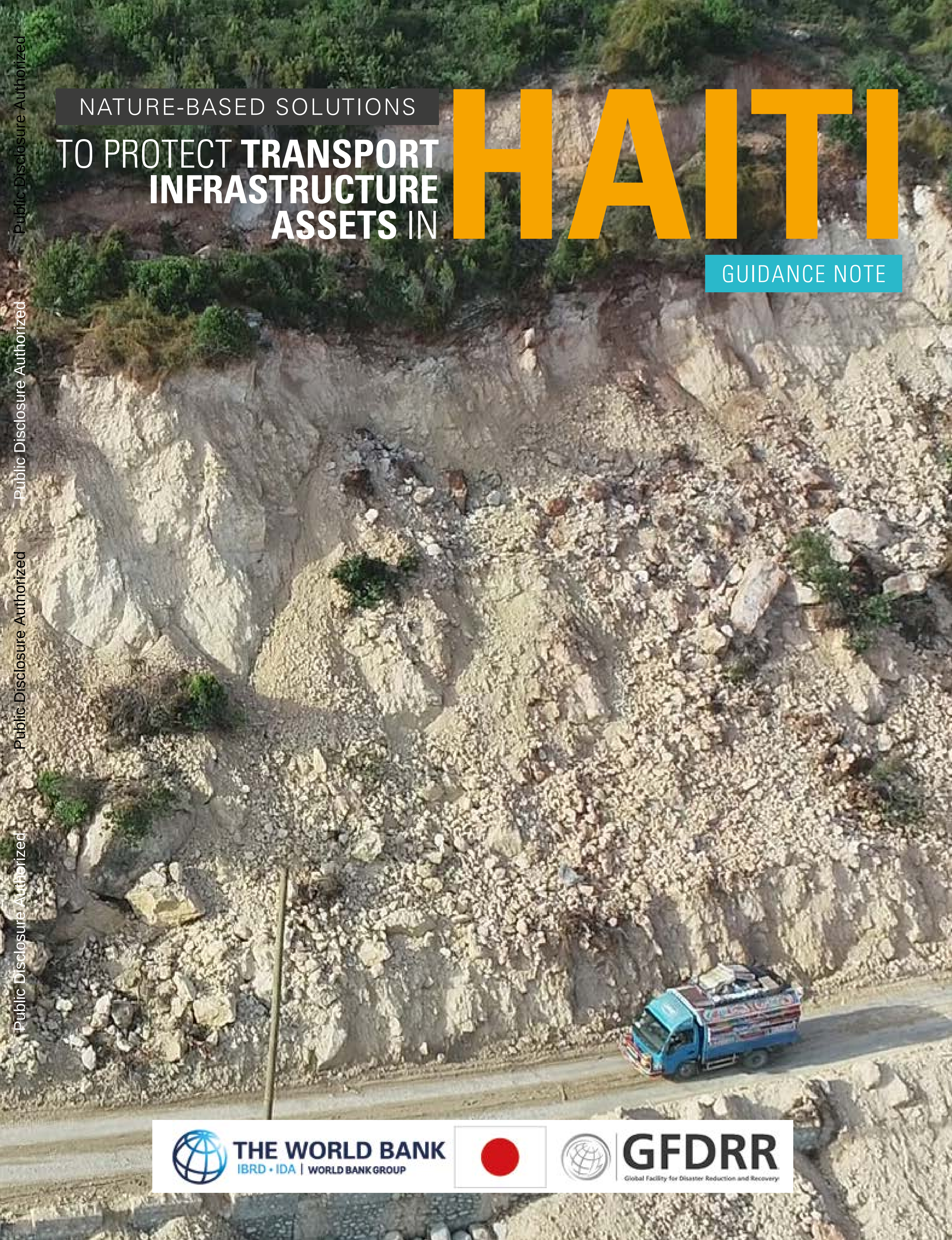

NATURE-BASED SOLUTIONS TO PROTECT TRANSPORT INFRASTRUCTURE ASSETS IN HAITI

GUIDANCE NOTE

THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP

GFDRR
Global Facility for Disaster Reduction and Recovery

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Cover photo: Lorgensky Pelicier/UNOPS

Note from the Authors

On Saturday August 14, 2021, a 7.2 magnitude earthquake struck the southern and southwestern part of Haiti. The U.S. Geological survey located the epicenter of this earthquake 8 kms from the town of Petit Trou de Nippes, about 150 kms from the capital of Port-au-Prince, and the same region devastated by Hurricane Matthew 5 years ago this month. Three departments in Haiti, the South, the Nippes and Grand'Anse were severely impacted. Although being less catastrophic than the January 2010 earthquake, according to official data, an estimated 800,000 people were affected, of which 2,207 have died, 12,268 were wounded, and 650,000 need humanitarian response.

