, financial, and technical elements related to the location of transport assets, engineering and design standards, maintenance and operation of physical assets, and contingency programming. This includes for example updated records of asset location, condition, and performance level; defined asset objectives and intended levels of service and performance (including user expectations); appropriate maintenance, operations, and investment plans and corresponding budgets; and clear governance arrangements—who owns what and who is responsible and accountable for operation, maintenance, and financing of assets under management.

Today, asset management systems also need to effectively incorporate climate change and natural disaster risks into decision-making processes, which involves such activities as mapping hazards, identifying vulnerable assets, understanding the consequences of asset failure, planning to prevent disruptions (rather than reacting after disasters), and building back better after disasters.

Individual countries, depending on specific needs and conditions, will adopt asset management support systems with different levels of complexity and resource requirements. The choice often depends on the size and complexity of the transport network, the level of environment and other risks that the country and transport sector faces, as well as the varying availability of financial and technical resources.

In this context, a quick survey was deployed in a sample of nine countries in the Pacific and Caribbean regions to assess the maturity of their transport asset management systems. The survey, completed by government authorities and World Bank staff, resulted in a rating on a scale from lowest (1) to highest (5) level of competency for five characteristics of the asset management systems in the sample countries. The five categories, addressing knowledge about asset extent, performance levels, function and criticality, lifecycle costs, and funding strategy are presented in Figure 3.1.

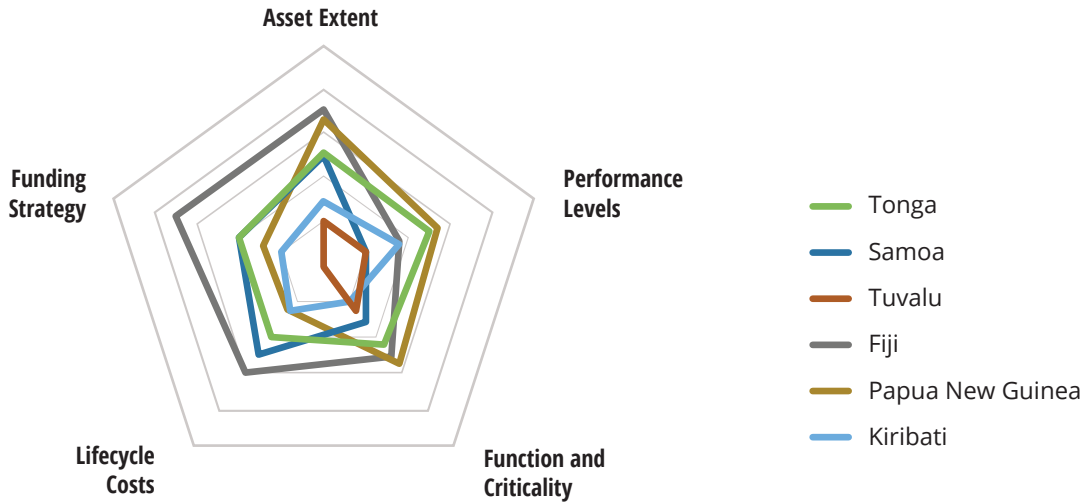
**Figure 3.1. Characteristics of Asset Management Systems Evaluated in the Transport Assessment Management Survey among SIDS**



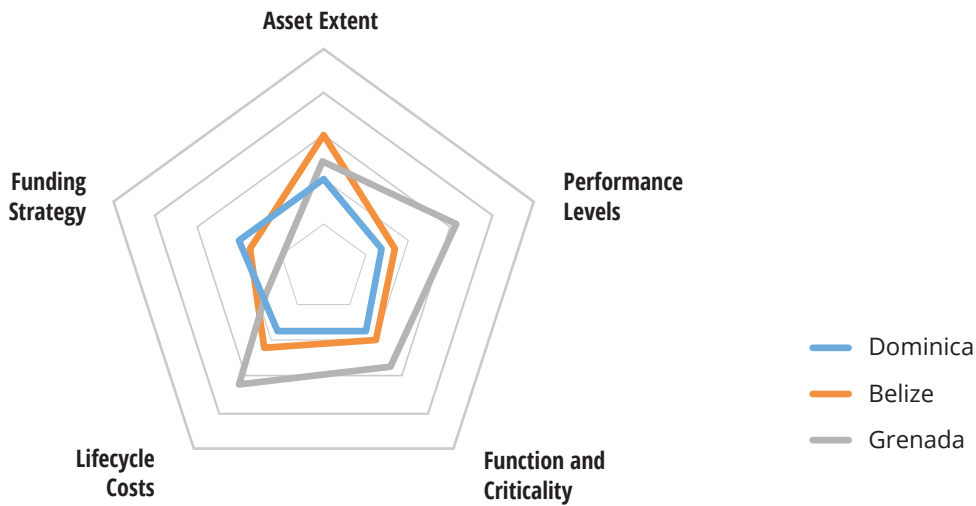
Among the six respondents in the Pacific Region, Fiji's self-assessment suggests a relatively higher capacity in road transport asset management overall in relation to its five surveyed peers in the Pacific, and particularly in terms of knowledge of asset extent, understanding of function and criticality, lifecycle costs, and funding strategy, while its scores are relatively low related to the performance levels characteristic. Tuvalu's ranking was the lowest, compared to the other five respondents, in terms of self-perceived road transport asset management capacity overall (Figure 3.2)<sup>4</sup>.

<sup>4</sup> The survey focuses on asset management capacity, not on actual on the ground conditions. Often, due to factors outside an institution's control, countries with high asset management capacity may have poor condition assets due to issues such as funding limitations. Even with good asset management, such as in Fiji, a maintenance backlog can lead to delays in the improvement of network condition that could reduce vulnerability.

**Figure 3.2. Transport Asset Management Survey Results for a Sample of SIDS in the Pacific Region Focused on Road Transport**



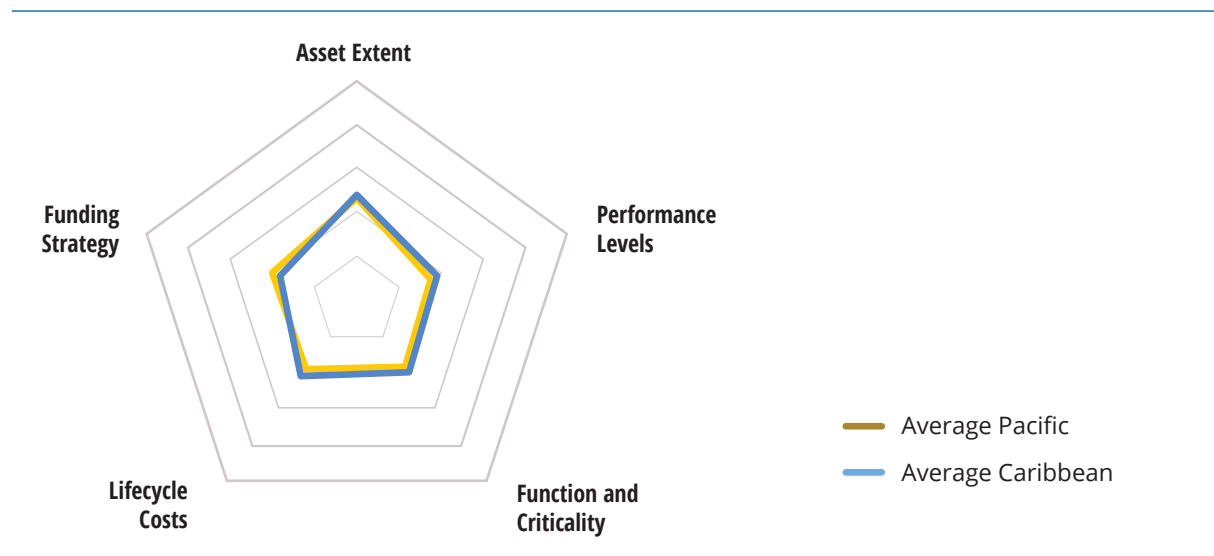
**Figure 3.3. Transport Asset Management Survey Results for a Sample of SIDS in the Caribbean Region Focused on Road Transport**



Among the three respondents in the Caribbean Region, Grenada indicated relatively more knowledge of required performance levels, function and criticality, and lifecycle costs (Figure 3.3). Importantly, all three countries recently benefited from World Bank Technical Assistance, which made viable the necessary data collection, acquisition, and management, and this is reflected in the survey results. It is expected that, in the near future, the result for the funding strategy element would improve as enhanced data access is conducive to improvements in strategic planning.

Finally, when comparing average results for the two regions, the analysis shows a similar pattern of low competency in road transport asset management. The combined result masks the variety in scores among countries, but indicates an overall need for countries in both regions to enhance capacity and competency in this field (Figure 3.4).

**Figure 3.4. Average Score for Countries in the Pacific and Caribbean Regions for the Five Key Characteristics Assessed in the Transport Asset Management Survey**



### 3.2 Integrating Climate Change Uncertainty in Transport Asset Management

When integrating climate and disasters risk considerations in transport asset management systems, the uncertainty of climate change impacts at the local level must be recognized. Uncertainties emerge both due to the challenges of modeling complex climate systems, as well as from a lack of clarity or uncertainty around policy actions and human behavior related to the reduction of greenhouse gas (GHG) emissions and adoption of adaptation measures.

In the particular case of SIDS, given their small size and the fact that they are surrounded by oceans, downscaling the changes in global climate to the country level presents a wide range of potential local climate scenarios. For instance, in Kiribati some models project an increase in extreme peak daily rainfall of 53 percent, while others predict an increase of 92 percent, for the same GHG emissions scenarios. In Fiji, some models estimate an increase in annual precipitations while other models predict a decrease, again for the same GHG emissions scenario. These large differences in projections bring a risk of “maladaptation,” which needs to be considered in the design of long-term strategies.

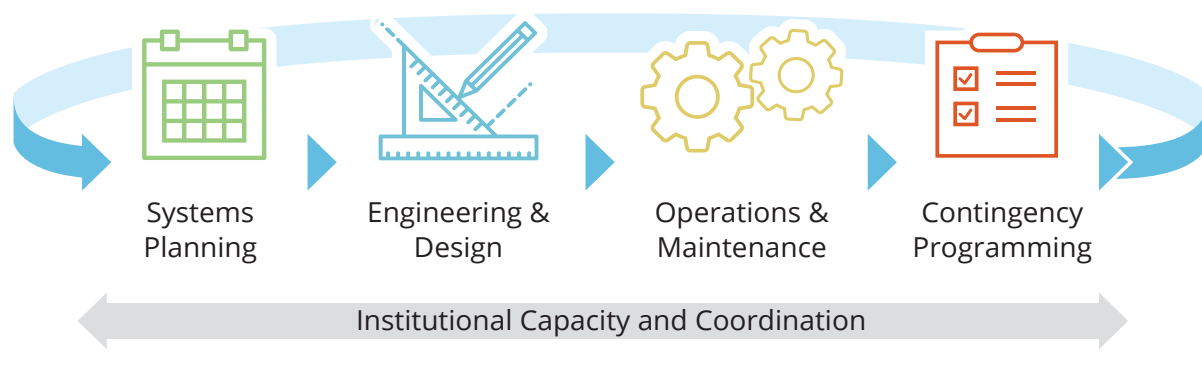
The large level of uncertainty means decision makers need to plan for the unexpected. In the Pacific, some countries already start observing failures they have never seen before. Under the Tuvalu Aviation Investment Project (TvAIP), for example, the country's 20-year-old runway was resealed to repair cracks and extend its service life. Within six months, however, areas of the pavement began to “blister” and vent cracks formed, leading to pavement “heaving”—lifting and breaking. A study found that the events happened because coral is porous and the combination of surface water and the up and down movement of tides pushes air and moisture toward the surface; with nowhere to go, it eventually forced its way to the top. With climate change, Tuvalu is seeing more intense precipitation, as well as sea level rise, which are considered to be contributors. This type of failure had only been observed once in the world before, and it had been impossible to anticipate and plan for it.

To help decision makers plan for the unexpected, many pragmatic approaches can be used. In the case of the Tuvalu airport runway, the plan is to use additional financing to test several potential solutions and implement the most cost effective one. In general, to address the uncertainty around future climate change impacts, infrastructure needs to be designed to withstand a wide array of possible changes in climate conditions. To do this, new solutions must be tested and their robustness assessed through stress-testing under a wide range of plausible conditions. In this context, it can also be useful to choose low regret design and engineering solutions that can withstand a variety of climate conditions. Another option is to increase the flexibility of investments, for example by choosing engineering designs that have a reduced lifetime or that are easy to retrofit in the future once additional information is known on the direction, magnitude, and speed of climate change and on the performance required.

### 3.3 Integrating Climate and Disaster Risk Considerations in Transport Infrastructure Lifecycle

Within the World Bank, considerable experience exists with the integration of climate and disaster risk considerations in the transport sector. Fourteen such best practices are presented in this section, to demonstrate existing experiences across SIDS and elsewhere, and present opportunities for all SIDS to move toward resilient transport.

The case studies are presented within the context of the transport infrastructure lifecycle, a practical framework that can be used by government authorities to guide the integration of climate and disaster risks in transport asset management. Shown in Figure 3.5, the framework consists of 4 components—systems planning, engineering and design, operations and maintenance, and contingency programming—supported by institutional capacity and coordination.

**Figure 3.5. Transport Infrastructure Lifecycle Framework**

By addressing the life cycle of transport infrastructure, the framework supports a holistic approach toward transport asset management that facilitates the mobilization of required resources and their application in a cost-effective and informed manner. As government authorities, despite evidence of increasing climate and disaster risks, often struggle to secure budget for transport resilience, improved information on the status of assets, climate and disaster risks, and available solutions can facilitate inter-agency dialogue and support informed decision making. The comprehensive framework also empowers government authorities to define maintenance and rehabilitation schedules and prioritize investments, thus ensuring a cost-efficient use of resources to maximize the benefits from investments. In the sections that follow, descriptions and best practices (linked to the case studies in Part II of this report) for each of the components of the framework are described.

## Systems Planning

Systems planning, the first component of the transport infrastructure lifecycle framework, offers the opportunity to increase transport resilience through improved analysis and planning. Systems planning (see featured best practices), can involve analysis to better understand which infrastructure is critical and vulnerable, as well as measures to shift the deployment of long-life infrastructure away from disaster-prone areas, or plan for the use of transport infrastructure as part of disaster risk management.

To increase socio-economic resilience to future shocks, SIDS governments need to ensure their transport network will deliver a minimum acceptable level of service after disasters strike. However, with limited resources, governments are not able to protect an entire network against all possible disruptions and must focus on the most critical assets (such as roads with the most traffic, greatest socio-economic relevance, or most expensive consequences in the event of disruption) and identify the best interventions to protect these assets against potential disruptions. In addition, government authorities need to anticipate and plan for future changes in risks due to climate change.

Systems planning can help SIDS deliver on these requirements by for example defining the levels of service and performance that transport assets should deliver under different circumstances; improving the understanding of the asset base, through asset inventory and mapping; and keeping track of the condition of assets through regular condition assessments. Moreover, systems planning involves understanding future demand, mapping and quantifying the risks to assets and service delivery, and monitoring system performance.

In three countries—Samoa, Mozambique, and Cabo Verde—recent and ongoing World Bank projects demonstrate how systems planning can be used to strengthen transport resilience to reduce losses in assets, income, and well-being (see also Case Studies 1 and 2 in Part II of this report).

### Best practices

- *Analyze transport systems at network level to identify critical infrastructure, choke points, and redundancy, to better understand implications for socio-economic development.*
- *Where possible, shift long-lived infrastructure away from disaster-prone areas to avoid development lock-in.*
- *Design and manage transport infrastructure for both connectivity and disaster risk management purposes, particularly for hydromet-related hazards.*



**Figure 3.6. Samoa's Vulnerable West Coast Road**



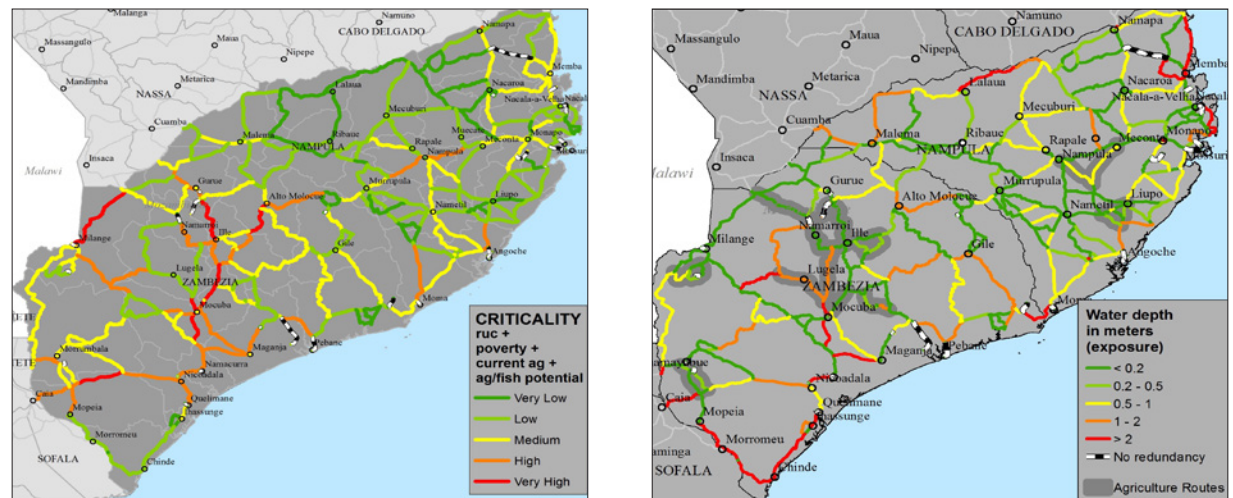
Photo Credit: Sean Michaels.

In Samoa, where about 70 percent of the population lives within a kilometer of the coast, enhanced systems planning is used to both prepare and respond to the impacts of natural disasters and climate change (Case Study 1 and Figure 3.6). Using funding from the Pilot Program for Climate Resilience (PPCR), for example, the country recently completed a Vulnerability Assessment and Climate Resilient Road Strategy for its road network. The work included a comprehensive risk assessment across the country to identify areas vulnerable to climate change and natural disasters, using commercially available and affordable assessment tools. Data was assessed and categorized into types of vulnerability, including proximity to the coastline, elevation above sea-level, and susceptibility to landslides, with the information displayed in Google Earth and other software. Data files with vulnerability information and hazard risks were also included in the Samoa Land Transport Authority's (LTA) existing asset management system as data became available. To ensure use of the new tools and resources, weekly tutorials were held to build staff capacity. Other recent activities in Samoa to strengthen systems planning have included redundancy investments for critical infrastructure such as roads and bridges, the construction of pedestrian evacuation routes, and policy and planning activities that address disaster and climate risks.