The earthquake severely impacted the infrastructure sector specially the transport assets. Estimates indicated that 147 km of national and departmental roads and about 510 km of no primary roads were damages in those three departments. The total effects to the transport sector summed up to 150 million dollars including damages and economic losses. Due to road damage many communities lost all access to the rest of the island that resulted in 407,000 additional people in the Grand'Anse and the Sud Department losing access to critical services for days.

This guidance note was finalized few weeks prior to the disaster and hence its content does not reflect the impacts and damages described above. this note focusses extensively in the affected area, as the motivation for this work came as result from the reconstruction efforts after Hurricane Matthew. The three same departments affected by the recent earthquake were part of the pilot areas and were visited by the team in 2019 and 2020. For example, it provides National Road 7 (RN7) and Departmental Road 25 (RD25) as case studies from application of NBS solutions and both roads were severely impacted by the earthquake.

We hope that this guidance note can support the recovery efforts by providing and strengthening the knowledge and framework to incorporate nature-based solutions in road transport projects and by ensuring that the infrastructure sector follows a Build Back Better Approach for a Stronger and Resilience Haiti.

October 2021 - Malaika and Xavier

Acknowledgments

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INDEX

1. INTRODUCTION

1.1

Haiti's vulnerability to natural hazards and climate change

Located in the Caribbean Sea Haiti is approximately 28,000 square kilometers. Haiti occupies the western third of the island of Hispaniola (La Isla Española); and the Dominican Republic which occupies the eastern two-thirds of the island. Northwest of the northern peninsula is the Windward Passage, a strip of water that separates Haiti from Cuba, which is about ninety kilometers. The eastern edge of the country borders the Dominican Republic.

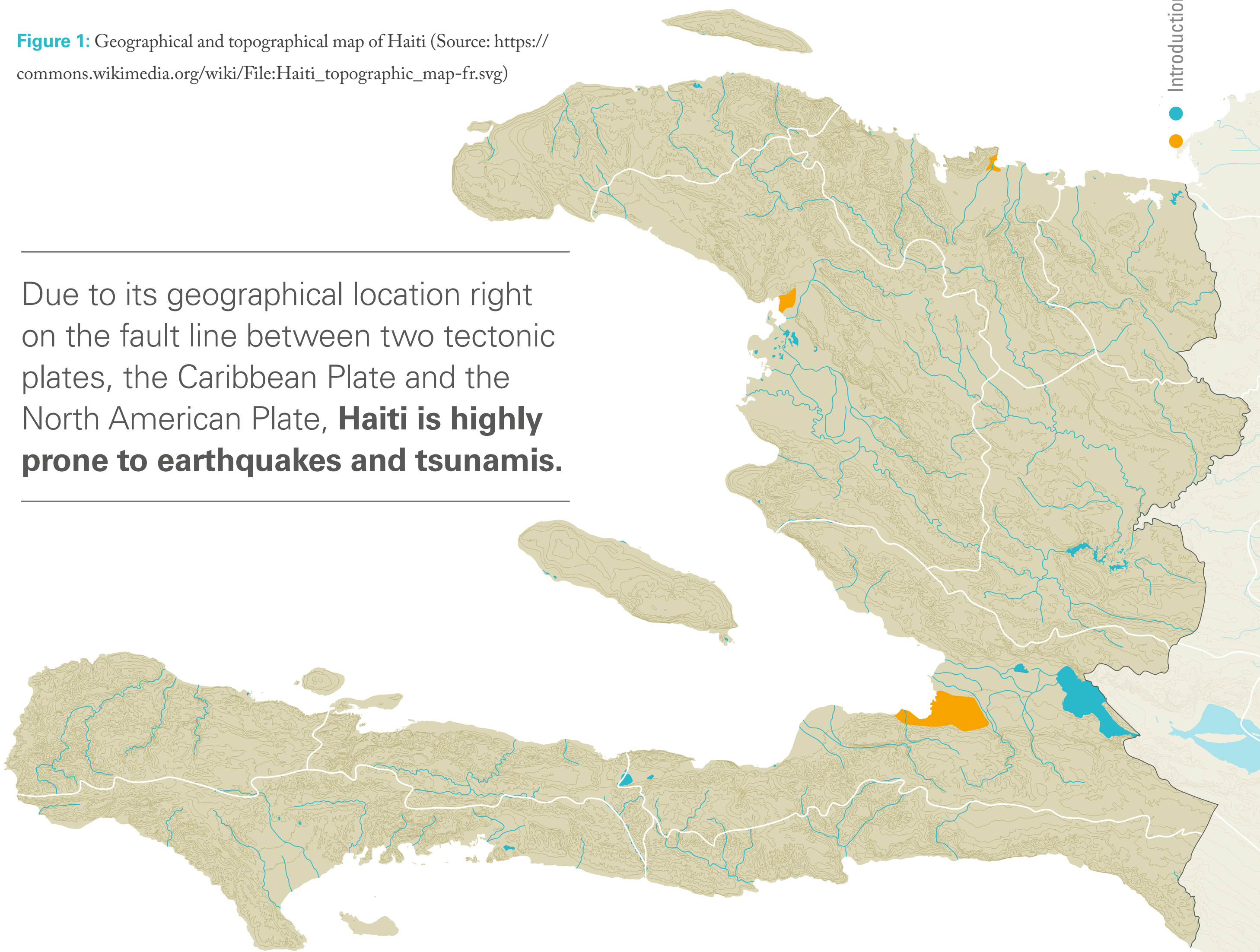
The mainland of Haiti has three regions: the northern region, which includes the northern peninsula; the central region; and the southern region, which includes the southern peninsula. In addition, numerous small nearby islands make up a part of Haiti's total territory, the most notable of which are Gonâve, Tortue – Tortuga -, Grande Caye, and Vache.

The rugged topography of central and western Hispaniola is reflected in Haiti's name, which derives from the indigenous Arawak place-name Ayti ("Mountainous Land"); about two-thirds of the total land area is above 1,600 feet (490 meters) in elevation. Haiti's irregular coastline forms a long, slender peninsula in the south and a shorter one in the north, separated by the triangular-shaped Gulf of Gonâve. Within the gulf lies Gonâve Island, which has an area of approximately 290 square miles (750 square km).

Haiti is one of the countries to be most exposed to hazards in the world, with more than 96 percent of its population at risk of two or more hazards[2]. Due to its geographical location, on the fault line between two tectonic plates, the Caribbean Plate and the North American Plate, Haiti is highly prone to earthquakes and tsunamis. As a mountainous country, landslides are very common along all river valleys, where years of deforestation has left the upper reaches of the western basins bare. Furthermore, because Haiti is in the path of the Atlantic regional hurricane belt, every year Haiti is subjected to the impact of severe storms during the regular hurricane season between June 1st and November 30th. This usually results in significant inland and coastal flooding. Also, during that time the country is exposed to other natural hazards such as increased coastal erosion or drought (usually within a period of five years, coinciding with El Niño conditions).

Climate change has been forecast to increase the frequency and severity of extreme hydro-meteorological events in Haiti, therefore exacerbating the impact of these hazards. This will result in higher temperatures and prolonged the duration and intensify tropical storms and hurricanes. Extreme rainfall events are also expected to worsen, while the dry season will add to the effects of climate change, with changes in the periodicity and frequency of drought. Sea level rise will increase the impact of coastal erosion and flooding for coastal areas.

Figure 1: Geographical and topographical map of Haiti (Source: https://commons.wikimedia.org/wiki/File:Haiti_topographic_map-fr.svg)



Due to its geographical location right on the fault line between two tectonic plates, the Caribbean Plate and the North American Plate, **Haiti is highly prone to earthquakes and tsunamis.**

The impact of climate change on road infrastructure has already been observed in many areas such as in the deterioration of pavements, on road foundations, in eroding road bases, the incapability of the capacity of drainage and overflow systems to deal with stronger or faster velocity of water flows, and impacted bridge foundations.