In Mozambique (see Case Study 2), the World Bank has been working with its road authority to prioritize road interventions based on flood risk and economic development potential. Although Mozambique is not a SIDS, the innovative approach to integrate climate and disaster risk into a prioritization of interventions is considered replicable in SIDS with road networks. The project used a four-step process to support decision making for two provinces, Zambezia and Nampula. Steps included (a) mapping the road network using a mobile application, (b) developing a road network model to assess the criticality of road assets, with criticality based on performance loss due to disruptions and proximity to agricultural sites, among others, (c) using hazard maps to assess flood risks by district and determine a ranking of suitable interventions based on risk and criticality, and (d) stress-testing potential interventions under several climate scenarios to ensure service delivery could withstand future climate change impacts. Asset criticality and exposure maps for Zambezia province are shown in Figure 3.7. The proj-

ect supported the two provinces in prioritizing investments, with two specific interventions (cleaning and repair of bridges and an upgrading of culverts) identified as the most robust ones for almost every district. The two interventions had a lower capital cost and returned a high benefit, mostly in term of avoided damage to the infrastructure due to flood events.

**Figure 3.7. Asset Criticality and Exposure Maps to Support Prioritization of Transport Interventions in Mozambique**



A. Asset Criticality Map

B. Flooding Exposure Map

Finally, in Cabo Verde—an archipelago of 10 small islands in the central Atlantic Ocean off the coast of West Africa—the World Bank is working with the government to conduct a road network vulnerability assessment for the impacts of natural disasters and climate change. As most of the Cabo Verde islands are mountainous, its road network goes through steep hills and slopes. In recent years, droughts as well as strong rainfalls, a hurricane, and a volcanic eruption have all led to frequent traffic disruptions and the isolation of some communities, mainly because of landslides. As rural roads and rural population are mostly vulnerable to these external shocks, the assessment will be used to provide concrete recommendations to Cabo Verde’s climate adaptation strategy for its road network.

## Engineering and Design

Engineering and design, the second component in the transport infrastructure lifecycle framework, relates to measures that enhance the resilience of infrastructure through improvements in design and engineering standards and construction materials specifications to ensure these can withstand the impacts of natural disasters and climate change (see best practices feature box).

Recent progress in natural hazards risks mapping and climate change modelling has made practitioners aware of the challenges of using traditional engineering and design practices. The changing environment and high performance level requirements for resilient transport infrastructure demand improved designs that can meet constrained budgets, local material availability, and local capacity constraints, while still observing environment and social safeguards. New engineering and design best practices (see also Box 2.2), however, are available or are being developed to meet these challenges, and examples include some best practice projects led by the World Bank in Tuvalu and Kiribati, Cabo Verde, several coral atolls in the Pacific, and Sri Lanka (see Case Studies 3, 4, and 5).

In Tuvalu and Kiribati, similar to the situation for other SIDS, the island countries' remoteness and their generally limited availability of technical expertise and equipment complicate development of transport assets. Supported by the World Bank, both countries have been experimenting with a different type of pavement, using geocells, for the construction of low-volume roads, and the technology has proven to be ideally suited to the remote islands (Figure 3.7). As described in Case Study 3, geocell pavements can be constructed with local labor and portable equipment, using a high-density polyethylene (HPDE) formwork that is light and easy to transport. Experiences have shown that constructing a geocell pavement is in fact simpler than laying a bituminous pavement, and it can be done using either labor or equipment based methods. Addressing similar challenges, in Cabo Verde, dirt roads are being upgraded with more climate resilient granitic cobblestones, a construction material that is available and produced locally, generating jobs and revenues for the local population.

### Best practices

- *Apply innovative materials, upgraded design standards, and specifications that enhance robustness of infrastructure.*
- *Identify and reduce risks for and around infrastructure through hazard assessment of project sites.*
- *Modify designs and implement preventive measures and response mechanisms based on infrastructure-level vulnerability assessments and identified points of weakness.*

In another example, described in Case Study 4, coral atolls in the Pacific islands are having to adopt innovative methods and materials to promote coastal protection and reduce vulnerability to impacts from sea level rise and storm surges due to climate change and tropical cyclones. With the support of the World Bank, the coral atoll islands have tested a suite of solutions to address these challenges, identifying three types of revetment suitable for deployment: (a) rock revetment, formed with a geotextile filter fabric on a formed slope, overlaid by layers of small rocks and large rock armor; (b) geosynthetic container (GSC) revetment, or “geobags,” typically consisting of a geotextile pillows filled with sand (Figure 3.8), having the key advantage that containers can be shipped empty and filled with local sand on site; and (c) concrete masonry block (CMB) revetment, or “besser blocks,” an ubiquitous building material throughout the region. Besser blocks are often locally manufactured with coral sand, gravel, and imported cement, fulfilling social and environmental safeguards.

**Figure 3.8. Engineering and Design Solutions Applied in Tuvalu, Kiribati, and Coral Atolls in the Pacific Islands**



A. Geocell Formwork for Low-Volume Roads in Tuvalu and Kiribati



B. Geosynthetic Container Revetment for Coral Atolls in the Pacific Islands

Photo Credit: Oliver Whalley.

Photo Credit: [elcorock.com](http://elcorock.com)

Finally, in Sri Lanka, to address a critical road asset management element, a pioneering effort was undertaken to use Geosynthetic Reinforced Soil (GRS) technology to strengthen bridge embankments (see Case Study 5 and Box 2.3). While traditional bridge construction requires the installation of piles for the abutment foundations—a lengthy and expensive process that involves specialist materials, skills, and equipment, GRS abutments offer a promising alternative. In Sri Lanka, GRS abutments have proven to be useful for rapid and resilient construction amenable to using locally available materials, without the need for specialized equipment. With GRS, bridges can be constructed in as little as five days and at a cost 30-50 percent below those of traditional approaches used in Sri Lanka.



## Operations and Maintenance

Given the small budgets available to road authorities in SIDS, efficient road maintenance is critical to ensure the functionality of the road network and prevent high costs for repairs or infrastructure replacement. In addition, continued operations and provision of transport services is key in a post-disaster situation, to support emergency services and limit losses in income and well-being (see the feature box on operations and maintenance best practices).

Building on good systems planning and engineering design practices, interventions in operations and maintenance can add a new level of resilience by securing economic and social developments and reducing recurrent reconstruction costs due to frequent disasters. With systems planning and engineering design focused on ensuring delivery in the presence of rare and extreme events, proper maintenance and operation of assets ensures the best value on a regular basis, achieving a high level of performance while reducing costs.

In addition, in terms of operations, a key element involves making users of transport services better able to cope with transport service interruptions, such as those that follow a disaster. In this context, government authorities, service providers, as well as users of transport services need to discuss the challenges and potential solutions involved with interrupted services. Questions to ask, for example, could include: Can agricultural production be stored while the transport system is interrupted; is refrigeration an option in some cases with high-value products (and would that require generators and fuels); how could the tourism industry manage stranded tourists; and how can a reduced capacity network accommodate not only emergency services but also other services that are economically critical? Specific challenges will vary among countries, but participatory exercises involving stakeholders may help identify reasonable and affordable solutions that can limit the impact of transport service interruptions and thus reduce losses.

For maintenance, a key element is the availability of reliable data about location, condition, performance, and risks. As described below and in Case Studies 6-8, World Bank projects in Dominica, Saint Lucia, and Belize have focused on data acquisition and analysis to provide relevant ministries, such as those for planning, finance,

### Best practices

- *Inventory and map transport infrastructure assets with open and inter-operable technologies.*
- *Improve institutional, financial, and contractual arrangements for infrastructure maintenance.*
- *Mobilize local communities for operations and maintenance of road assets using a gender inclusive approach.*

transport, and works, with reliable and updated information that can be used to assess maintenance needs and effectively respond to extreme events.

In Dominica, the Ministry of Public Works and Ports (MoPWP) developed a risk-based asset management system (AMS) aimed at identifying optimal investment strategies to reduce roadway risks and vulnerability to hazards and maintain its functionality performance at an acceptable level (Figure 3.9). In Saint Lucia, the Ministry of Infrastructure (MoI) introduced a smartphone application that is low-budget and easy to use for assessment of road conditions. And in Belize, an information management system was deployed to enable easy access to transport asset data that could assist in decision-making for building transport network resilience. Experiences in the three countries showed that lack of data can be overcome with the use of new, easy-to-use technology, along with asset survey methods to collect, store, and analyze data. Attention needs to be paid to cultural and procedural aspects at all government levels to facilitate the adoption of new technologies and procedures.

**Figure 3.9. Damaged Road Network in Dominica following 2017 Hurricane Irma**



Photo Credit: Yohannes Yemane Kesete.



Next, one particular project experience from Vietnam is also considered very relevant for SIDS (Case Study 9). In the country's steep, mountainous areas, where many poor ethnic minorities reside, costs of road maintenance are very high due to the challenging terrain and increasingly unpredictable, extreme rainfall associated with climate change. The poor communities in the area lack resources to cover maintenance costs, and even when funds are available, many contractors refuse to work in the mountains because of the risk of landslides during rainy seasons. To address these challenges, the innovative approach developed under the project was to engage local communities—through the Provincial Women's Union—in road maintenance activities (Figure 3.10). As described in the case study, engaging local women communities not only improved road conditions and connectivity, but also increased economic opportunities and women's social standing in the community.

The project demonstrated the importance of gender awareness and capacity building with all stakeholders (transport and local officials, social organizations, as well as community groups) for effective and inclusive local road asset management. Gender and social inclusiveness in road asset management can be delivered through a variety of instruments, such as microenterprises, small scale contractor development, and empowering of existing social organizations. The experience in Vietnam highlighted the importance of involving men as well as women in community road asset management. Working together can foster better communication between spouses and, more importantly, is critical to gaining men's as well as women's commitment to stewardship of local roads.

**Figure 3.10. Construction of Road Drainage Systems by Local Communities in Vietnam**



Photo Credit: Ngan Hong Nguyen.

Finally, in São Tomé and Príncipe, authorities are working to build resilience through hazard and transport mapping, while involving communities in road maintenance (Case Study 10). Road maintenance in the archipelago is complicated, with the country's entire road network situated along coastlines and slopes. In addition, the humid climate, with year-round rainfall, necessitates ongoing maintenance of the road network, of which only 21 is asphalted. To improve its understanding of the vulnerability of the road network, São Tomé and Príncipe is conducting an analysis that combines hazard and transport infrastructure mapping. The findings will inform the selection of segments for upgrades, as well as design standards for new construction, integrating considerations of impacts of climate change in both. As part of the solution, the country engages local communities in road maintenance to conduct low-to-medium scale road rehabilitation works. The community groups have the capacities and competencies to perform small works for coastal protection or slope stabilization, using local materials and traditional best practices.



## Contingency Programming

In SIDS, climate and disaster risks cannot be fully eliminated; despite system planning, engineering and design solutions, and sound operations and maintenance, integrating climate and disaster risk considerations in the transport infrastructure lifecycle also means planning for a quick and effective response, with protocols and financing, following a disaster event to mitigate post-disaster impacts (see best practices feature box).

By investing in proper preparedness and response protocols, World Bank operational teams have developed and embedded the so called Contingency Emergency Response Component (CERC) within disaster risk management and climate change adaptation projects in the Caribbean and the Pacific. The CERC allows for the earmarking of investment project funds to be disbursed against a disaster, following the adequate ex-ante technical preparation and logistical planning for its disbursement and use.

As described in Case Study 11, the CERC was successfully triggered in Saint Vincent and the Grenadines and Dominica, allowing a quick restoration of road connectivity following disaster events (Figure 3.11). In Dominica, Tropical Storm Erika, which passed over the island in August 2015, produced prolonged high intensity rainfall resulting in rapid flooding and estimated damages and losses of 90 percent of GDP. Damage was experienced across an estimated 24 percent of the road network with partial damage to 44 percent of the bridges. The CERC embedded in the Disaster Vulnerability Reduction Project in Dominica was triggered for US\$1 million within 6 weeks of the tropical storm to retroactively finance pre-approved post-disaster emergency works.

Importantly, CERC-financed activities commenced immediately following the event to address immediate transport needs. The government rapidly executed over 60 contracts to re-open transport access across the island; clear debris and landslide materials; and procure cement, aggregate, sand, and other materials. The application of the CERC in Dominica showed that ex-ante preparation, the availability of lists of consultants and contractors, and matrices of critical goods facilitate rapid procurement of services and ease the budgetary constraints on ministries in charge of restoring connectivity.

### Best practices

- *Invest in emergency preparedness and response to meet local and regional evacuation, response, and recovery needs and relief distribution.*
- *Pre-qualify goods and service providers to support speedy procurement processes and effective post-disaster damage assessment.*
- *Prepare financial protection strategies, including disaster reserve funds, contingency budgets, and insurance programs that apply directly to repair and replace public transport infrastructure components damaged by a climate-related disaster.*

Figure 3.11. Bailey Bridge in Saint Vincent and the Grenadines Purchased under the CERC, 2016



Photo Credit: World Bank.

In Tonga (see Case Study 12, contingency programming has been addressed through investments in emergency response systems and procurement regulations. Aware of its high exposure to natural disasters, Tonga has established provisions in its legal framework and institutional arrangements to manage disaster preparedness, response, and rehabilitation. In addition, the country has identified the need for an advanced procurement system (compatible to that of international donors) to enable a timely, efficient, and transparent acquisition and deployment of goods and services related to emergency response.

Finally, in Cabo Verde, a new type of contracting is being used as part of its contingency programming. The country is deploying performance-based contracting for its roads with contracts that provide for four years of maintenance; under the contract, the contractor ensures a permanent level of services to the road. As a result, needed small-scale emergency repairs are immediately made, while for larger emergency works the contractor can be quickly mobilized as they are already on-site and have a valid contract and unit prices agreed. Performance-based contracting reduces the duration of traffic disruptions due to landslides.

## Institutional Capacity and Coordination

Underlying the four components of the transport infrastructure lifecycle framework is institutional capacity and coordination. This component is key for successful implementation across the framework, as engagements to enhance climate resilient transport are multi-disciplinary in nature, covering topics that typically fall under the mandate of various institutions. For example, to enhance the resilience of roads vulnerable to landslides, slope maintenance and remediation may be required. In some areas, this would require strategic land acquisition to protect the road and its users, which would benefit from a procedural agreement between the land transport authority and the ministry of natural resources and environment.

In addition to institutional arrangements, it is important to look at the incentives in place for inter-agency collaboration and for the integration of climate and disaster risk consideration into transport asset management decisions. In some cases, incentive mechanisms need to be put in place, such as the creation of funds for maintenance and rehabilitation and definition of procedures and requirements to channel these funds through an effective asset management system.

Various complementary approaches can be used to initiate and strengthen inter-agency collaborations for transport resilience. Proven strategies include (a) use of inter-agency steering committees to work on climate resilient transport projects; (b) set up of inter-agency procurement panels to assess technical proposals that require a blend of multi-disciplinary skills for analysis; (c) use of memorandums of understanding between relevant ministries and agencies and amendment of legal acts that present a conflict in the roles of the various entities; and (d) support to ministries of finance and planning that are responsible for strategic development efforts to establish a systematic approach for climate and disaster resilient infrastructure. To further facilitate inter-agency collaboration, an integrated, government-wide effort to set objectives and monitor results for climate resilience can provide the required focus and incentives for implementation, leading also to more sustainable decision making on the highest levels of government as these strategies and frameworks can extend beyond political cycles.

### Best practices

- *Develop integrated government-wide objective setting and results monitoring for climate resilience to provide the required focus and incentives during implementation.*
- *Apply alternative organizational coordination mechanisms to facilitate cooperation across institutional mandates.*
- *Balance capacity building with capacity supplementation to ensure long-term sustainability of management systems.*

Several SIDS are already conducting diagnostic assessments of their legal and regulatory frameworks to identify the gaps and conflicts around agency roles and responsibilities related to strengthening transport sector resilience. In Samoa for example, following the Vulnerability Assessment and Climate Resilient Road Strategy (see Case Study 1), a draft paper has been submitted to the cabinet to officially endorse the conclusions and recommendations of the strategy and help facilitate a mainstreaming process among institutions to ensure road surveys are conducted annually and information is freely shared with Land Transit Authority (LTA) staff. Such mainstreaming is important to ensure continuity and proper use of the assessment and available data, also providing insight to LTA asset management and maintenance over time. Available information could be supplemented by condition surveys to provide an informative snapshot of the effectiveness of performance contracts and how well they are being managed.

As important as inter-agency coordination is the need for institutional capacity for developing and maintaining a climate and disaster resilient transport system. With limited government or even donor funding available and with the structural constraints and attrition issues faced by SIDS, capacity building may need to be combined with “capacity supplementation” for niche areas. For instance, the collection and analysis of bathymetric and topographic data using LIDAR to assess road network vulnerability involves a level of expertise that is difficult for a ministry or LTA to sustain, but this task can be outsourced to specialized consultants who can analyze the data and present it to the government for decision making. Even with capacity supplementation, however, training and on-the-job learning remain essential for government agencies to understand the tools at their disposal. When tools are relatively easy to use or must be used regularly by staff, capacity building should come before capacity supplementation. With adequate training, staff will be equipped and motivated to sustainably manage and maintain the tools. In Samoa, for example, the LTA has received hands-on training in the use of its road surveys tool to support management of national road assets.

## Integrated Approach across Lifecycle Components

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Disaster and climate resilience can be integrated into each separate component of the transport infrastructure lifecycle framework, with efforts in individual components together reinforcing and strengthening the overall resilience of the transport system. Good examples of an overall integrated approach are the Tuvalu Aviation Investment Project (see Case Study 13), developed in response to the impacts of Cyclone Pam in 2015, and efforts in Cartagena, Colombia, to ensure the resilience of a major port (Case Study 14).

Due to its extreme isolation—Tuvalu is located 1,100 kilometers north of Fiji and 3,000 kilometers northeast of Australia, the island can only rely on its Funafuti International Airport for timely outside support after disasters strike. Following Cyclone Pam, however, demand levels and airplane loads for emergency relief were much above the airport's handling capacity and runway design parameters (Figure 3.12). To prepare for future disasters, considering specifically increasing climate change threats, the government with the World Bank prepared the Tuvalu Aviation Investment Project as part of the larger Pacific Aviation Investment Project (PAIP).

**Figure 3.12. Offloading of a C130 in Tuvalu following Cyclone Pam in 2015**



Photo Credit: Nora Weisskopf.



In an integrated approach across all transport infrastructure lifecycle components, the project included objectives to not only revise infrastructure design specifications to enhance resilience to the impacts of climate change, but also enable more effective responses to natural disasters. This included upgrades in runway pavement strength to handle increased airplane loads; improved building standards for reinforced structures at the passenger terminal, fire station, and flight services building; and better drainage to allow the airport to more rapidly resume operations following an extreme event. The project also included a preventive maintenance system that will strengthen climate resilience and support island airports with technical assistance during emergencies. Other measures were also included, such as enhanced water storage and emergency response capacity to support post-disaster activities, as well as an upgrade of communication technology for non-disaster and disaster situations.

The overall success of PAIP relies on multi-country coordination and proper maintenance protocols to ensure service can be maintained as much as practical during extreme events or in case of developing threats. Coordination involves all countries across the network of airports in the Pacific, as well as the closest main sources of relief, Australia and New Zealand.

In Cartagena, Colombia (see Case Study 14), a climate risk assessment for the Muelles el Bosque Port was carried out to ensure reliable port operations despite future climate change related risks. Although Colombia is not a SIDS, the climate risk assessment is a useful tool that can be replicated in SIDS. Sea level rise might affect ports in various ways, such as for example by changing the depth of navigation channels (sometimes increasing, sometimes decreasing as a result of changed erosion patterns), increased flooding risks or risk of seawater surcharge in drainage pipes, lower clearance under bridges, or changes in river flows and lake levels, among others.

To better understand the risks to the port, the study used various climate scenarios to estimate potential impacts on the port's annual revenue between 2035 and 2055. The study also assessed the risk of future surface floods on goods handling and storage on the port's island site, modeling which parts of the port would likely be flooded under certain scenarios. Importantly, the study found that key climate impacts on port operations may come in parts of the port's transport chain that are outside the port company's operational or financial control, namely in the area of the supply and demand of goods. For the part of the transport chain that is within the port company's control, the most significant operational impact is related to an increased disruption of port access as a result of a higher frequency of flooding of the causeway connecting the port to the mainland. Based on the analyses and study recommendations, the port company invested US\$10 million in upgrades of the infrastructure and the causeway.

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PART I. CLIMATE AND DISASTER RESILIENT TRANSPORT IN SMALL  
ISLAND DEVELOPING STATES: A CALL FOR ACTION

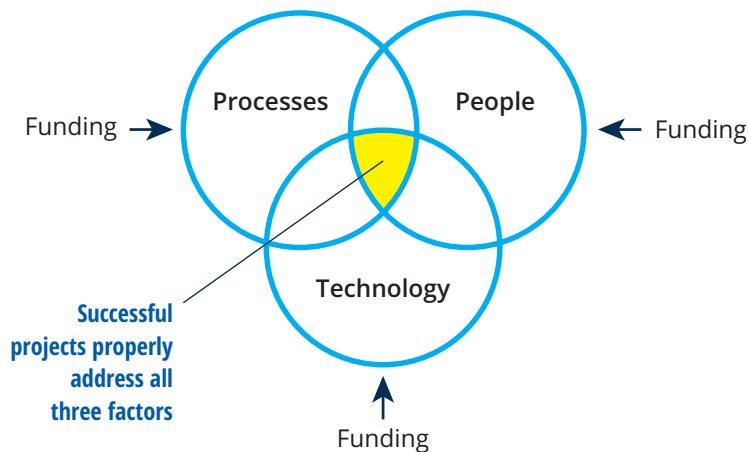
## Chapter 4. Scaling Up Resilient Transport Systems in SIDS

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As described in Chapter 3, across SIDS and in other countries, relevant experience is available on how to move toward more resilient transport within and across all components of the transport infrastructure lifecycle framework, and country governments are ready to take action. What is needed now is the right support from multiple countries and donors, to provide SIDS with the opportunity to take their next steps on a resilient transport path that fits their country, context, and population needs. Enhancing the resilience of transport systems generates many economic and social benefits, and doing so is a priority to deliver on sustainable development goals and climate nationally determined contributions of SIDS.

Chapter 4 builds on the three previous chapters to propose a program of activities that will enable SIDS to replicate and scale up best practices along the transport infrastructure lifecycle, factoring in three key elements to enable sustainability of transport asset management systems: technology, processes, and people (Figure 4.1). Experience in SIDS has shown that investments in asset management systems that do not properly consider these three elements ultimately fail (World Bank 2006). Failure, for example, can result from adopting technologies that are too complex for the local context or are under-resourced; from adopting processes that are not an integral part of how agencies make investment decisions; or from not ensuring that appropriate staff capacity and incentives are in place, leading to systems not being maintained or used for decision making and operations. Only by recognizing and addressing all three factors for success, upgraded asset management systems for SIDS can be of value and sustained in the medium and long-term.

**Figure 4.1. Factors Supporting Successful Asset Management Systems**



Source: World Bank 2006.



## 4.1 A Path Forward

Moving forward, individual SIDS will have unique requirements and needs related to the development of climate and disaster resilient road, air, inland-water, and maritime transport asset management systems. Already today, infrastructure asset management systems vary considerably among SIDS as a result of local conditions and levels of maturity (see also results of the Transport Asset Management Survey in Chapter 3).

To address these differences, while leveraging experiences among SIDS and coordinating donor involvement, a path forward is proposed to ensure the most appropriate and effective support is available to SIDS to develop climate and disaster resilient transport asset management systems. The proposed path to address people, processes, and technology elements of transport asset management systems consists of four components: (a) development of country needs assessments and transition plans for integrating resilience into decision making; (b) deployment of selected solutions to enhance resilience of the transport sector; (c) capacity building and knowledge exchange among SIDS; and (d) fundraising and reassessing capital needs.

### *Component 1: Development of Country Needs Assessments and Transition Plans for Integrating Resilience into Decision Making*

To provide a foundation for integrating climate and natural disaster resilience into decision making in SIDS, Component 1 will focus on the development of country-specific needs assessments and transition plans for transport resilience. As needed, climate and disaster vulnerability and risk assessments are also included.

Objectives for this component are to identify the capacity and constraints faced by individual SIDS and relevant transport authorities, determine what is feasible given those constraints and opportunities, and, finally, define a strategy and activities to upgrade the existing transport asset management system and define a plan to deliver resilient transport systems in the short, medium, and long terms. Both the needs assessments and transition plans should cover the five elements of the transport infrastructure lifecycle—systems planning, engineering and design, operations and maintenance, contingency planning, and institutional capacity and collaboration—and address relevant aspects related to people (capacity, incentives), processes (policy and legal framework, institutional mandates and protocols, planning and decision making procedures), and technology (tools and data).

Specific outputs of Component 1 will be:

- Characterization of the current transport asset management system, or an “As Is” scenario.
- Consensus on the desired transport asset management system, or a “To Be” scenario, which integrates climate change and disaster resilience into the decision-making process.

- Transition plan, to be defined in close consultation with government agencies and stakeholders, for integrating climate and disaster risk considerations into the decision-making process in a properly institutionalized and sustainable manner, addressing also capacity building needed to sustain the effort.

### ***Component 2: Deployment of Solutions to Enhance Resilience of Transport Sector***

Following the definition of specific needs and the development of a transport resiliency transition plan, Component 2 focuses on the actual implementation by SIDS of policies and measures to enhance resilience of the transport sector and upgrade their asset management systems following the strategy designed under Component 1.

Measures can relate to one or more components of the transport infrastructure lifecycle framework and involve for example systems planning, improvements to design standards and construction specifications, use of new construction materials, improvements in disaster preparedness, and upgrades to the disaster response. The existing experiences described in Chapter 3 and case studies in Part II of this report all demonstrate appropriate interventions that can be adapted to address specific needs. Importantly, any measures must include indigenous knowledge and consider local social and cultural values (Box 4.1).

#### **Box 4.1. Resilient Solutions through the Social and Cultural Lens**

Natural disasters are not new concepts for SIDS countries, and indigenous knowledge must be harnessed as part of the introduction of resilient solutions. It is not uncommon, for example, to see traditionally constructed buildings surviving storms that destroyed modern structures.

In the same way, the asset management system used to prioritize investments needs to consider local social and cultural values. These have been found in cases to significantly alter investment priorities—for example by limiting options for accessing land.

Under Component 2, specific attention will be paid to systems planning and the development of transport asset management systems to integrate climate and disaster risk considerations into decision making across the life-cycle of transport infrastructure (Box 4.2). Specifically, following from the needs assessment and transition plans, activities will work to improve decision makers' access to reliable information on existing assets and combine it with information about their vulnerability to natural disaster and climate change impacts to improve asset management and prioritize investments. As described in Chapter 3 and the case studies, several geospatial platforms have been developed and piloted in SIDS that would allow upgrading of asset management systems to fulfill these functions. Risk data and information generated in other initiatives such as CCRIF in the Caribbean and PCRAFI in the Pacific can be used to estimate incurred losses and evaluate the efficiency of solutions to improve planning of resilient investments.

#### Box 4.2. Questions Addressed by Transport Asset Management Systems

Transport Asset Management Systems address several questions along the transport infrastructure lifecycle:

- **Systems planning:** Where should new transport links be built? What is the value of redundancy?
- **Engineering & design:** What types of new materials and construction standards should be considered to increase resilience?
- **Operations & maintenance:** How to most effectively support risk based operation and maintenance spending, using GIS and other technological solutions combined with a financial understanding of contingent liability and lifecycle costs?
- **Contingency programming:** What measures can limit social and economic losses from natural disasters and climate change impacts?
- **Institutional capacity and coordination:** How can the legal and policy frameworks be strengthened to enable deployment of resilient transport? How can institutional capacity be enhanced to operate asset management systems in a sustainable manner?

To improve disaster preparedness and disaster response, other measures are available. As part of Component 2, SIDS could improve the effectiveness of contracting by using new contracting modalities such as performance based contracts or framework contracts for post-disaster responses. SIDS may also identify a need for early-warning systems, institutional and communication protocols, and financial mechanisms for support during disaster response (see also Case Study 11 on CERC in the Caribbean and Pacific).

Output of Component 2 would be the implementation of specific policies and measures, as appropriate for the country, including the upgrading of existing or installation of new transport asset management systems to enable agencies to prioritize investments in the most critical and appropriate locations given budget constraints.

### ***Component 3: Capacity Building and Knowledge Exchange***

To sustain development and improvements under Components 1 and 2, the third component focuses on building the necessary capacity and knowledge exchange among and within SIDS, as the introduction of a resilient transport system also requires a commitment to having in place people with the required skills, motivation, and incentives. An overall strategy for capacity building and knowledge exchange, which would be informed also by the outcomes of assessments in Component 1, could include:

- ***Organizational development and local capacity building.*** The work of transport and other agencies could be supported through an assessment of training needs and delivery of structured training programs to address skill gaps.
- ***Regional trainings and workshops.*** On a regional level, trainings can take place on a regular basis for participating countries that are engaged in transport resilience to encourage peer to peer learning and support the exchange of technical solutions.
- ***Knowledge platform.*** Finally, a broader knowledge platform will support the sharing of best practices, technical publications, and other knowledge materials relevant to scaling up resilient transport in SIDS, providing access to knowledge shared by SIDS, including indigenous knowledge, and resources from across the donor community.

### ***Component 4: Fundraising and Reassessing Capital Needs***

Financial assistance on climate and disaster preparedness is presently available to SIDS (and other countries) through the Global Facility for Disaster Reduction and Recovery (GFDRR), managed by the World Bank. GFDRR provides risk finance and risk transfer facilities that support overall government budget. To mention a few of these initiatives, the Catastrophe Deferred Drawdown Option (Cat-DDO) provides countries with a pre-approved credit line that can be accessed when a national emergency is declared following a natural disaster, provided that the country commits to developing an integrated Disaster Risk Management Strategy. The Contingent Emergency Response Component (CERC) allows for rapid reallocation of uncommitted funds in an investment project financing toward urgent needs in the event of a crisis or emergency to finance physical, economic, and social recovery. The Caribbean Catastrophe Risk Insurance Facility (CCRIF) and the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) offer hurricane and earthquake coverage to participating governments in the Caribbean and Central American region and to the Pacific region respectively.

To complement this, GFDRR makes available technical assistance grants to integrate climate and disaster risk considerations along the transport asset lifecycle. To strengthen and complement these efforts additional financial resources could be made available. While it is too early in the program to consider specific financial instruments and solutions, two potential areas of exploration are as follows:

- 1. *SIDS Transport Resilience Funds.*** Transport Resilience Funds could be established within the ministries of finance of participating countries. Financial resources could be put into the fund on an annual basis, with the amount based on the level of climate and disaster losses a government elects to avoid through physical investment. A rules based approach, as defined by the Fund, would govern the prioritization and execution of works. Transport Resilience Funds could be supported by donors to catalyze high returning investments.
- 2. *Transport Asset Management Endowments for SIDS.*** The most ambitious approach to financing improved transport asset management would be for donors to capitalize an endowment that would finance physical investments on an annual basis. These resources could either provide support through the Transport Resilience Fund or sectoral level support, as described above. The benefit to such an approach would be that the annual expenditure would be financed by the investment returns from the endowment, which would enable financial support to be delivered at a meaningful level into perpetuity. Such an endowment would require a significant upfront transfer from donors to a facility, but future donor investment would no longer be necessary.

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PART II. CASE STUDIES

# Resilient Transport Innovations in Small Island Developing States

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## Overview

In recent years, a wide range of measures has been implemented across SIDS to enhance their transport resilience. Table C.1 below provides an overview of best practice case studies in this area, which have been implemented with the support of the World Bank Group and cover interventions across the transport infrastructure lifecycle framework. While the presented case studies have been developed in response to specific situations and government requests, the general concepts behind them are ready to be replicated across SIDS once tailored to the specific country context.

**Table C.1. Overview of Case Studies on Resilient Transport Innovations in SIDS**

Systems Planning	Engineering & Design	Operations & Maintenance	Contingency Programming
<p><b>Case Study 1 / Samoa:</b> Enhanced Systems Planning to Better Prepare for and Respond to Natural Disasters and Climate Change Impacts</p>	<p><b>Case Study 3 / Kiribati &amp; Tuvalu:</b> Climate and Disaster Resilient Roads Using Geocell Concrete Pavements</p>	<p><b>Case Study 6 / Dominica:</b> Development of a Risk-based Infrastructure Asset Management System</p>	<p><b>Case Study 11 / Caribbean:</b> Using the CERC in Limited Capacity Environments to Reduce Road Network Interruptions following a Disaster</p>
<p><b>Case Study 2 / Mozambique:</b> Prioritization of Road Interventions under Flood Risks and Uncertainty</p>	<p><b>Case Study 4 / Coral atolls of the Pacific Islands:</b> Local Materials for Climate Resilient Coastal Protection</p>	<p><b>Case Study 7 / Saint Lucia:</b> Using Smartphone Apps to Increase Resilience of Road System</p>	<p><b>Case Study 12 / Tonga:</b> Emergency Response System and Procurement Regulations</p>
	<p><b>Case Study 5 / Sri Lanka:</b> Geosynthetic Reinforced Soils for Rapid and Low Cost Bridges</p>	<p><b>Case Study 8 / Belize:</b> Information Management Systems for Enhanced Resilience of Transport Assets</p>	
		<p><b>Case Study 9 / Vietnam:</b> Empowering Women to Manage Rural Road Maintenance: Lessons from Vietnam</p>	
		<p><b>Case Study 10 / São Tomé and Príncipe:</b> Building Resilience Through Communities Involvement in Road Maintenance</p>	
			<p><b>Case Study 13 / Tuvalu:</b> Climate and Natural Disaster Resilient Airport</p>
			<p><b>Case Study 14 / Colombia:</b> Climate Risk Assessment for Muelles el Bosque Port</p>

# Systems Planning: Case Studies in Samoa and Mozambique

## Case Study 1. Enhanced Systems Planning to Better Prepare for and Respond to Natural Disasters and Climate Change Impacts

**Location:** Samoa

**Author:** Sean Michaels




**Photo Credit:** Sean Michaels

### CHALLENGE

Samoa's population and infrastructure is vulnerable to the impacts of natural disasters and climate change (Figure C.1). Approximately 70 percent of the people live within one kilometer of the coast, and most hospitals, schools, port facilities, power plants, airports and roads are in the coastal zone. Consequently, tropical cyclones and earthquake-generated tsunamis have caused severe damage to infrastructure and other economic assets with significant adverse effects on livelihoods.

**Figure C.1. Samoa's Vulnerable West Coast Road**



**70%**   
live within one  
km of the coast

Most infrastructure  
located within one  
kilometer of the coast

It is estimated that Cyclone Ofa (1990) and Cyclone Val (1991) caused combined damage to assets and production valued at 2.5 to 3 times Samoa's annual gross domestic product (GDP). The 2009 tsunami had a devastating impact on the southern shores of both Upolu and Savai'i, leading to 143 reported deaths and an estimated 5,274 people made homeless. In terms of infrastructure, the greatest costs were found in the transport sector where the coastal road and accompanying sea walls were severely damaged. More recently, Tropical Cyclone Evan (2012) caused severe flooding in Upolu, killing at least 5 people, displacing 7,500 people, and damaging more than 2,000 houses. Total losses were estimated at US\$210 million, or about 30 percent of GDP.



Following each of these events, primary roads and bridges were badly damaged or left irreparable, impeding access to basic infrastructure and services. Responses to such disasters have historically been swift with strong support from the donor community; however, systematic planning to prepare the road network for disasters and climate change has only gained significant traction within the past several years.

## SOLUTION

In response to the challenge posed by natural disasters and the impacts of climate change, Samoa has made a strong push for greater systems planning to reduce vulnerability. With the recent adoption of sectoral and spatial planning tools, road network redundancy investments for critical infrastructure like roads and bridges, the construction of pedestrian evacuation routes, and policy and planning activities that address disaster and climate risks, Samoa is forging a coherent and multi-pronged approach to systems planning.

Under the Samoa Post Tsunami Reconstruction Project (PTRP), a World Bank emergency operation designed to assist the government in its efforts to relocate and rehabilitate affected communities living in the island of Upolu, a new project was deployed to support the construction of the East Coast Inland Route and the upgrading of the Lepa-Lalomanu Route. Both routes provide all-weather alternatives to the coastal roads. The redundancy investments in strategically located roads were a key factor in enabling the relocation and evacuation of previously at-risk communities. The roads also contribute to increasing the climate resilience of the communities they serve, as they are constructed away from higher-risk coastal areas. Communities are also now safer due to the construction of pedestrian access routes that serve as evacuation routes in the event of extreme weather events.

Within the framework of the Pilot Program for Climate Resilience (PPCR), also deployed in Samoa by the World Bank, the Project Enhancing the Climate Resilience of the West Coast Road recently completed a Vulnerability Assessment (VA) and a Climate Resilient Road Strategy (CRRS) (Vulnerability Assessment of the Samoa Road Network Final Report). The work provides Samoa with a comprehensive assessment of its road network, identifying areas that are vulnerable to severe weather events and the impacts of climate change, while analyzing current practices in network development, maintenance, and asset management (Figure C.2 and Figure C.3). Based on the analysis, the climate resilient road strategy:

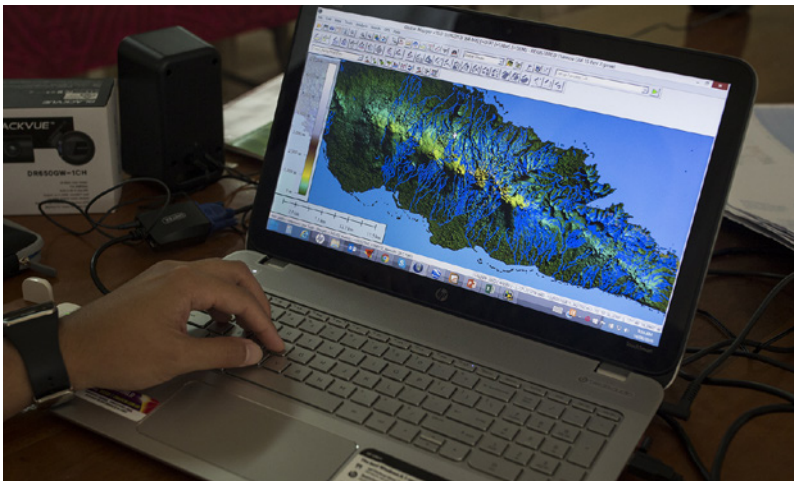
- a. Outlines a general climate change adaptation policy framework and objectives for the national road network.
- b. Identifies and prioritizes specific locations that require investments to improve the resilience of the national road network with decisions not just based on the vulnerability of network assets, but also incorporating economic and social analyses; this includes short and medium-term climate resilient investments (for example raising low-lying coastal roads, installing drainage, stabilizing slopes, and strengthening coastal protection) as well as long-term investments such as building new or enhancing alternate roads for redundancy purposes.