The country's vulnerability, in particular the road infrastructure to natural hazards and climate change has increased by development trends. For instance, the deforestation process in the country, which has resulted in the loss of most of its forest cover, making the country prone to increased erosion processes and landslide events. The impact of hurricanes, tropical storms, floods, and droughts has aggravated other anthropogenic factors such as inappropriate urbanization practices, the unsustainable use of natural resources, and inadequate waste management practices. Additionally, decades of poverty, political instability, and violence has left its infrastructure severely compromised, and its inability to cope with climate impacts and natural hazards.

1.2

Nature-Based solutions for resilient road infrastructure

Conventional hard engineering/grey infrastructure interventions are not able to adapt and compensate for the various effects of climate change (e.g., sea level rise), and thus need to be regularly maintained and reinforced, with significant cost implications. In addition, these structures often use unwanted negative impacts (e.g., coastal erosion) in other locations of the surrounding environment, significantly altering the function of the specific physical environment (e.g., shorelines) because of the interaction of the protection strategies with natural processes, as well as the corresponding ecosystems. In the coastal environment, hard engineered structures such as seawalls, breakwaters, or revetments, often result in reductions of sediment transport and the loss of intertidal habitats of wetlands and beaches.

Biodiversity and ecosystems provide important benefits to society, specially to adapt to the adverse effects of climate change and reducing disaster risk. For example, coastal vegetation, like mangroves can dissipate wave action, protect shorelines, accommodate flood flows, and forested mountains and slopes can stabilize sediments, mitigating landslides ([3];[4]). The ecosystem can prolong the sustainability and life spans of infrastructures such as roads, protecting investments in engineered defenses and restoring salt marshes adjacent to sea walls.

Strengthening the resilience of natural hazards and adapting to climate change is a process that should be incorporated in road authority's planning cycle and risk management procedures. Nature-based solutions (NBS) are an attractive alternative to hard engineering solutions, very often recognized as cost-effective interventions, which when feasible within a specific context, can enhance the sustainability and resilience of road infrastructure against the impact of natural hazards and climate change effects.

There is a need to integrate disaster risk reduction and climate change adaptation interventions NBS, into existing and future designs of road infrastructure to build its resilience. One condition would be to provide the tools to ensure that Haitian stakeholders can plan, manage, and initiate interventions that would consider the landscape in a holistic manner.

1.3

Purpose and scope of the guide

This Guide builds on the continuous growing work of NBS, including existing guidelines, frameworks, and principles relevant to climate change adaptation, disaster risk reduction, conservation, and development. An overview of existing guidelines, on which this Guide is based, is provided in Annex 1.

This Guide aims to promote the use of nature-based interventions as part of a broader portfolio of structural (risk reduction and adaptation) measures to enhance the sustainability and the resilience of road infrastructure in Haiti, as an alternative or with similar conventional hard engineered solutions, providing unambiguous evidence to why NBS should be considered by national and local transportation/road management agencies.

Through the provision of a step-by-step methodological approach to assist practitioners in the integration of NBS into transport sector investment projects, this Guide presents a resource and a tool for identifying/selecting, funding, designing, and implementing NBS for the protection of road infrastructure in the specific context of Haiti. The document highlights sustainable evidence-based approaches to ensure that current and future road infrastructure investments, as well as wider land use developments, can be made resilient against natural hazards and climate change effects in a more cost-effective, environmentally responsible, and socially beneficial way.

The NBS approaches highlighted in this Guide have multiple use and can be applied in different contexts, often overlapping across sectors, with the understanding that the site-specific context often determines the design, materials, and construction methods needed to be used. Ideally, NBS should be promoted and built into sector policies and design standards, taking into consideration that in some contexts they work best when used in combination with conventional engineering solutions.

1.4 Audience

The Guide is meant to be used as a strategic tool to support local and national governments, the private sector, practitioners, donors, NGOs, and civil society organizations in the planning, design, implementation, and management of NBS enhancing resilience of road infrastructure. The Guide is therefore intended for:

A. Public sector and Civil Society Organization

Stakeholders from public organizations and governments responsible for the planning, designing, or monitoring maintenance of transport infrastructure projects. Such users include professionals involved in infrastructure asset management, emergency and civil contingency planning and response, appraisal and design of road networks, shoreline management, as well as local community groups.