- c. Determines specific measures to update design and planning standards as well as maintenance procedures considering expected climate change.
- d. Prepares tools to assess the vulnerability of road assets to climate events, including methodologies for determining the adequacy of existing roads to resist climate impacts.
- e. Reviews the institutional and legal framework and recommends specific reforms to facilitate climate change resilience in the road sector from infrastructure and operational perspectives.

**Figure C.2. Consultations on the use of Road Network Vulnerability Assessment Tools**



**Figure C.3. Systems Planning Under the Vulnerability assessment and Climate Resilient Road Strategy in Samoa**



Because of this engagement, Samoa now has an investment and maintenance strategy to enhance the climate resilience of its road network, as well as new methodologies, techniques and software, and the institutional capacity to more effectively plan and manage the road network. These outputs were approved by Samoa's Cabinet Development Committee in August 2017, setting a milestone of transformative change in the way that climate change is addressed in Samoa's transport sector.

Additionally, through the Enhanced Road Access Project, the government is in the process of preparing national design standards for maintaining and constructing more climate resilient roads and bridges that are better able to withstand expected increases in the frequency and intensity of extreme climatic events. The technical assistance aims to capture best-practice standards used by other countries in the Pacific and will take on board relevant recommendations stemming from Samoa's VA and CRRS and other relevant documents. The adoption of such standards will increase the sustainability of Samoa's roads and bridges and help limit the need for recovery efforts.

It is important to note that an area within the network that is considered less vulnerable today, may be among the most vulnerable years, months, or possibly even days from now, should its infrastructure and population be compromised by natural disasters or severe weather events. Therefore, systems planning needs to be treated as a dynamic process, which means tools such as Samoa's VA and CRRS need to be updated routinely to provide policymakers with the best available information for informed investment and policy decisions. Similarly, climate resilient roads and bridges need to be reassessed systematically to ensure they reflect the most effective and fit-for-purpose design standards readily available. Recurrent anticipatory action will not allow countries to completely evade the effects of natural disasters and the impacts of climate change, but it goes some way to limit the need for recovery efforts and thus is worth pursuing.

## Case Study 2. Prioritization of Road Interventions based on Economic Development Potential and Flood Risk

**Location:** Mozambique

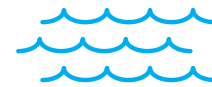


**Authors:** Julie Rozenberg, Xavier Espinet, and Satoshi Ogita

**Photo Credit:** Xavier Espinet

### CHALLENGE

The Zambezia and Nampula provinces of Mozambique have high incidence of poverty, with the great majority of the population practicing subsistence farming. Investments in the transport sector have the potential to improve access to markets and in this way increase farmers' revenues, reduce poverty, and provide a significant contribution to the national economy. The country, however, is also highly exposed to flooding hazards associated with river overflow and storm surges. In Zambezia and Nampula the road network has low redundancy, resulting in disruptions that isolate communities for extended periods of time. The Road Authority of Mozambique wants to prioritize road investments to maximize the connectivity of farmers to markets and enhance the reliability of the transport network under extreme weather conditions.



**Road network is highly exposed to flooding, which creates extended isolation for communities**

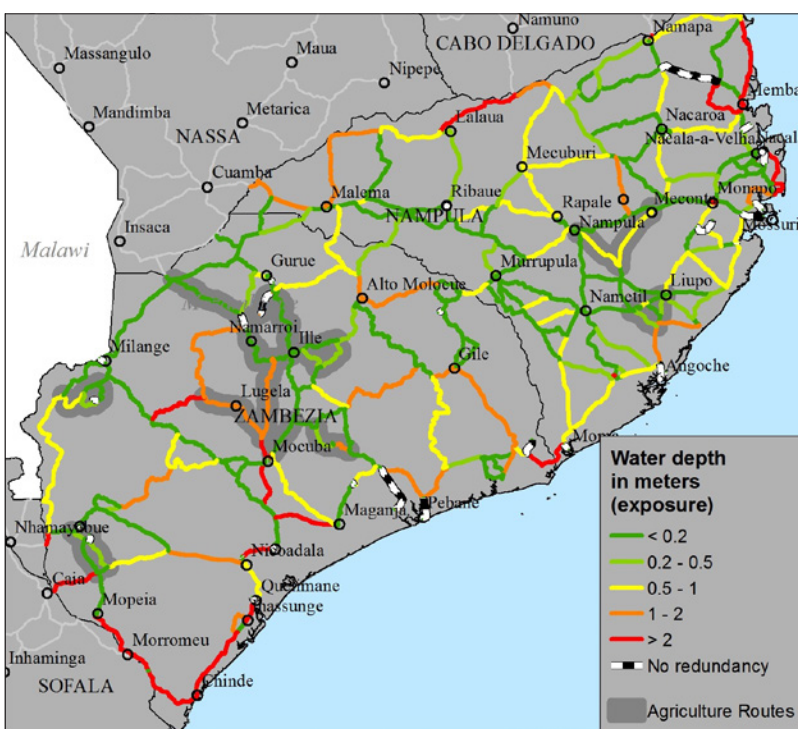
### SOLUTION

The World Bank provided technical assistance to the Road Authority of Mozambique, using a network and intervention prioritization approach, to identify critical and vulnerable roads in the Provinces of Zambezia and Nampula, as well as identify and prioritize interventions to enhance reliability of the road network for rural communities.



**Step 2: Assessing the exposure of the transport network to floods.** Modeling was done to produce water depth maps for four different climate scenarios (present and future) and changes in land use conditions. The analysis considered 10 different flood recurrence intervals (from 5 to 1000 years). Flood maps, for present time and future climate scenarios, were overlaid with the transport infrastructure network to identify vulnerable infrastructure. Vulnerability is expressed as the cost of repairing and rebuilding bridges, culverts, and road surface when a flood occurs. (Figure C.5.)

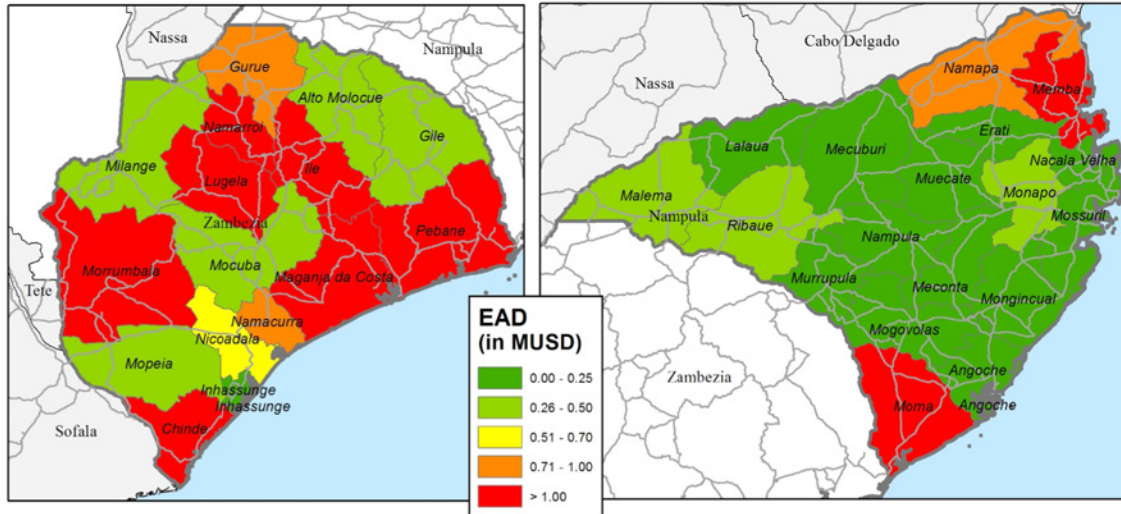
**Figure C.5. Exposure Map for Nampula and Zambezia Road Network Based on Maximum Water Depth**



**Step 3: Calculating the vulnerability and hazard risk.** This risk, expressed in terms of expected annual damage to infrastructure, was calculated for each district in the two provinces. In Nampula, the most vulnerable districts were identified as Moma, Mema, and Namapa, while in Zambezia they included Ile, Maganja, and Pebane (Figure C.6).



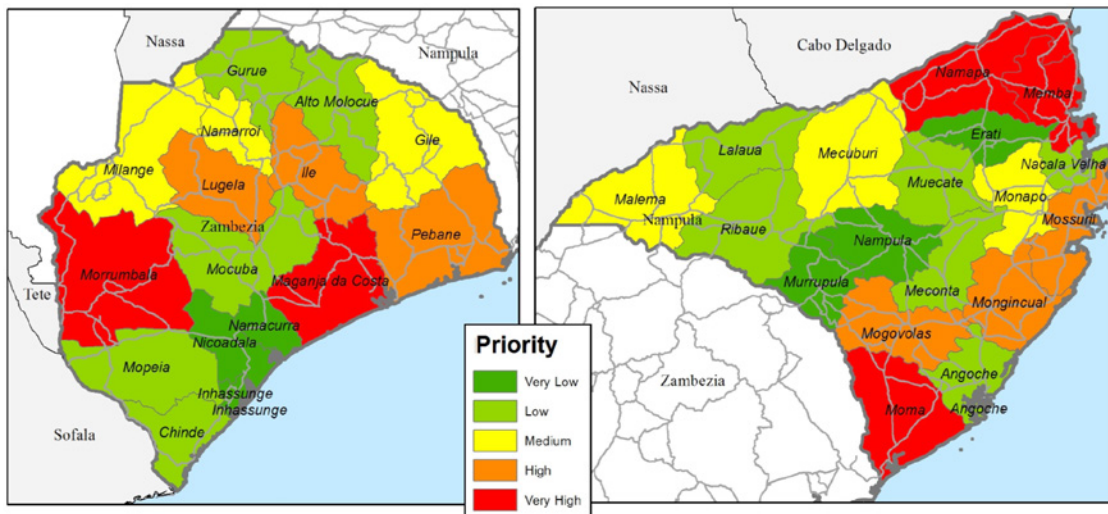
**Figure C.6. District Risk Expressed as Expected Annual Damage (EAD) to Infrastructure under Current Climate Conditions**



Note: Primary roads not included. Results are shown for Zambezia (left) and Nampula (right).

**Step 4: Prioritizing districts for intervention.** Using a prioritization matrix that combines criticality and hazard risk, districts with both high criticality and high risk can be identified and prioritized for investment. As shown in figure Figure C.7, top priority districts in Zambezia are Morrumbala, Lugela, and Maganja, while those in Nampula are Moma, Memba, and Namapa.

**Figure C.7. District Investment Prioritization Maps for Zambezia and Nampula**



Note: District prioritization is shown for Zambezia (left) and Nampula (right).

## Identification and Prioritization of Road Interventions

Following the identification of priority districts, the next step was identifying road interventions in the high priority districts. Five different investment options were identified in each of the selected high priority districts, based on discussions with local stakeholders during two workshops held in Quelimane and Nampula. Each investment was a potential combination of five engineering solutions: (a) upgrading to surface treatment, (b) upgrading to gravel road, (c) rehabilitating earth roads, (d) cleaning and repairing bridges, and (e) replacing culverts.

The final step of the study was the economic evaluation of those interventions including direct and indirect risk-reduction benefits. The economic evaluation included four kind of economic benefits: (a) reduction of flood risk for the users, (b) reduction of flood risk for the road agency (lower repair and construction costs after flood events), (c) reduction of road user costs due to improvement of road conditions, and (d) reduction of maintenance expenditure due to improvement of road conditions. Additionally, the economic evaluation was calculated for 2000 scenarios, to capture the uncertainties that may affect the performance of each investment through changes in eight different factors: (a) climate projections, (b) flood duration, (c) traffic growth in the absence of interventions, (d) elasticity of traffic growth that results from agriculture increase, (e) discount rate, (f) repair time, (g) construction cost, and (h) bridge repair cost.

The results suggested that given the limited budget per district (approximately US\$15 million) a cleaning and repair of bridges together with an upgrading of the culverts would be the most robust intervention in almost every district. The cleaning and repairing of bridges and upgrading of culverts had a lower capital cost and returned a high benefit, mostly in term of avoided damage to the infrastructure due to flood events. The other types of investment—paving, gravelling, or rehabilitating—had higher capital costs, and with a budget of US\$15 million, very few kilometers of road could be upgraded. In addition, the low traffic volumes in these provinces made it hard to justify these latter interventions.



# Engineering and Design: Case Studies in Kiribati and Tuvalu, Coral Atolls, and Sri Lanka

## Case Study 3. Climate and Disaster Resilient Roads Using Geocell Concrete Pavements

**Location:** Kiribati and Tuvalu

**Author:** Oliver Whalley



**Photo Credit:** Oliver Whalley

### CHALLENGE

Climate change is leading to major changes in the intensity and duration of rainfall in many countries. These changes are creating the need to construct more resilient roads than the traditional unsealed or surface dressed pavements, which are susceptible to weather damage and require ongoing maintenance. For small island states, it is also important to have technologies that can be readily implemented without importing substantial equipment.



**Intensity and duration of rainfall affect road surface conditions**

### SOLUTION

Cement concrete geocell pavements were introduced to Kiribati and Tuvalu to provide climate and disaster resilient low-volume roads.

Geocell pavements consist of an interlocking set of unreinforced concrete blocks formed by pouring cement concrete into a thin plastic lattice (Figure C.8). The resulting composite structure serves as a flexible but imperme-

**Figure C.8. Geocell Formwork Ready for Placement of Concrete**



able pavement surface. Ranging from 75 to 150 mm thick, and 150 mm to 300 mm square, the cells are shaped by a high-density polyethylene (HDPE) sacrificial formwork that remains in the final pavement. This plastic mold forms concrete blocks into an interlocking shape, which allows mechanical transfer of load from one block to those surrounding it, thus providing an enhanced ability to resist loads.

Geocells differ from conventional block paving in their mechanical keying that occurs as a result of the distorted face of the cells. Protrusions in one block lock into cavities in adjacent blocks, creating a joint that is better able to transfer loads. This interlocking effect means that geocell pavements are effective in spreading load and can do without the aggregate base course and subbase layers of traditional pavements, relying instead on load transfer between blocks. Doing away with these layers reduces the need for materials and reduces costs.

Geocells also have the advantage that they can be constructed in very constrained alignments—including curves—where large paving equipment would have difficulty operating. They also work well in densely populated urban areas that prohibit street closures and can be constructed very quickly compared to other pavements.

The construction of a geocell pavement is also more simple than that of a bituminous pavement and can be done using either labor or equipment based methods in five steps:

- a. The subgrade is leveled and shaped to achieve the necessary crossfall. It is then compacted, using either small rollers or hand operated plate compactors.
- b. Edges are excavated and a wooden edge beam formwork is installed. The beams provide horizontal restraint to the geocells and prevent water ingress.
- c. The HDPE geocell formwork is anchored in place, tensioned with steel reinforcing pegs, and then expanded to its full width and the length of the road section.
- d. Once the formwork is expanded and tensioned, high-slump concrete is mixed, poured, and spread into the cells before broom finishing and curing. The modular nature of the geocells means it can be constructed using small mixers or, for large areas, with concrete agitator trucks if available.
- e. After curing of concrete, the edge beam formwork is removed and pavement edges are backfilled. The pavement can be used within about a week when the concrete reaches a strength of 15 megapascal (MPa), while for durability the mix design would have a strength of 30 MPa.

In Tuvalu—a country with severe fresh water limitations—the concrete was modified with an additive so that salt water could be used instead of fresh water. Without steel reinforcing in the concrete, the performance with salt water should be similar to fresh water.

Geocell pavements are ideally suited to remote islands because they can be constructed using labor with portable equipment, and the HPDE formwork is light and easy to transport. As the cost of construction depends on the availability of aggregate, no hard and fast rule exists to determine costs. However, its ease of construction, climate and disaster resilience, and long-term performance make it an effective option for constructing resilient low-volume roads in small island states (Figure C.9).

**Figure C.9. Feeder Road on South Tarawa, Kiribati Before and After Construction of Geocell Pavements**



## Case Study 4. Local Materials for Climate Resilient Coastal Protection

**Location:**  
Coral atolls of the Pacific Islands

**Author:** Oliver Whalley

**Photo Credit:** Oliver Whalley

### CHALLENGE

Climate change is leading to rising sea levels and an increased intensity of tropical cyclones in many countries. This threat is especially real for small island states, where climatic changes are creating a need to construct more resilient coastal protection structures that can resist erosive forces and protect precious land and life sustaining infrastructure. Often, however, locally available material to construct coastal protection is limited, and use of materials of opportunity is widespread, with these ad hoc structures having short design lives and sometimes even exacerbating the impacts of erosion. For small island states, it is also important to have technologies that can be readily implemented without importing material.



Increased intensity  
of tropical cyclones

Coastal erosion  
caused by rising  
sea level

### SOLUTION

To address these challenges in the Pacific, three alternative solutions—rock revetment, geosynthetic container (GSC) revetment, and concrete masonry block (CMB) revetment—have been used. Each approach has its own advantages and disadvantages.

#### Rock Revetment

These conventional rock armor structures have been widely used throughout the Pacific. The structure is formed using a geotextile filter fabric placed on a formed slope, overlaid by a cushioning layer of small rock and finally a layer of large rock armor. The high porosity created by the voids between the rocks provides, together with the slope, effective energy dissipation. This structure is well suited to be adapted to future climatic change, for example with an additional rock layer placed on top or with crests raised to prevent overtopping.

The rock revetment solution was used at a critical site in South Tarawa, Kiribati (Figure C.10). Its construction, however, came at a very high cost as no rock of sufficient size and density was available locally. To build the revetment, rock armor had to be transported from Fiji, 2000 kilometers away by



ocean barge, at a constructed cost of approximately US\$8,000 per lineal meter for a moderate wave energy site close to a primary international port. While a rock revetment is often the best technical solution (featuring a long 50-year design life and good energy dissipation), construction may often not be feasible because of the high cost, highlighting the challenge of providing coastal protection on coral atolls where dense volcanic aggregate isn't available.

**Figure C.10. Rock Revetment in Temaiku, South Tarawa**



### **Geosynthetic Container (GSC) Revetment**

A solution that does make use of local materials is the use of geotextile containers (GSCs, Figure C.11). Commonly known as 'geobags', they typically consist of a geotextile pillow filled with sand. A key advantage of GSCs is that they can be shipped empty and filled with local sand on site, thus forming an economic solution in remote locations such as outer islands where transport costs are high. While small containers can be filled and placed by hand, large ones up to 2.5 cubic meters are more effective in high energy locations. One disadvantage is that these large containers require slurry pumps, filling frames, and large excavators to fill and place. A GSC revetment costs approximately US\$1,600 per lineal meter at a moderate wave energy site close to an international port.

With a design life of up to 20 years and extensive design guidance available, this approach can make effective use of locally available sand. As a flexible blanket, rather than a rigid structure, GSCs can move in large wave events, but can typically be repositioned if equipment is available. Given GSC bags consist of heavy duty fabric, they are exposed to vandalism and debris damage, although they can be patched with hand equipment.

**Figure C.11. Geosynthetic Container Revetment**



Source: [Elcorock.com](http://Elcorock.com).

An important consideration with this approach is the need for a sustainable local source of sand, as removal from a beach can exacerbate erosion. To address this concern, sustainable sources of aggregate have been developed in Tuvalu and Kiribati, with scoping conducted in the Marshall Islands.

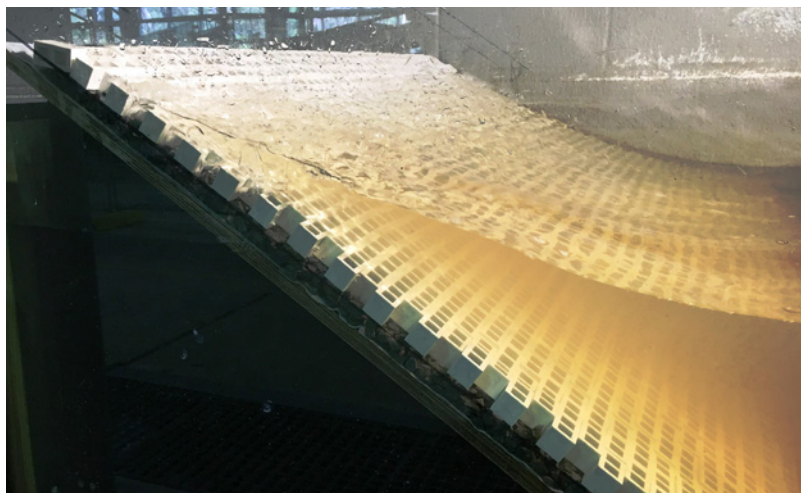
### **Concrete Masonry Block (CMB) Revetment**

One promising alternative—proven in physical modeling and set for piloting in the Pacific Islands—is the use of concrete masonry block (CMB) revetments. CMBs or “besser blocks” are a ubiquitous building material throughout the region. CMBs are frequently manufactured locally with coral sand, gravel, and imported cement, and are widely available with established supply chains. They can also be placed without heavy construction equipment, typically by hand. Cost is only US\$520 per lineal meter at a low wave energy site close to an international port.

When laid in an interlocking pattern on a revetment slope, CMBs prove to be very stable in low wave energy environments. Options to adapt to climate changes are, however, limited, with the raising of crest the only option. Other disadvantages include the small size of units, which limits their stability and design life up to an expected maximum of 10 years depending on concrete quality.

Recent engineering research funded by the Pacific Regional Infrastructure Facility (PRIF) has developed design guidance for this approach, with the structures observed to perform beyond expectations in physical model trials (Figure C.12). Low-cost CMBs can be used to form a blanket type structure to cover the face of a revetment, similar to conventional materials such as Seabees. This approach would provide an efficient coastal protection solution that makes good use of local materials.

**Figure C.12. Model of Concrete Masonry Block Revetment Tested to Failure**





## Case Study 5. Geosynthetic Reinforced Soils for Rapid and Low Cost Brides

**Location:** Sri Lanka

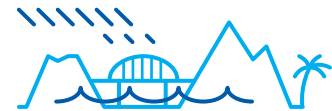
**Author:** Oliver Whalley



**Photo Credit:** Oliver Whalley

### CHALLENGE

Climate change is leading to increased intensity of rainfall in many countries. This threat is significant for Sri Lanka, where more rain means rivers must carry higher volumes of runoff from the island's mountainous terrain to the sea. Sri Lanka's bridges serve as critical links in the transport network, taking road and rail traffic across rivers, but this aging infrastructure is typically in poor condition, with 50 percent of the country's bridges suffering from significant deterioration that is making them particularly vulnerable to high flood flows (Figure C.13). Overtopping can damage or destroy a bridge, limiting connectivity while detours are put in place or repairs and replacements are constructed. Traditional piled foundations for bridge abutments are slow and costly to construct, meaning it can be months before connectivity is restored. With limited budgets, the extent of what can be achieved is restricted.



**50% of the country's bridges suffering from significant deterioration**

**Figure C.13. Typical Damage to a Bridge Abutment caused by Flood Flow in Sri Lanka**



Source: [Elcorock.com](http://Elcorock.com).

## SOLUTION

**Geosynthetic Reinforced Soil (GRS) technology.** To address these challenges, a World Bank funded study looked at applying innovative GRS technology to the bridges of Sri Lanka. The study produced promising results, finding that locally sourced material could be used in conjunction with GRS to construct bridges faster and at a lower cost than traditional piled abutments.

At each end of a bridge is a structure that supports the weight of the deck. Known as abutments, these are often the first part of a bridge to fail. Blockage of the main water channel by debris can cause water to seek out the path of least resistance around the sides of the bridge, thus placing the abutments at risk.

Traditional bridge construction requires the installation of piles for the abutment foundations—a lengthy and expensive process that involves specialist materials, skills and equipment.

Geosynthetic Reinforced Soil (GRS) abutments offer a promising alternative. They allow for rapid and resilient construction of bridge abutments using locally available materials, without specialized equipment. With GRS, bridges can be constructed in as little as five days and at a cost 30-50 percent below the cost of traditional approaches used in Sri Lanka.

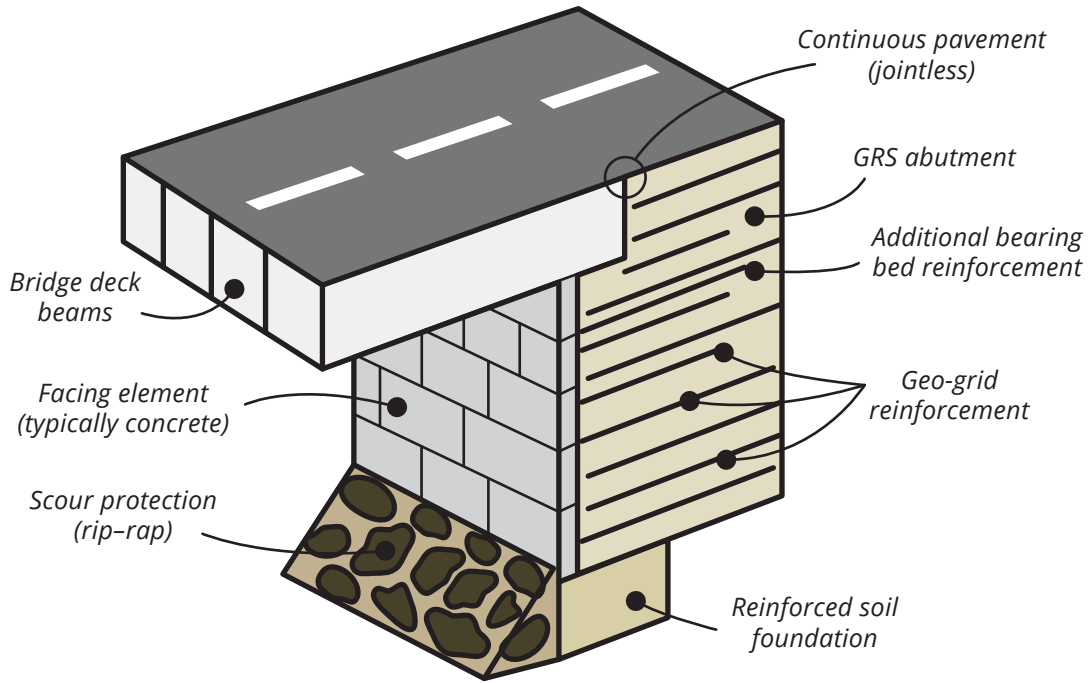
GRS abutments are based on “geogrids,” a plastic mesh made of high-density polyethylene (Figure C.14). Layers of soil and geogrid are combined to create a solid foundation for the bridge deck. Construction can be completed with basic earthmoving and compaction equipment, and a range of local fill materials can be used with guidance from geotechnical specialists. When laid between layers of carefully compacted soil, a geogrid reinforcing system improves the properties of local soil to allow it to withstand the load of a bridge deck (Figure C.15).

**Figure C.14. Typical Geogrid for Use in Bridge Construction**



Source: Tensar, n.d.

Figure C.15. Schematic of a GRS Abutment for Bridges



With this approach, abutments can be constructed quickly, at a significantly lower cost and also with no pavement joint to maintain. An added bonus is that this approach has a higher level of seismic resilience should the ground shake in an earthquake. Like with any abutment, protection from erosion by water (known as scour) is of critical importance, but with well-designed scour protection (such as rock boulder armor known as rip-rap), a GRS abutment will be just as resistant to this type of failure as a piled bridge.

In the Sri Lankan context where poor bridge condition is common, the study found that local crushed aggregate was ideal for GRS abutment fill, being low risk, low cost, and readily available. Concept designs were produced for a sample of four bridges, with a conclusion that the GRS approach could result in savings of 30 to 50 percent, not to mention a shorter construction time and added resilience.

While the promise of this technology has been clearly demonstrated in Sri Lanka, many other locations could put GRS to good use and enjoy similar benefits. Given that bridges are critical links in the land transport network, GRS can bring a resilient and efficient solution to protecting and restoring connectivity. GRS abutments are an example of a low-cost, high-impact technology that shows how engineering innovation can go a long way toward protecting and restoring infrastructure against the devastating effects of a changing climate.

# Operations and Maintenance: Case Studies in Dominica, St. Lucia, Belize, Vietnam, and São Tomé and Príncipe

## Case Study 6. Development of a Risk-based Infrastructure Asset Management System for Dominica

**Location:** Dominica



**Authors:**

Mohammad Dehghani and  
Yohannes Yemane Kesete

**Photo Credit:** Mohammad Dehghani and  
Heinrich Bofinger

### CHALLENGE

Dominica's roadway network is prone to flood and landslide hazards (Figure C.16). After Tropical Storm Erika in 2015, around 60 percent of the roads in the country were inaccessible. The storm resulted in a major setback to the government's ambitious rehabilitation program, and it took several weeks to several months for the roadway system to recover. A Rapid Damage and Impact Assessment that was carried out after the storm led to a recommendation for the government

to use a risk-based asset management system to keep track of reconstruction, continuously assess infrastructure condition, perform a comprehensive and detailed vulnerability assessment of the road network to natural disasters, and prepare a multiyear investment and mitigation action plan.

**Figure C.16. Damaged Road Network in Dominica**



## SOLUTION

A project was implemented to develop a sustainable risk-based asset management system (AMS) for the Dominica Ministry of Public Works and Ports (MoPWP)'s roadway infrastructure. The AMS identifies optimal investment strategies to reduce the roadway's risk and vulnerability to hazards and maintain its functionality performance at an acceptable level.

### Problem Dimension and Complexity

The majority of Dominica's roadway infrastructure is built on steep topography, making it vulnerable to landslides. Moreover, the country has 365 rivers, which has necessitated the construction of many culverts and bridges that have increasingly become vulnerable to flood risks. As a small island, construction costs in Dominica are high, and the upkeep of infrastructure assets puts significant strain on government budgets. Slope stabilization, dredging, and other necessary resilience measures are critical for the continuous operation of the roadway, but further add to the financial strain. Finally, given the country's lack of road network redundancy, most roads must perform acceptably during natural disasters and should, at a minimum, be accessible to first responders. Figure C.17 depicts the dimensions and complexity of the situation.

**Figure C.17. Dimensions and Complexity of Road Maintenance in Dominica**



## Project Merits

Under the project, a methodology was developed that provides practical and operational steps to calculate criticality, risk, vulnerability, and other performance measures for Dominica’s roadway infrastructure. The methodology clearly explains how data should be processed to calculate the risk and vulnerability measures and how these measures are used in decision making. In addition, a model was developed to assist Dominica in the selection of assets for maintenance. Asset management practices typically are need-based, with assets selected on a worst-first basis. Under the project, a cross-asset resource allocation optimization model was developed to smartly select assets for maintenance to reduce hazard risk and achieve multiple other objectives.

## Project Steps

To develop the methodology and model, the project included five steps, including an assessment of strategic business processes, development of a risk-based asset management methodology, data collection, a risk and vulnerability assessment, and the development of a capital investment strategy (Figure C.18).

Figure C.18. Project Steps to Develop a Capital Investment Strategy in Dominica



### *Step 1: Assessment of Strategic Business Processes*

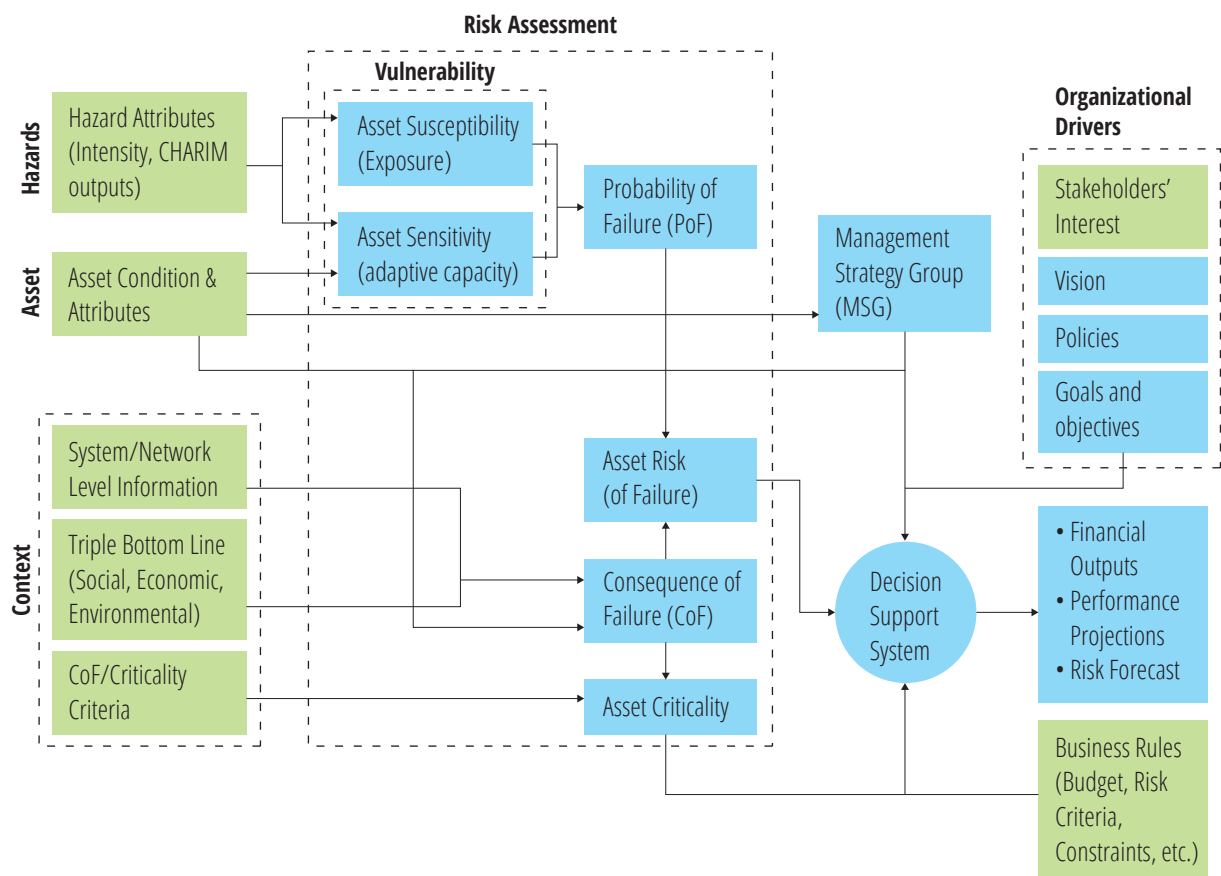
The first phase of the project was to assess MoPWP’s current practices, goals, and needs. This assessment included (a) a review of the ministry’s business process, including prioritization and decision-making; (b) collecting preliminary inventory data; (c) reviewing existing documents and strategic programs; and (d) developing a high-level framework for a risk-based asset management system that supports capital, operation and maintenance (O&M), and post-disaster activities and decisions.



**Step 2: Development of Risk-based Asset Management Methodology**

A risk-based asset management methodology was developed to determine appropriate and optimal infrastructure investment decisions. The methodology (Figure C.19) includes an asset risk and vulnerability assessment for landslides and flood hazards, which then is combined with an investment optimization algorithm that considers hazard risks and asset vulnerability along with organizational objectives and constraints in a decision support system.

**Figure C.19. Overview of Risk-based Asset Management Methodology in Dominica**





### Step 3: Data Collection and Analysis

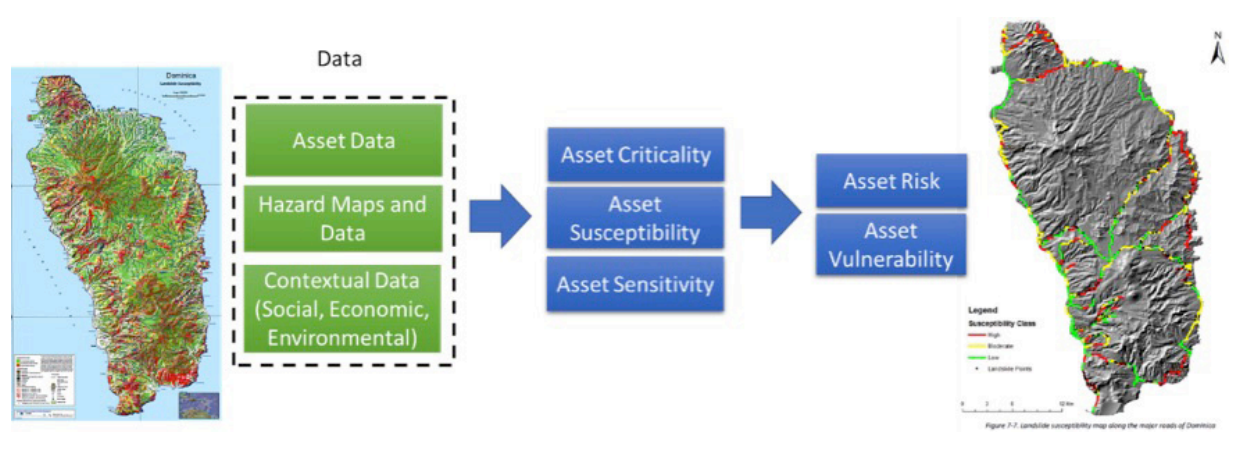
Following the development of the methodology, data was collected for main classes of assets including roadways, bridges, earthworks, drainage assets, and roadway supporting assets such as signals and guardrails. The data collected includes information about geometry, location, condition, age, and cost, as well as a history of failure and maintenance for each of asset.

### Step 4: Risk and Vulnerability Assessment

Next, a risk and vulnerability assessment was carried out to assess risks associated with landslides and flood and debris flow.

- **Landslides.** Landslide information was analyzed to determine the criticality, susceptibility, and sensitivity of each asset and to calculate asset risk and vulnerability (Figure C.20).

Figure C.20. Overview of Data Processing for the Risk and Vulnerability Assessment in Dominica



- **Flood and Debris Flow.** Flood and debris can cause flow severe damages to bridges and culverts. To assess risks and vulnerabilities, drones were used to scan and create elevation models of the riverbeds to conduct flood and debris flow risk assessments under various climate conditions.