B. Private sector

Engineers, developers, designers, and contractors (and other organizations) involved in the planning, development and/or construction of infrastructure and infrastructure management systems.

1.5

Structure of the guide

The Guide consists of seven sections: **Section 1** which introduces the scope and target audience of the Guide, **Section 2** outlines the context of Haiti and its road infrastructure at risk from disaster, **Section 3** introduces the concept of NBS, **Section 4** presents a brief introduction to the economics of NBS **Section 5** provides a stepwise approach to the planning and implementation of NBS, **Section 6** demonstrates the importance of stakeholder engagement in NBS, **Section 7** provides a catalogue of NBS for enhancing the resilience of road infrastructure suitable for Haiti's context, and finally **Section 8** presents designs prepared to strengthen Haiti's road infrastructure for two pilot sites in Haiti.

1.6

Tools and resources for NBS

Over the last decade, there has been a growing awareness, interest and momentum from communities, donors, policy, and decision-makers for the application of Nature-based solutions (NBS) as part of disaster risk reduction, climate change adaptation, mitigation, and sustainable development strategies. In addition, by increasing resilience to natural hazards and climate change, NBS interventions have provided multiple other socio-economic and environmental co-benefits.

The NBS concept has received immense interest in the scientific community in the last few years. A growing body of knowledge and experience continues to support the application of NBS in a diversity of settings, accompanied by an increasing number of tools and resources for their design and implementation for disaster risk reduction and climate change adaptation. Protocols, guidelines, and lessons learnt from the application of these approaches on several case studies exist, for the use of coastal areas and urban areas, as well as for agriculture and landscape management. In contrast to traditional hard engineered solutions, which has a long history of development of protocols and standards, these solutions are still emerging approaches that have yet to be fully evaluated and standardized, and further guidance and standards need to be developed to support all professionals involved in project development (e.g., designers, implementers, funders, evaluators, and others).

The progress of guidelines and lessons learnt from case studies helps to achieve a mutual understanding of the effectiveness, risk reduction and adaptation outcomes of these approaches. As a result, there is a need to continue building the body of knowledge and experiences on the application of NBS for disaster risk reduction and climate change adaptation of other sectors, such as the transport sector. By building on existing literature, this document aims to be one step closer to the standardization of guidelines for the use of NBS for the protection of road infrastructure, describing how these solutions can be conceptualized and applied in practice.

EU Initiatives for the promotion of NBS

NBS have been identified by the European Commission as a strategic frame to support sustainability. “The vision of the European Commission is to position the EU as a leader in nature-based innovation for sustainable and resilient societies”, and in order to achieve this, it has been very active in establishing an NBS evidence and knowledge base, developing a repository of best practices, creating an NBS Community of Innovators, and improving communication and NBS awareness. The following table lists the EU funding programs, NBS projects, platforms, and networks that have been or are being funded by the European Commission since 2011.

Research and innovation | Actions and partnerships

Biodiversa (http://www.biodiversa.org/)
Clever Cities (http://clevercities.eu/)
Connecting Nature (https://connectingnature.eu/)
EdiCitNET (https://cordis.europa.eu/project/rcn/216082_de.html)
Eklipse (http://www.eklipse-mechanism.eu/)
GRaBS (http://www.ppgis.manchester.ac.uk/grabs/)
Green surge (https://greensurge.eu/)
Grow Green (http://growgreenproject.eu/)
Inspiration (http://www.inspiration-h2020.eu/)
Nature4Cities (https://www.nature4cities.eu/)
Naturvation (https://naturvation.eu/)
NAIAD (http://www.naiad2020.eu/)
OpeNESS (http://www.openness-project.eu/)
OPERAs (http://operas-project.eu/)
OPERANDUM (https://www.operandum-project.eu/)
PHUSICOS (https://phusicos.eu/)
proGIreg (http://www.progireg.eu/)
Reconnect (https://reconnect-europe.eu/)
TURAS (http://r1.zotoi.com/)
Unalab (https://www.unalab.eu/)
Urban GreenUp (http://www.urbangreenup.eu/)
URBINAT (http://urbinat.eu/)
ReNAture (http://renature-project.eu/)

Dialogue platforms to promote innovation with NBS

ThinkNature (https://www.think-nature.eu/)
Oppla (https:/www.oppla.eu/)
EU Smart Cities Information System (SCIS) (https://www.smartcitiesinfosystem.eu/)
EU Climate Adaptation Platform CLIMATE-ADAPT (https://climate-adapt.eea.europa.eu/)
Sustainable Cities Platform (http://www.sustainablecities.eu/)

Source: [5]

2. HAITI’S COUNTRY CONTEXT - ROAD NETWORK AND DISASTERS

2.1

Haiti's key geographical features

The mainland of Haiti has three regions: the northern region, which includes the northern peninsula; the central region; and the southern region, which also includes the southern peninsula. The country has approximately 1,771 km of coastline, which are rocky and rimmed with cliffs, and the island's shelf extension totals around 5,000 square kilometers. The country is distinguished by its narrow coastal plains lying between steep mountain ranges and the coastline, and is also characterized by several major mountain ranges that extend from East to West (see Figure 1). About two-thirds of the total land area has an elevation above 490 meters.

Located in northern region is the Massif du Nord (Northern Massif), an extension of the central mountain range (Cordillera Central) of the Dominican Republic, which begins at Haiti's eastern border, north of the Guayamouc River, and extends to the northwest through the northern peninsula. The Massif du Nord ranges in elevation from 600 to 1,100 meters. It is adjacent to the Plaine du Nord (Northern Plain), which lies along the northern border of the Dominican Republic, between the Massif du Nord and the North Atlantic Ocean. This lowland area of 2,000 square kilometers, is about 150 kilometers long and 30 kilometers wide.

The central region consists of two plains and three sets of mountain ranges. The Plateau Central (Central Plateau) extends along both sides of the Guayamouc River, south of the Massif du Nord. It runs eighty-five kilometers from southeast to northwest and is thirty kilometers wide. The Plateau has an average elevation of about 300 meters. It is located on the southwest side by Montagnes Noires (Black Mountains), with an elevation of approximately 600 meters. The most northwestern part of this mountain range merges with the Massif du Nord. The Southwest of Montagnes Noires is near the Artibonite River, Plaine de l'Artibonite, which has a surface of about 800 square kilometers. South of this plain lies the Chaîne des Matheux and the Chaîne du Trou d'Eau, which is an extension of the Sierra de Neiba range of the Dominican Republic.

The southern region consists of the Plaine du Cul-de-Sac and the mountainous southern peninsula. The Plaine du Cul-de-Sac is bounded in the north by the Chaîne des Matheux and the Chaîne du Trou d'Eau, is twelve kilometers wide and extends thirty-two kilometers from the border of the Dominican Republic to the coast of the Baie de Port-au-Prince (Bay of Port-au-Prince). The mountains of the southern peninsula, an extension of the southern mountain chain of the Dominican Republic (the Sierra de Baoruco), extends from the Chaîne de la Selle in the east to the Massif de la Hotte in the west. The highest peak in this range is Pic la Selle, the highest point in Haiti, rising to an altitude of 2,680 meters, and located at a distance of 18 km from the coastline, with an average slope of 18.5°. The Massif de la Hotte varies in elevation from 1,270 to 2,255 meters.

Rivers are numerous but short, and most are not navigable. In total, Haiti has approximately 3,300 km of major (perennial) rivers, located in the Southwest and Central North. Although, over a hundred streams flow through Haiti, the largest river is the Artibonite river, which has a length of 245 kilometers (145 miles). It is shallow and long, and its flow averages ten times that. Second in length is Les Trois Rivières, which spills into the Atlantic in the town of Port-de-Paix.