**Step 5: Investment Optimization**

Finally, a model was developed to optimize cross-asset resource allocation. The model identifies optimal annual investments allocated to each asset to minimize risk and maximize network condition under budgetary and business constraints.

To analyze and prioritize investment options, the optimization model included (a) consideration of multiple stakeholders’ goals and objectives; (b) prediction of future asset performance using deterioration models; (c) a life cycle cost analysis (LCCA) to identify cost-effective strategies over the lifecycle of the assets; and (d) a greedy algorithm to approximate the most appropriate capital and O&M strategy each year. Following the analysis, the main outputs, also shown in Figure C.21, were as follows:

- Capital and O&M investment plans for different constrained and unconstrained scenarios.
- Asset and network performance projection over the planning horizon.
- Categorical analysis of performance and expenditure (such as by asset class, area, and year).

**Figure C.21. Outputs of the Decision Support System to Prioritize Investment Options in Dominica**



### *Tool Development and Implementation*

The asset management methodology, asset inventory database, and decision support system were integrated into an overall AMS tool, which was then customized to the needs and organizational structure of MoPWP, with user input incorporated during the tool's design and development. When completed, the tool was used to develop capital and O&M investment plans for different time horizons.

### *Sustained Implementation and Project Outcomes*

To sustain implementation, training sessions were provided to the staff to build sufficient competency for strategically managing the infrastructure without significant support from the Bank. Still ongoing, the project is expected to provide an opportunity for MoPWP to exercise more systematic and cost-effective asset management strategies that aim to reduce hazard risk and increase system performance. The sustainable implementation of the program is expected to result in short and long-term cost savings while increasing the levels of service provided to the community.

## Case Study 7. Using Smartphone Apps to Increase Road System Resilience

**Location:** Saint Lucia



**Authors:** Xavier Espinet, Roland Bradshaw, and Nicholas K.W. Jones

**Photo Credit:** Xavier Espinet

### CHALLENGE

Climate change is putting current and future road investments at risk. As governments, considering their very limited budgets, are forced to prioritize investments, transport asset management (TAM) systems are imperative to make smart decisions and increase the resilience of the transport system. While TAM success requires good and frequent road condition assessments, this is difficult for most SIDS due to limited financial resources and equipment.

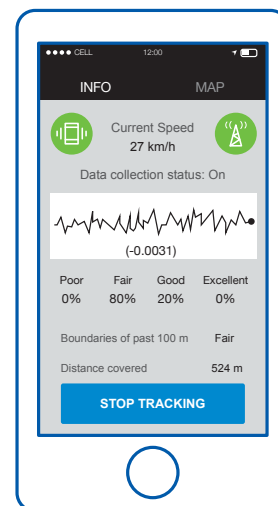


Climate change is putting current and future road investments at risk

### SOLUTION

A smartphone app was introduced to the Ministry of Infrastructure (MoI) in Saint Lucia as a low-budget and easy to use technique for road condition assessments.

In Saint Lucia, as in most SIDS, natural disasters on a recurrent basis exert significant damages to public assets; this negatively impacts economic growth, drives up national debt, and diverts resources from development and poverty alleviation to recovery and reconstruction. To move away from a reactive approach to disaster impacts and toward a strategic reduction of risk, the government of Saint Lucia needs to develop a better understanding of the country's public-sector risk at an asset level.



To address this challenge, a World Bank executed project, “Measurable Reduction of Disaster Risks Specific to Public Infrastructure in Saint Lucia,” was developed to support the government in building capacity to set clear risk reduction objectives, prioritize investments based on their cost effectiveness, evaluate and compare risk reduction options, and present better-informed risk reduction and climate adaptation projects to financing partners, including the international donor community.

The project also specifically aimed to lower existing barriers to proper road asset assessments and build capacity in the Saint Lucia road agencies, which led to the introduction of the smartphone app as an easy, replicable and inexpensive technique to survey and assess the condition of the road network. With smartphones widely used and all staff at MoI familiar with smartphone apps, the use of a free app seemed the perfect technology to easily and quickly implement a methodology with such a large demand. The selected app, RoadLab Pro, performs geo-mapping and can be used to estimate road roughness. RoadLab Pro was developed by the World Bank to provide a method to do road condition assessment for transport agencies in developing countries. Output data is shown in Figure C.22, while use of the app is demonstrated in Figure C.23.

**Figure C.22. Smartphone Output Data showing Road Conditions for the A20 Road South of Castries in Saint Lucia**

### A20 - Road Condition Assessment

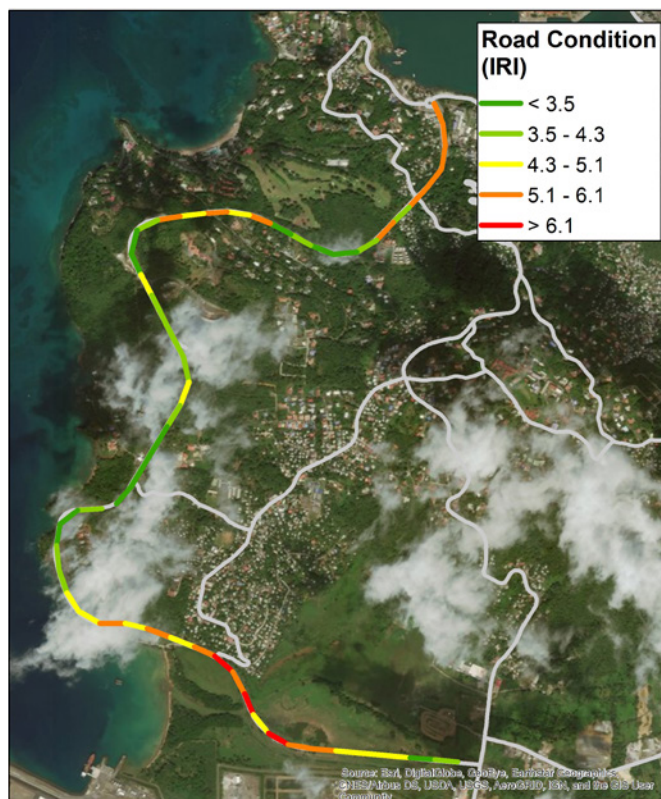
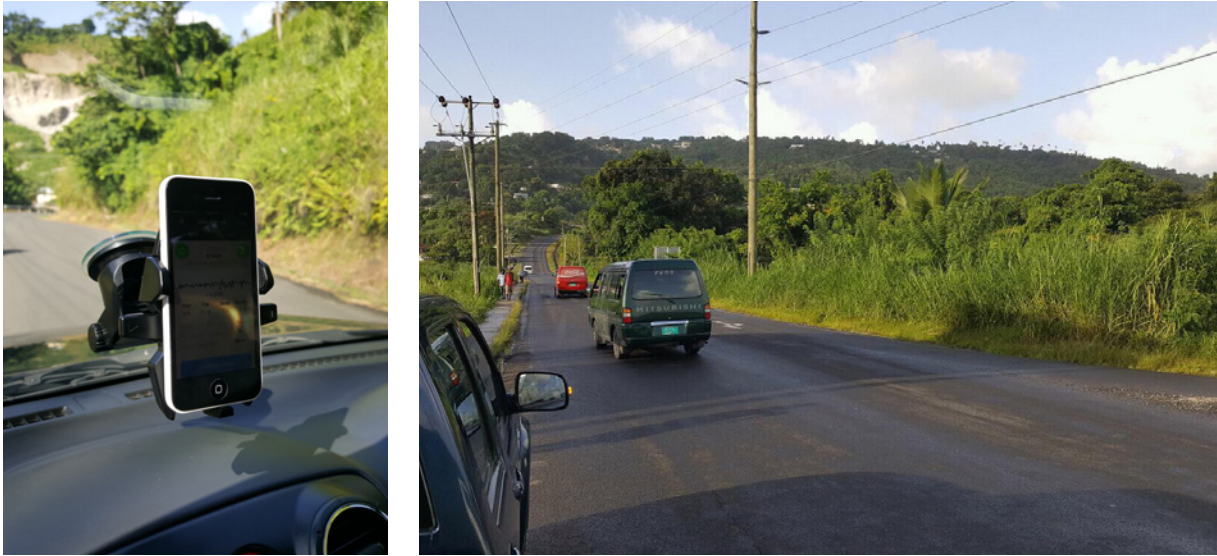


Figure C.23. Smartphone with App Used to Survey a Feeder Road in the Vieux Fort District in Saint Lucia



Next, to carry out the assessment, the project involved nine steps covering preparation work, field work for data collection, and data processing back in the office. Preparations included (a) identifying the number of roads to be analyzed and the overall work load, (b) defining the number of people and days of work based on available resources, (c) planning the route of each surveying team, and (d) acquiring the needed materials, such as phones with the app downloaded and a car cradle to hold the phone. Next, the actual field work consisted of (e) training the survey team and preparing the field equipment, (f) driving on the roads to be surveyed, assessing conditions and geo-tagging relevant features such as bridges and culverts, and (g) sharing data, either stored in the cloud or sent to a local GIS expert. Finally, again in the office, the post-survey work included (h) processing, cleaning and compiling data, and (i) creating GIS layers with the information from the survey.

The implementation of the project demonstrated that the use of smartphone apps for road assessments can be a suitable solution, as the techniques can easily be taught and successfully implemented, thus lowering existing barriers and enabling surveying, condition assessments, and asset management of roads in lower-capacity and under-resourced transport agencies in developing countries. In Saint Lucia, the collected information has helped the Ministry of Infrastructure to manage their transport assets with the goal of increasing the resilience of the island road system.



## Case Study 8. Information Management System for Enhanced Transport Asset Resilience

**Location:** Belize



**Authors:** Bishwa Pandey, Marion Caetano, Keren Charles, Steve Brushet, Phillip Barutha and Frederico Pedroso

**Photo Credit:** [www.nepcol.com](http://www.nepcol.com)

### CHALLENGE

Belize is vulnerable to the impacts of natural disasters and climate change, which can lead to high losses associated with road infrastructure damage. The country's Ministry of Works faces challenges in the prioritization of investments in road maintenance, rehabilitation, and operation due to uncertainty around future impacts of climate change and a lack of information on the location and conditions of transport assets and specific geo-hazards along the road network.

Before, during and after emergencies and disasters, access to reliable and updated information on transport assets—such as location, condition, and criticality—is essential. Decision makers, transport planners, and engineers, however, often struggle to have timely access to this kind of data. In addition, the sheer number of assets and their geographical distribution makes it difficult to collect, analyze, and understand their status in real time.



Natural disasters and climate change, can lead to high losses associated with road infrastructure damage

### SOLUTION

The World Bank partnered with the government of Belize and, in particular, with its Ministry of Works, to enhance the country's road asset management system and improve resilience to natural hazards and climate change impacts.

As a result of this collaboration, Belize has introduced the use of an information management tool, "SpatialEdge," tailored specifically to the country's needs. The tool has a user-friendly interface to facilitate data collection, management, access, and analytics, and uses geospatial technology that enables the use of a smartphone app (like RoadLab Pro) to collect information on the location and condition of transport assets. This ease of use not only facilitates timely updates but also reduces costs associated with recurring data collection.



The information management tool further includes business intelligence features that enable overlaying the natural hazard information on a transport asset inventory to facilitate the creation of “what if” scenarios for a variety of natural hazards and disasters, such as flooding, landslides, and hurricanes (Figure C.24). These scenarios can be used to better understand the likely impacts in terms of damage, losses, and costs associated with past and future natural disasters. The business intelligence features also specifically aim to provide timely information to support decision making on transport investment prioritization and the development of plans for disaster response and recovery.

**Figure C.24. Overlay of a Hurricane Cone of Influence to Identify Culverts Likely to be Impacted**

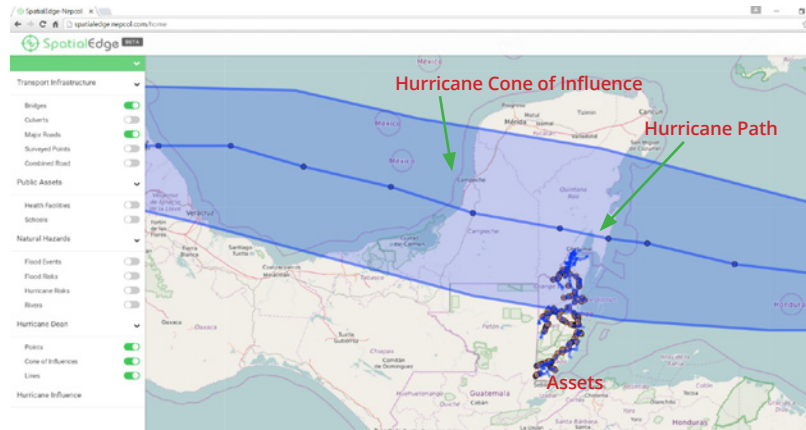
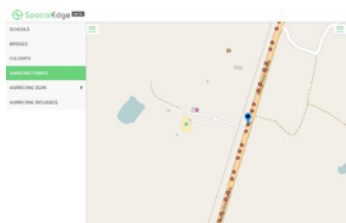


Figure C.25 displays the three key functions of Spatial Edge and its associated smartphone app in terms of capturing the location and condition of assets and analyzing this information in combination with information about specific hazard information for the road network.

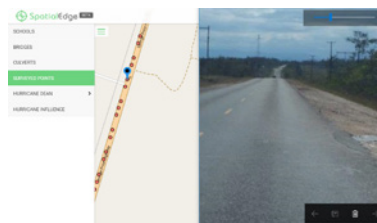
**Figure C.25. Use of an Information Management Tool for Road Condition Data Collection and Analysis**

### 1. Location of Assets



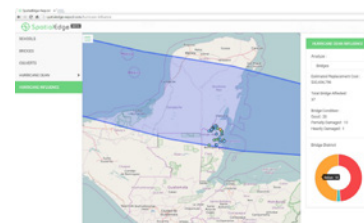
- A smartphone app mounted on moving vehicles captures georeferenced location of roads.

### 2. Condition of Assets



- Geotagged photos of assets are automatically captured during data collection campaigns.

### 3. Integration and Analytical Capacity



- Road infrastructure location and asset conditions are integrated with hazard maps.
- A user-friendly interface presents access to the data and what-if scenarios for a variety of natural disasters.

## Case Study 9. Empowering Women to Manage Rural Road Maintenance: Lessons from Vietnam with Relevance for SIDS

**Location:** Vietnam

**Author:** Phuong Thi Minh Tran



**Photo Credit:** Mari Clarke and Ngan Hong Nguyen

### CHALLENGE

In steep, mountainous areas of Vietnam, where many ethnic minorities reside, costs of road maintenance are very high due to the challenging terrain and the increasingly unpredictable and extreme rainfall associated with climate change. The low-income communities lack resources to cover maintenance costs, and poor road conditions limit access, constrain economic opportunities, and exacerbate poverty—particularly for women. Even when road maintenance funds are available, many contractors refuse to work in the mountains because of the risk of landslides during rainy seasons.

This challenge is similar to those in mountainous SIDS where roads are exposed to landslides.



In steep, mountainous areas roads are exposed to landslides

Due to the challenging terrain, costs of road maintenance are very high

### SOLUTION

To address these challenges around poor road condition and difficult maintenance conditions, local communities were engaged in the maintenance activities, and options were developed to reduce runoff and minimize the risk of landslides. This solution, which was identified for Vietnam, can also be considered for SIDS facing similar challenges.

#### Women-Managed Routine Rural Road Maintenance Program

In 2010, the World Bank's "Third Rural Transport Project (RTP3)" initiated a small pilot routine road maintenance (RRM) activity for ethnic minority women in five communes in mountainous Lao Cai Province (Figure C.26). The Provincial Women's Union (PWU), under the Vietnam Women's Union (VWU), managed the pilot with technical guidance from the Provincial Department of Transport (PDOT) and the District Urban Management Department, in coordination with Provincial, District, and Commune People's Committees. Based on very positive outcomes of the pilot, a Women-Managed Routine Rural

Road Maintenance Program was then developed to scale up the approach, with refinements, in more districts in Lao Cai Province, as well as in two additional provinces—Quang Binh and Thanh Hoa—between late 2012 and June 2014.

**Figure C.26. Construction of a Road Drainage System by Local Communities in Vietnam**



The Women-Managed Routine Road Maintenance Program has had far-reaching outcomes. Its bottom-up awareness raising, the many community road maintenance activities, and discussions on outcomes with Vietnam's Ministry of Transport and provincial, district, and commune leaders have raised awareness of the economic importance of routine road maintenance on commune roads and the need to finance it. Lao Cai Province has already enacted a policy to include commune road maintenance in the official budget, and the program also established vital new coordination mechanisms between provincial and district transport staff and the Women's Union, providing a model for collaboration with other social organizations.

Throughout the project, the Women's Union demonstrated the necessary organizational capacity to effectively plan and manage the work and payments on a large scale. The initiative also fostered a maintenance culture that changed local behavior from damaging commune roads to now protecting them. Working together on road maintenance also strengthened local social cohesion. By putting women in charge rather than treating them as passive recipients, their status and influence on decision-making in the community and households improved, family violence decreased, and the entire community benefitted from better roads.

### Bioengineering to Prevent Erosion

Recognizing the importance of preventing slope and coastal erosion and the need to reduce runoff and landslides during the rainy season, the Women's Union also engaged in activities to make the roadsides more climate resilient and attractive. To achieve this, the Union managed 2293 people who planted 39,235 trees along 87.4 kilometers of roads that were maintained by women-managed groups (Figure C.27).

**Figure C.27. Transport of Materials for Reforestation on Slopes to Reduce Water Runoff and Landslides**



### Economic and Social Outcomes of the Women-Managed Program

Generating income for ethnic minority and poor women and their households was only part of a larger picture. First, the actual income from routine road maintenance was small. Because of the large number of people engaged in the efforts, the average payment per person was about \$203,615.28 VND (about US\$9.61). Even this small amount, however, was significant for the poor ethnic minority participants who made up 63 percent of the total RRM workforce.

Second, local people as well as officials and Women's Union units at all levels realized that the economic gains from maintaining the road—which ensured year-round access—was much more significant than the money earned doing the maintenance. Specific gains included (a) greater access to markets and market information, leading to expanded crop production; (b) increased opportunities for employment and small business development; (c) lower costs for fuel, vehicle maintenance, farm inputs, and consumer goods; and (d) shorter travel times and fewer road accidents.

The changes resulting from the maintenance facilitated increased income and improved quality of life. The head of a Commune in Bac Ha district in Lao Cai Province noted that, in the past, “women could not drive motor bikes to Bac Ha market because the roads were too rough. They walked, which took a lot of time.” Now with road maintenance, “50 percent of the women go, on their own, by motorbike to the market and take children to school on motorbikes.”

Improved access to school, particularly in the rainy season, was noted in all focus group discussions. While before many children walked to school, with the improved roads in the project communes many households have purchased bicycles for their children’s travel. The chair of one Commune People’s Committee noted that “this has reduced the drop-out rate,” adding that “there is no child of school age who is not going to school.” Better maintained roads also provide easier access to health care services, particularly when urgent care is needed. The chair of a Commune People’s Committee in Bac Ha district said that “in the past people used herbs when they were sick. Now they can take children and the elderly who are sick to the clinic in the commune or district.”