2.2

Haiti's natural hazards and climate change context

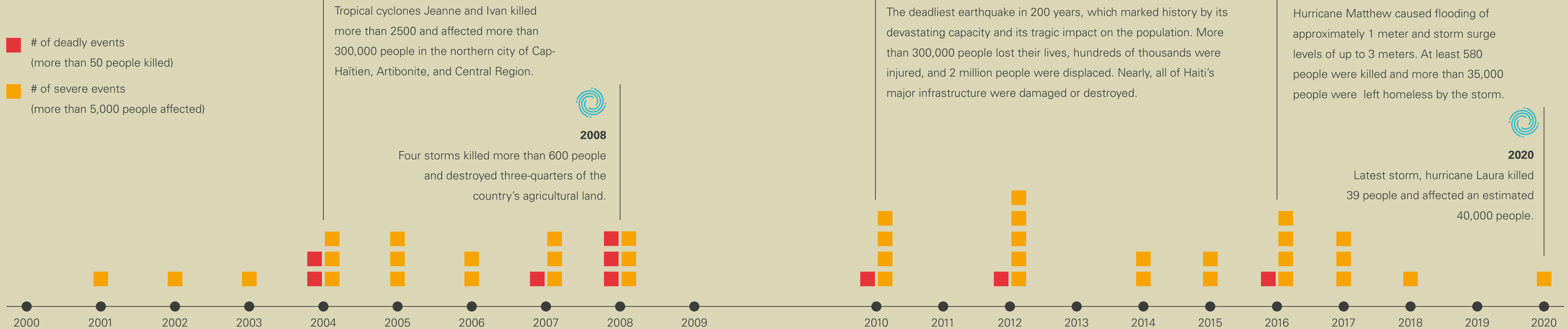
According to data collected by the Haitian Ministry of Agriculture, Natural Resources, and Rural Development (Ministère de l'Agriculture, des Ressources Naturelles, et de Développement Rural, MARNDR), the average observed temperatures rose by more than 1 degree centigrade between 1973 and 2003. Extreme and variable weather conditions alternate between drought in the dry season (December to April) and intense storms and hurricanes in the wet season (May to November). Haiti lies in the hurricane belt of tropical storms that originate in the Atlantic Ocean and strike Caribbean islands every hurricane season. According to Haitian natives, the country has experienced radical changes in climate variability, especially during the rainy season and the frequency and intensity of hurricanes and tropical storms, which has led to flooding and erosions. The impacts which are magnified by severe environmental degradation and is highly likely attributed to climate change. The changes in variability and extreme weather noted by Haitian citizens are in line with the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). For example, the report indicates that in the 1990's, 35 percent of tropical cyclones were classified as Category 4 or 5, in comparison to only 20 percent in the 1970's.

Flooding is a major problem in almost all of Haiti's 30 major watersheds, due to intense seasonal rainfall, storm surges in the coastal zones, deforested and eroded landscape, and sediment-laden river channels. During tropical storms and hurricane season an average of 200 millimeter of rain may fall in a month[6] . This leads to rapid runoff from deforested and eroded mornes (small mountains) and hills (flash floods), as well as the overflowing of rivers.

Flooding washes away fertile soil, depositing it on riverbeds of the Artibonite, the Grande Rivière de Jacmel, and the Rivière de Grande Anse). Massive sedimentation has raised the beds of many waterways and have created a complete absence of embankments and levees. These factors intensify the next round of flooding, leading to the destruction of crops, farmland, and agricultural infrastructure, as well as the loss of livestock and human lives. Climate change is expected to exacerbate these problems.

The low-lying plains of the Ouest and Artibonite departments and the narrow coastal zones of the Sud, Sud-Est, Grande Anse, and Nippes departments are especially vulnerable to flooding. On the Cul de Sac Plain of the Ouest department, the Rivière Blanche and Rivière Grise basins are particularly subject to severe flooding. Heavily populated coastal towns, such as Jacmel, Les Cayes, and Gonaïves, lie in the direct path of the storms.

Recent disasters in Haiti[7]



2.3

Road infrastructure in Haiti

Haiti has a road network length of approximately 3,400 km. It is degraded, having lost about 30% of its extension during the last 15 years. The road network national, departmental, and municipal scales, has the following classification (see Figure 2):

- The ***national network (primary)*** covers 978 km and connects main cities of socioeconomic or political importance.
- The ***departmental network (secondary)*** has a length of about 1,615 km and connects urban areas with the national network.
- The ***municipal network (tertiary)*** covers approximately 873 km and ensures connectivity with the rest of the municipalities.