Another important outcome of the project was that women’s leadership roles in the management of the routine road maintenance enhanced their status and self-esteem. Husbands were more respectful and willing to help with child care and housework, and women for the first time began to offer their opinions in community meetings. The leader of a PWU said that women-managed routine road maintenance provided “opportunities for women to act as pioneers in the protection of rural roads, environment and other movements.” A commune vice chair observed that: “these [routine road maintenance] activities have been very positive in the way they have improved the status of women. Before, women were second class doing house work only. Now they participate in public and community activities.” A senior expert at the Ministry of Transport noted that, in her view, “RTP3 is the only [Vietnam transport] project that treated women as actors, not just as recipients.”



## Case Study 10. Building Resilience Through Community Involvement in Road Maintenance

**Location:** São Tomé and Príncipe

**Authors:** Mustapha Benmaamar and Nicolas Desramaut



**Photo Credit:** Mustapha Benmaamar and Nicolas Desramaut

### CHALLENGE

Situated on the equator, São Tomé and Príncipe (STP) is an archipelago with two main inhabited islands. Due to the geography of the islands—with high volcanoes in the center and populations and economic activities mainly along the attractive coastlines—the country's entire road network is situated either along slopes or coastlines (Figure C.28). For two of the three national roads (National Roads 1 and 2), challenges are combined, with both roads having exposure to coastal erosion and storm surges on one side, and to landslides and rockfalls on the other.

**Figure C.28. Roads in São Tomé and Príncipe are Wedged between the Coast Line and Inland Volcanoes**



In recent years, one of the most important roads in the country—providing a connection to the airport—had to be rebuilt as the old road would now already be 70 meter offshore. The new road, however, is facing similar challenges, with some part of its pavement already taken away by the sea. This time, no set back area to relocate the road is available.

To complicate road maintenance, the climate is very humid, with annual precipitation exceeding 7 meters in some parts, with year-round rainfall. These conditions require regular road maintenance for the country's road network, of which only 21 percent of roads (230 kilometer out of 1,100 kilometers) is asphalted.

## SOLUTION

São Tomé and Príncipe is conducting an analysis, combining hazard and transport infrastructure mapping, to improve their understanding of the vulnerability of the road network. Results will inform the selection of segments for upgrades as well as design standards for new construction, integrating considerations of impacts of climate change in both. As part of the solution, the country engaged local communities in road maintenance to conduct low-to-medium scale road rehabilitation works. (Figure C.29.)

Figure C.29. Slope Stabilization in São Tomé and Príncipe



### Coordination of Interventions at Higher Levels

Responsibilities for all transport related activities in São Tomé and Príncipe fall within the Ministry of Infrastructures, Natural Resources, and Environment (MIRNMA). The main agency on road transport is the National Institute of Roads (INAE), but responsibilities are shared with the Directorate for Transports and Communication (DTC) and the National Road Fund (FRN), an autonomous government fund in charge of financing the maintenance and construction of roads. INAE is responsible, among other things, for road maintenance, implementing the road development strategy, planning for road projects, and compiling and maintaining road and related statistics.

Coordination and implementation of activities to adapt to climate change are organized by the Directorate General for the Environment (DGA), also under MIRNMA. Having both agendas (infrastructure and climate change adaptation) within the same ministry is very helpful, as it allows for better cooperation and integration at the initial stages of activities. Both INAE and DGA can be involved in activities to improve the road network. In the preparation of the second phase of an adaptation project supported by the Global Environment Facility and the World Bank, for example, INAE has been involved at a very early stage to address the protection of road networks in communities where the project will intervene. At the same time, DGA is involved in preparations for a resilient transport project, leading a study on the conceptual design for both coastal protection and road rehabilitation of the Capital water front. The involvement and collaboration of both authorities has been facilitated by the arbitrage and vision provided at the ministerial level; the collaboration will continue during the planned resilient transport project, with both entities (DGA and INAE) as key members of the steering committees.



### Road Maintenance by Community Committees

In addition to the lead government agencies, another key stakeholder in the road transport sector is the *Grupo de Interesse e Manutenção de Estradas*, or GIME. Established in 2005 with support from the European Development Fund, the GIMEs are community organizations that have contracts with INAE to maintain some of the rural and urban roads in the country using a results-based approach.

The GIMEs are organized in four regional federations or FRAMEs (*Federação Regional das Associações de Manutenção de Estradas*), with three federations covering the island of São Tomé and one the autonomous region of Príncipe. In addition, a national federation (FNAME) is in charge of the groups' interaction and negotiation with INAE.

In total, 32 GIMEs cover the country, with each group having about 50 members on average, half of which are women, all from local communities. The GIMEs carry out routine maintenance of paved and unpaved roads. At their peak, the GIMEs employed 1,600 persons, providing livelihoods for 8,000 Saotomeans (around 5 percent of the total population). The work performed by the groups is regularly monitored, with one passage per month to identify what needs to be done for each road segment and one to determine the status of the roads and possible penalties. These penalties could be a reduction in remuneration, but mostly they are settled through the provision of additional work. The expected level of maintenance of the roads is discussed and agreed with each GIME for each road segment, following national guidelines and conventions signed with INAE and FNAME. The exact results criteria depend on the type of road (asphalt, paved with stones, or earth) and its initial state.

In addition to receiving income, GIME members benefit from local recognition, access to tools, and trainings. Some GIMEs even own bigger equipment and have access to some raw materials, procured by the FNAME. These GIMEs can also undertake more elaborate road maintenance such as filling pot holes, performing coastal protection, and doing slope stabilization works using gabions. Although GIMEs used to provide routine maintenance for the county's 1,100 kilometers of road network at an average unit cost of US\$1000 per kilometer per year, today they only cover 860 kilometers due to budget constraints following the end of the support of the European Development Fund.

### Best Use of Local Capacities and Resources

As mentioned, GIMEs have the capacities and competencies to perform small constructions of coastal protections or slope stabilizations, such as gabions, walls, and drainage systems. They have been involved in a variety of projects and are able to use local materials and traditional best practices.

Currently, a project in development in São Tomé and Príncipe aims to provide support to this maintenance strategy, with the consolidation of the institutional set-up, the development of sustainable financial strategies for the National Road Fund, and support for the GIMEs through capacity building and materials.

# Contingency Programming: Case Study on the use of CERC in the Caribbean and Case Study in Tonga

## Case Study 11. Using the CERC in Limited Capacity Environments to Reduce Road Network Interruptions following a Disaster

**Location:**  
Caribbean and Pacific SIDS

**Authors:**  
Keren Charles, Nicholas Callender,  
and Simone Esler

**Photo Credit:** World Bank

### CHALLENGE

Road networks in SIDS are exposed to multiple hazards and are highly vulnerable to natural disasters and the impacts of climate change. Heavy rainfall may cause erosion and scouring of roads and bridges; flooding and coastal inundation can result in road damage, closures, and limited use of roadways; and strong winds may cause debris to obstruct traffic flows. Compounding road network exposure and vulnerability is the limited redundancy of road transport networks in SIDS, which means even small failures or interruptions may have disproportionately high consequences for the movement of goods and provision of services. From a disaster response perspective, road network operability is critical, with failures inhibiting timely provision of first response, relief services, and safe evacuation of citizens. Following a disaster, however, the short-term response to road network restoration can be challenging and time-consuming due to capacity constraints, coordination and logistical challenges, and a lack of earmarked resources, while medium-term measures such as repair and reconstruction of roads and bridges can be costly. As such, Caribbean and Pacific SIDS governments have placed a high premium on financial and logistical support for rapid network restoration in the event of a natural disaster.



Heavy rainfall, strong winds, flooding and coastal inundation can result in damage to roads and bridges



## SOLUTION

Acknowledging the need for rapid support following a disaster, the World Bank has developed and embedded the Contingency Emergency Response Component (CERC) within disaster risk management and climate change adaptation projects in the Caribbean and the Pacific. The CERC allows for the earmarking of investment project funds to be disbursed against a disaster, following the adequate ex-ante technical preparation and logistical planning for its disbursement and use.

CERC preparation supports post-disaster planning and guarantees the availability and rapid mobilization of resources for the procurement of critical goods and services required for response and reconstruction activities. Due to the ex-ante preparation, the CERC strengthens national pre-disaster planning capacity in anticipation of post-disaster needs and fosters coordination among stakeholders involved with disaster preparedness and response. Preparations also include the pre-definition of critical imports, goods, and services and the pre-qualification of contractors and consultants, along with the development of standard contractual documents.

The CERC mechanism has been successfully implemented in Dominica and Saint Vincent and the Grenadines (SVG) to restore road network connectivity by funding debris removal in the former and procuring critical materials for road reconstruction in the latter country. In addition, as described below for Tonga and Samoa, the CERC also provides a platform for governments to prepare for contracting and environmental considerations with respect to debris removal in the Pacific.

### **Dominica, Tropical Storm Erika 2015**

Tropical Storm Erika, which passed over Dominica in August 2015, produced prolonged high intensity rainfall resulting in rapid flooding and estimated damages and losses of 90 percent of GDP. Damage was experienced across an estimated 24 percent of the road network with partial damage to 44 percent of the bridges.

Within six weeks of the storm, the CERC embedded in the Disaster Vulnerability Reduction Project in Dominica was triggered for US\$1 million to retroactively finance pre-approved post-disaster emergency works. CERC-financed activities commenced immediately following the event to address immediate transport needs, and the government executed over 60 contracts to re-open transport access across the island; clear debris and landslide materials; and procure items such as cement, aggregate, sand, tarpaulins, and gabion baskets.

Although after the storm approximately 60 percent of the roads in the country were inaccessible, extensive sections were made accessible within the first two weeks, partially through CERC financing. The ex-ante preparation, lists of consultants/contractors, as well as matrices of critical goods all allowed for rapid procurement of services and eased budgetary constraints, in particular for the Ministry of Public Works.

### Saint Vincent and the Grenadines, December 2013 Trough

The December 2013 Trough in Saint Vincent and the Grenadines (SVG) resulted in the death of 9 people, the displacement of 775 people, and damage and losses of US\$108.4 million (15 percent of GDP), of which US\$82.6 million was in the transport sector. Bridges and roads were destroyed by landslides and the rapid movement of water that contained boulders, resulting in communities without connectivity and cut off from emergency response services.

Within four weeks of the event, the CERC, embedded in the Regional Disaster Vulnerability Reduction Project, was triggered for US\$1.9 million to procure Bailey bridges for temporary access to communities where bridges were damaged or destroyed (Figure C.30), as well as geotextile fabric for repairs of damaged road infrastructure and assorted galvanized pipes and fittings to repair damaged water infrastructure.

Through the CERC, the Ministry of Transport and Works was able to obtain the needed materials to replace critical road infrastructure, thus reducing the time transport networks were interrupted.

**Figure C.30. Bailey Bridge in Saint Vincent and the Grenadines Purchased under the CERC, 2016**



### Tonga and Samoa, January 2017

In response to a request from the governments of Tonga and Samoa for support in the operationalization of the CERC, which is embedded in their Pacific Resilience Projects, the World Bank provided a two-day workshop including a simulation exercise in both countries (Figure C.31). The training not only provided a better understanding on the use of the CERC for government and other stakeholders, but also enhanced emergency preparedness by bringing together officials from key ministries and agencies<sup>1</sup> to discuss immediate needs and response activities following a disaster. In addition, the training provided insights on the financial decision-making processes following a natural disaster, and discussed how the CERC can be used to mobilize maritime or air transport to support response activities post-disaster.

Given the importance of debris removal following a disaster, the workshop focused on the process of mobilizing contractors to remove debris, the procedures for handling potential hazardous waste, and other social and environmental safeguard considerations associated with reinstating road access. As a result of this training, the countries are more prepared to deal with potential impacts to their transport infrastructure following a disaster and better understand how the CERC can be used to support these efforts.

**Figure C.31. CERC Preparation Workshop in Samoa, 2017**



<sup>1</sup> Stakeholders involved in the workshop included, in Tonga, the Ministry of Finance; Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (including the National Emergency Management Office, Met Office, and Environment Division); the Ministry of Natural Resources; the Tonga Broadcasting Commission; and the Tonga Police and Armed services. In Samoa, stakeholders included the Ministry of Finance (including the Climate Resilience Investment Division); Ministry of Natural Resources and Environment (including the Disaster Management Office); Ministry of Health; Ministry of Works, Transport and Infrastructure; Electric Power Corporation; Samoa Audit Office Land Transport Authority; and Samoa Water Authority.

## Case Study 12. Emergency Response System and Procurement Regulations

**Location:** Tonga

**Author:** Jesus Renzoli



**Photo Credit:** Jesus Renzoli and  
Chris Bennett

### CHALLENGE

Tonga is highly exposed to natural disasters such as earthquakes and tsunamis and has experienced several cyclones, including Category 5 tropical cyclones Winston (2016), Ian (2014), and Heta (2003), as well as Category 4 tropical cyclones Jasmine (2012), Wilma (2011), and Waka (2001). The lessons learned from experiencing these natural disasters are that:

- a. Early warning and declaration of state of emergency before landfall contributes to saving lives and to a prompt response to the disaster.
- b. Expectations must be managed right from the beginning of the recovery, including on responsibilities and specific goals for intervention, while communication has to be consistent and comprehensive to coordinate all recovery efforts.
- c. Recovery takes time and can easily cross between government administrations, including election periods. Therefore, a phased approach to recovery should be considered to allow some flexibility in terms of priorities.
- d. After the initial disaster assessment, a considerable amount of time is required to define a list of beneficiaries if no rules are set beforehand about beneficiary categories for new houses or repairs. In addition, a deadline must be set to close the beneficiaries list and prevent the ongoing addition of new requests as that leads to uncertainty in the planning of resources and procurement. Finally, a lack of clarity about land ownership can cause delays during disaster recovery and re-construction, making it important to have updated registries of land ownership.
- e. Good contract management and administration are crucial to ensure good supervision of works.
- f. Designs (including specifications, drawings, and bill of quantities) for infrastructure construction must be readily available to avoid delays in procurement.
- g. To facilitate identification of contractors, it is helpful to have a register of local contractors, noting however that post-disaster it is challenging to identify contractors with experience and financial capability—especially considering that many or most may have also been impacted by the disaster, while international contractors may be outside the budget available.
- h. Procurement of equipment and materials can be challenging due to the remote location of islands and work sites, with many supplies needing to be imported from abroad.



## SOLUTION

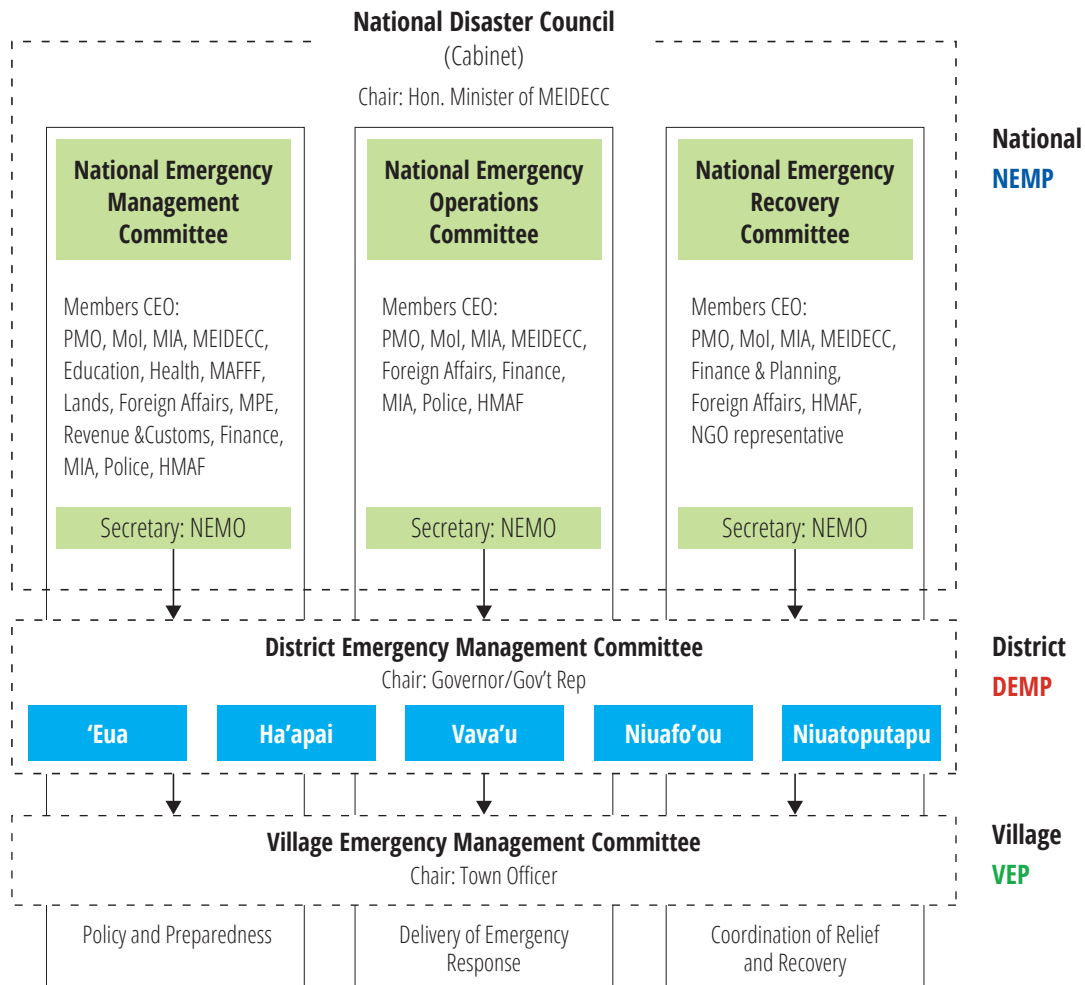
Aware of its high exposure to natural disasters, Tonga has established an Emergency Response System that is guided by provisions in its legal framework and through institutional arrangements to manage disaster preparedness, response, and rehabilitation. In addition, the country has identified the need for an advanced procurement system (compatible to that of the international donors) to enable a timely, efficient, and transparent acquisition and deployment of goods and services related to emergency response.

In its Emergency Management Act of 2007 (updated in December 3, 2014), Tonga has defined an emergency management governance structure. Headed by the National Disaster Council (Cabinet), this structure empowers several committees on the national and local levels (Figure C.32). Committees on the national level include:

- ***National Emergency Management Committee (NEMC)***. The NEMC is responsible for managing emergencies and coordinating recovery and rehabilitation work. The committee, chaired by the Minister of Meteorology, Energy, Information, Disaster management, Environment, Climate change and Communications (MEIDECC), is also tasked with developing the National Emergency Management Plan.
- ***National Emergency Operations Committee (NEOC)***. The task of the NEOC is to activate ministries and organizations in response to an event; liaise with ministries, non-government organizations, and community groups in the execution of emergency management roles and responsibilities; carry out initial damage assessment; collate and prioritize disaster relief requirements; and manage the distribution of immediate relief supplies.
- ***National Emergency Recovery Committee (NERC)***. Lastly, the NERC coordinates the recovery phase following an event, including carrying out detailed damage assessments in partnership with NEOC, coordinating the provision of emergency relief, and coordinating all recovery and rehabilitation works that are carried out in the affected area.

Under the national level, lower-level committees—on district and village levels—complement the activities of the committees on the national level.

Figure C.32. Institutional Arrangements for Tonga's Emergency Response System



### District Emergency Management Committee (DEMC)

On the district level, tasks of the DEMC are to (a) prepare and regularly review a District Emergency Management Plan; (b) provide recommendations to the NEMC about disaster risk reduction and emergency management activities in the district; (c) provide support to communities before, during, and after an event; (d) ensure community awareness of emergency management; (e) identify and coordinate the use of resources for emergency operations in the district; (f) manage emergency operations in the district in accordance with the policies and procedures issues by the NEMC; and (g) establish and review communications systems in the district during emergency to ensure information about an event or emergency in the district is promptly provided to the NEMC. Capacity may vary among districts, and the NEMC is tasked to provide adequate support to ensure disaster-related reporting of districts with weak capacity is not compromised.

### **Village Emergency Committee (VEC)**

On the local level, VECs are responsible for developing and implementing effective emergency management in the villages in accordance with policies issued by NEMC. Specific VEC tasks include (a) providing reports and making recommendations to the DEMC about disaster risk reduction and emergency management; (b) ensuring community awareness of the emergency plan; (c) identifying and coordinating the use of resources for emergency operations in the village; (d) establishing and reviewing communication systems in the village for use during an event; and (e) ensuring that information about an event or emergency in the village is promptly provided to the DEMC. The DEMC is also tasked to ensure emergency management coverage (for assistance during the emergency or for prevention, assessment, or recovery phases) is provided to villages with weak capacity.

### **Procurement for Emergency Response**

Until 2015, Tonga's Emergency Management Act and Public Procurement Regulations did not provide the legal basis, institutional arrangements, or instructions for expedite and simplified procurement procedures required in post-disaster situations. The country's public procurement regulations (2016), however, include provisions for limited bidding during emergency situations. They also imply an acceptance of the emergency procedures of donors related to procurement, stating that "Where these Regulations conflict with the procurement rules of a donor or funding agency, the application of which are mandatory pursuant to or under an obligation entered into by the government, the requirements of those rules shall prevail, but in all other respects, procurement shall be governed by the provisions of these Regulations." This provision is important to prevent procurement challenges post-disaster as donor procurement guidelines, such as those of the World Bank and Asian Development Bank (both with programs in Tonga), may also address procurement in emergency situations, for example by mentioning the possibility of advance procurement, higher thresholds per procurement methods, and direct contracting.

Given the distribution of funds and procurement system in Tonga, district and village levels are not expected to be involved in carrying out procurement in emergency or disaster situations in the interest of the District or Community, as such procurement will be carried out at the central level. The composition of the NEMC implies that, in case of disaster, the Ministry of Finance may appoint a high official with signatory authority to oversee procurement decisions.

Considering that funds are scarce (in case of major disasters possibly only sufficient for the initial reaction), Tonga is expected to resort to international finance when major disasters occur. In this case, donors will look for the presence of appropriate arrangements to execute the funds in a timely, transparent, and accountable fashion. The more prepared the country is for emergency procurement (including advance procurement), the faster and more efficient the disaster response.

# Integrated Approach across Lifecycle Components: Case Studies in Tuvalu and Colombia

## Case Study 13. Preparing Small Island Airports for a Changing Climate

**Location:** Tuvalu

**Author:** Nora Weisskopf



**Photo Credit:** Nora Weisskopf

### CHALLENGE

Among the Pacific Island Countries (PICs), Tuvalu is deemed one of the most vulnerable. Located about 1,100 kilometers north of Fiji and more than 3,000 kilometers northeast of Australia, Tuvalu has an approximate total land area of only 26 square kilometers, spread across nine islands. Tuvalu's islands are also very low-lying, with maximum elevations of approximately 4.5 meters above sea level, the second lowest in the world. These geographical features have considerably exposed Tuvalu to the impacts of climate change. Storm surges, king tides and floods (which are common and have intensified due to changes in weather patterns), as well as sea level rise and more extreme weather events such as tropical storms and cyclones—until 2015 never experienced in Tuvalu—have resulted in significant damage to the islands and their inhabitants in the past. The combination of remoteness and climate vulnerability makes Tuvalu's international airport the most critical node in its transport network in the event of a disaster. Ensuring its resilience requires unique engineering solutions, robust systems, and government preparedness.



Tuvalu's islands are very low-lying with maximum exposure to the impacts of climate change

### SOLUTION

Under the World Bank supported Tuvalu Aviation Investment Project (TvAIP), part of the larger Pacific Aviation Investment Project (PAIP), a number of concepts and design approaches were incorporated (including into the infrastructure itself) to build in measures to ensure resilience to the impacts of climate change and also enable more effective responses to natural disasters.

### Pavement Strength

When determining the required pavement strength for a runway, the so-called Pavement Classification Number (PCN), this number is assessed based on the current and potential future aircraft types that will use the airport facilities. What happens, however, if you require a much heavier aircraft to bring in emergency supplies? This was precisely the case in 2011 when water reserves were so critically low in Tuvalu that the New Zealand military used a C130 military aircraft to bring in additional water. While the ATR72 that normally serves the airport has a maximum take-off weight of 23 tons, the maximum take-off weight of a C130 is 70 tons. This meant that the fully loaded C130 aircraft was three times as heavy as what the runway had been designed for. Ultimately this operation resulted in considerably damage to the runway. To account for future similar circumstances, special considerations were made in the design to allow heavier aircrafts to land during emergencies, an occurrence that is anticipated to become more frequent given Tuvalu's vulnerabilities. (Figure C.33.)

Figure C.33. C130 Offloading in Tuvalu in 2015 after Cyclone Pam



### Building Standards

The project constructed a new terminal and a rescue fire station/flight services center. All structures had their structural capacity increased to cater for heavier tropical storms, with designs based on the latest design standards.

### Water Storage

Water shortages are a considerable issue in Tuvalu as droughts are frequent and water storage capacity is limited. To account for this within the terminal design, TvAIP financed an 800,000-liter rainwater collection cistern to ensure sufficient rainwater reserves during droughts.

### Emergency Communications Infrastructure

As part of PAIP, a Very-Small Aperture Terminal (VSAT) is being financed to replace the existing informal system of phone calls between air traffic controllers and civil aviation authorities (Figure C.34). This is bringing in a robust, satellite based ground-to-ground communications system that can be used for emergency communications in case of a disaster.

Figure C.34. VSAT Satellite Dish



### Preventative Maintenance

PAIP is also working with all participating states on the award of a regional maintenance concession that will work with airport operators to develop maintenance regimes for airport infrastructure. This preventative maintenance system will strengthen climate resilience and support island airports with technical assistance during emergencies.

### Emergency Response Capacity

As part of the capacity building efforts of TvAIP, technical assistance has been provided to the Ministry of Transport and Communications (MTC) to develop an airport emergency plan to strengthen response capacity of civil aviation ministries.

### Pavement Drainage Design

After the completion of the runway resurfacing, in several areas pavement failures were observed that threatened to disrupt critical operations. Extensive independent testing showed that the failures were caused by pressure build up under the runway resulting from water infiltration exacerbated by tidal and sea level impacts. This phenomenon has shown to be extremely rare and has only been observed and documented in research in a few instances, most notably at Hong Kong airport runway and some cases in Australia, and could have not been anticipated using traditional engineering design approaches. Given the uniqueness of the defects, no ready-made solutions were immediately available, and currently a 3D model of the catchment area is being developed as part of a complete catchment drainage study to determine the interaction of storm water runoff from the runway/apron, the roads, the built-up areas, and the open spaces, and assess the resulting peak flows and drainage pathway. In addition, different design solutions will be tested over a period of three months during the cyclone season to identify the most suitable and cost-effective approach to be implemented. Following this, regular monitoring will be undertaken post-construction.



## Case Study 14. Climate Risk Assessment for Muelles el Bosque Port

**Location:** Cartagena, Colombia

**Author:** Vladimir Stenek



**Photo Credit:** IFC and IFC 2011

### CHALLENGE

Infrastructure and transport are among the sectors most exposed to climate change, with both critical to national economic performance, growth, and development. Ports in particular play a vital role in the world economy as more than 80 percent of goods traded worldwide are transported by sea.

In developing countries, ports handle more than 40 percent of the total containerized traffic, of which a significant portion relates to the export of goods and materials produced in the country, which means climate impacts on ports will have wide socio-economic ramifications. For some ports, climate change related risks could manifest through changes in the level or patterns of shipping, increased flooding (affecting movements within ports and causing damage to stored goods), reduced or changed navigability of access channels (for example because of sea level rise and changed erosion patterns), and business interruptions. At the same time, other ports might see opportunities as a result of climate change. As a port's reputation for reliability is key to its success, ports that are more resilient to disruption from climate events are expected to do better.

Recognizing the potential significance of climate change to ports, the Adaptation Program of the International Finance Corporation (IFC) of the World Bank Group commissioned a study for the Terminal Marítimo Muelles el Bosque (MEB) in Cartagena, Colombia (Figure C.35).

Water temperature and rainfall conditions in Colombia are expected to change as a result of climate change, which may lead to increased flood events for the port. Projections from 10 general circulation models (GCMs) point at temperature increases in Cartagena between 0.7 to 1.2°C by the 2020s and 1.2 to 2.2°C by the 2050s, compared to a 1961–1990 baseline. Meanwhile, average precipitation on wet days has already increased by 0.6 percent per year in Cartagena between 1941 and 2009, and evidence exists that precipitation is becoming more intense in some parts of the country. Climate models, however, have poor agreement on the expected changes in precipitation, stemming from both the country's complex topography and uncertainty related to future changes in tropical cyclones. This means that building transport resilience for the port means its authorities must manage gaps in knowledge and data.

Figure C.35. Aerial Photograph of Isla del Diablo, the Island Site of Muelles el Bosque Port



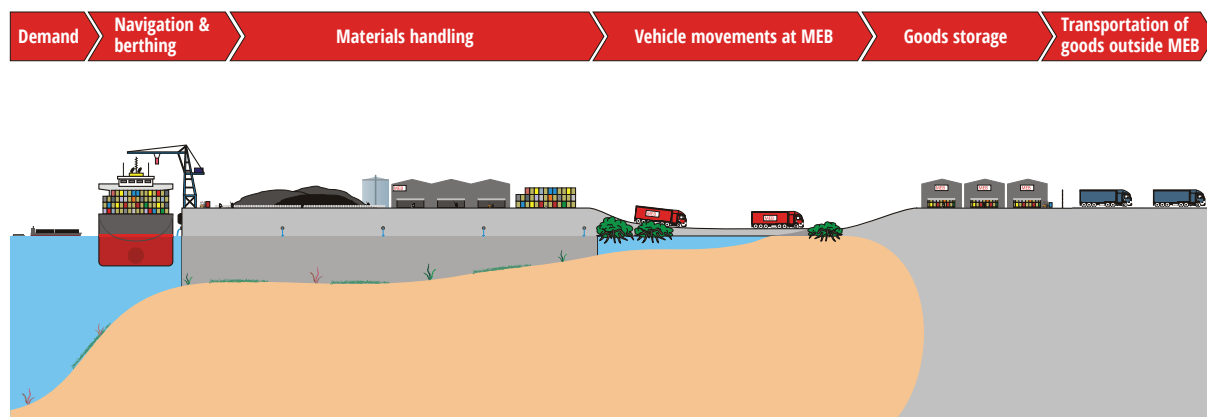
On the photograph, the following parts of the port can be seen:

- A and B: Port quays;
- C: Grain silos;
- D: Coke storage area;
- E: Patio for containers;
- F: Part of the causeway that connects to the mainland site; and
- G: Mangrove around the causeway.

## SOLUTION

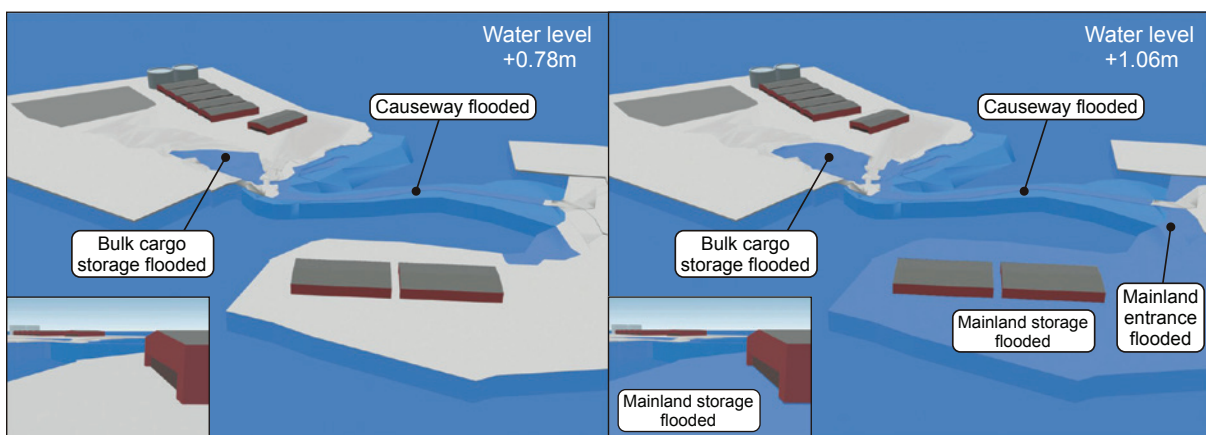
To plan for this uncertainty and increase transport resilience for the port, the study considered both an observed sea level rise scenario of 5.6 millimeter per year, as well as an accelerated sea level rise scenario of up to 1.3 meter by 2100. Moreover, based on an understanding of the importance of the overall transport of goods through the port, the study assessed potential effects of climate change on the entire chain of transport responsible for moving goods, including the supply and demand of goods, maritime transport, and ground transport (Figure C.36). Specific goals were to assess material vulnerabilities and risks that may affect the port's operations and affect financial, environmental and social sustainability.

Figure C.36. Conceptual Model of a Cargo Handling Port and Main Success Criteria that can be Affected by Climate Change



Importantly, the study found that key climate impacts on port operations may come in parts of the chain outside the port company's operational or financial control, namely in the area of supply and demand of goods. In this case, closely following the market and making adjustments are the best response. For the part of the transport chain that is within the port company's control, the most significant operational impact is related to an increased disruption of port access as a result of a higher frequency of flooding of the causeway connecting the port to the mainland (Figure C.37).

**Figure C.37. Projected Seawater Flooding in a 3D Model of Muelles el Bosque Port in 2050**



Note: The map shows seawater flooding during the highest spring tides and highest water level on the bay attributed to wind set up and rainfall.

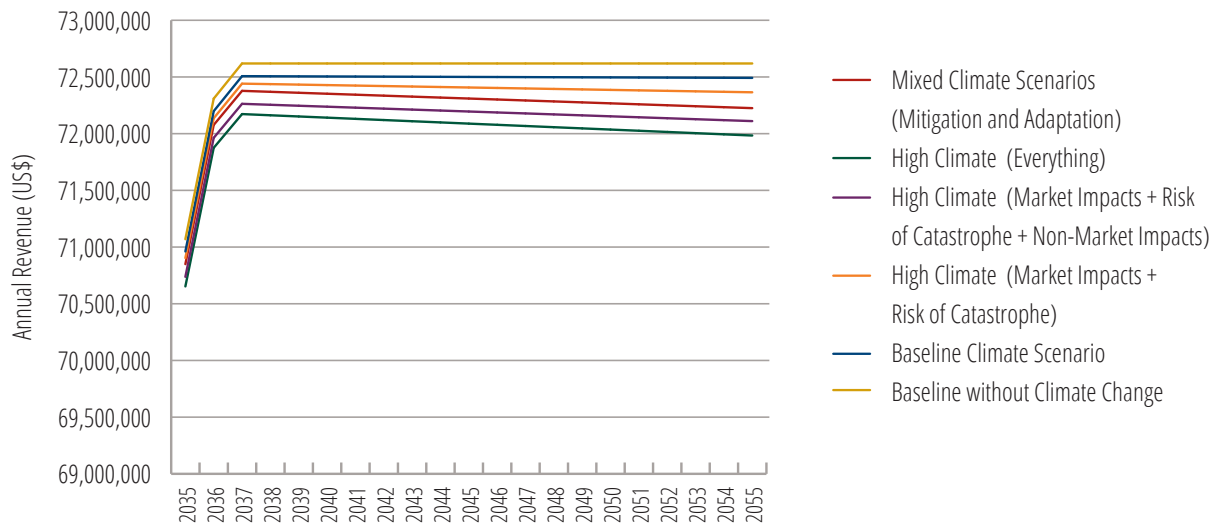
### Climate Models and Impacts of Rising Sea Level on the Port

In countries, such as Colombia, where climate models perform poorly, the public sector must support the development of improved high resolution climate change projections. In Colombia, this has been done through the national Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), which has developed regional climate projections using the PRECIS modeling system.

In general, considering climate models as well as navigation and berthing requirements, sea level rise is expected to lead to an increase in navigable water depths in many coastal ports and shipping channels, while generally decreasing requirements for dredging. At the same time, however, changes in rates of coastal erosion and deposition will affect the depths of some navigation channels and lead to increased dredging costs. In addition, increased capital expenditure may be needed in ports where sea levels rise above the operability range of infrastructure and equipment. For instance, reduced clearance under some bridges will limit their use by large vessels under low water level conditions. Climate change can also lead to reduced river flows or lake levels in some areas with severe implications for navigation and port access.

In the specific case of Cartagena Bay, the study adopted a practical approach to assess the potential implications of climate change for MEB's imports and exports. Considering for example climate implications on demand and trade level patterns, the Stern Review on the Economics of Climate Change estimated that by the 2050s average costs of climate change could be as much as 1.25 percent of global per capita consumption. For the MEB, the implications of such global GDP reductions could amount to an annual revenue loss of about US\$ 640,000 by 2055 (Figure C.38).

**Figure C.38. Potential Global Economic Impacts of Climate Change on Muelles el Bosque Port Annual Revenue between 2035 and 2055 (in US\$)**



The study also assessed the risk of future surface floods on goods handling and storage on the port's island site, considering that combined changes in surface water runoff and sea level rise could lead to flood risks and seawater surcharge of drainage pipes. In the accelerated sea level rise scenario (estimated to be 1.7 meter above the port plan datum), toward the end of this century the mean sea level during the highest spring tide is expected to reach the critical limit of the port's drainage system, above which it can no longer cope with both the seawater ingress and increased rainfall. When adding the effect of storm surges to this scenario, seawater ingress is expected to be critical to drainage already earlier in the century.

Finally, the study also addressed impacts to infrastructure, buildings, and equipment, and found these to not be significant. Other relevant aspects for the functioning of the port addressed by the study included the working of insurance policies, which do not cover assets outside of the port area and thus are not effective for business disruptions, and the environmental impact of MEB operations under climate change scenarios. These later impacts were also not expected to be significant, with the exception of (a) an expected 30 percent increase in energy use for refrigeration with associated greenhouse gas emissions; (b) a possible increase of the risk of overflow of sediment traps and oil/water traps due to seawater flooding at the port; and (c) a limited, but not impossible, increased risk of pollutant runoff during episodes of surface flooding.

Based on the analyses in the study and the recommendations, the port company invested US\$10 million in upgrades of the infrastructure and the causeway. Figure C.39 shows the new causeway.

**Figure C.39. Before (2009) and After (2016) Images of Muelles el Bosque Port Showing the New Causeway**



Source: Google Earth.

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