The road network is characterized by:

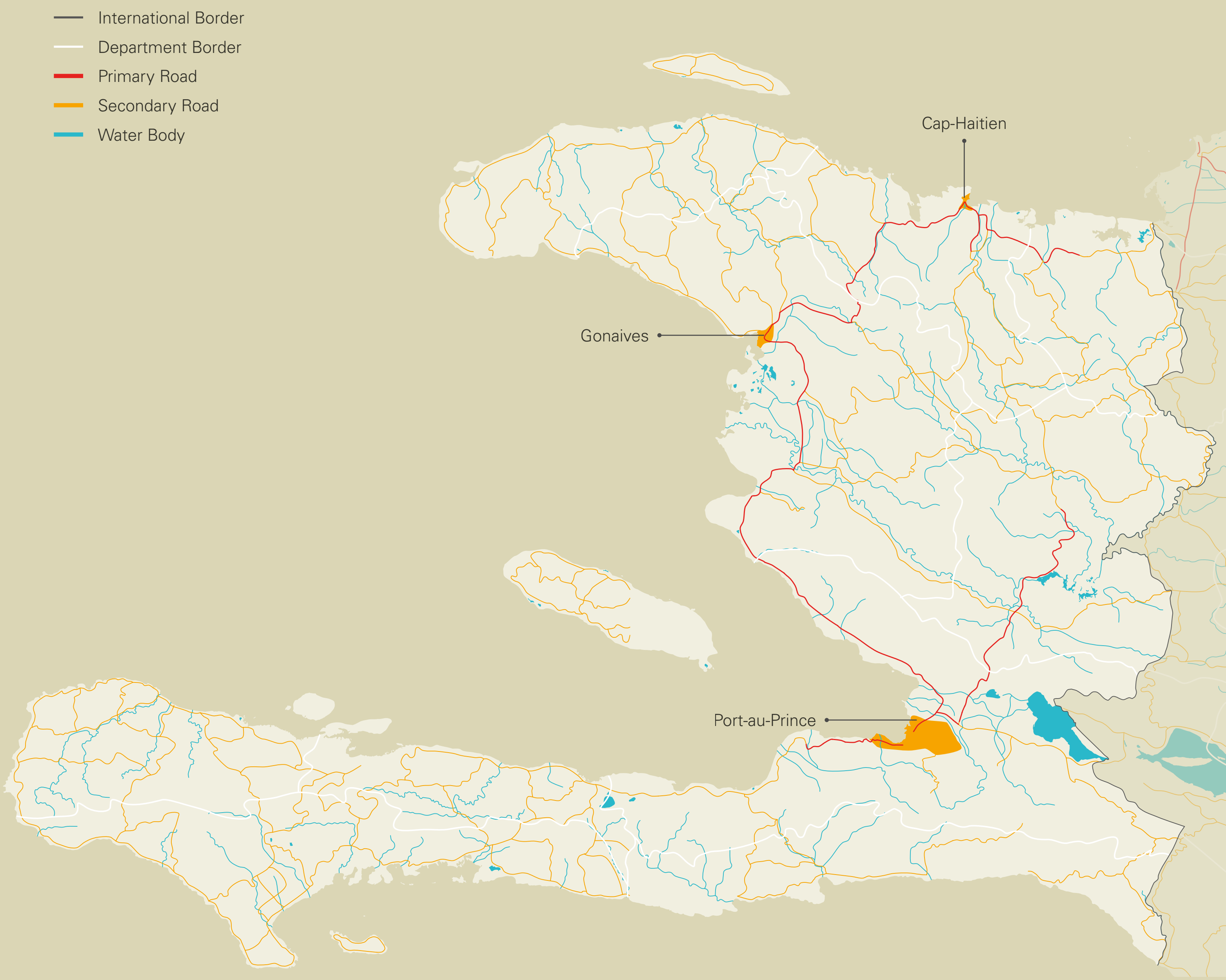
- A small portion of paved roads (less than 20%) is concentrated along the primary network.
- Limited number of roads are bounded by bridges at river crossings and gullies.

In the past, Haiti has witnessed severe damage to its main roads and bridges as a result of the impacts of various natural hazards. Such impacts still limit the access and usage of functioning roads, with severe implications (e.g. connectivity) for people. Damaged roads prevent the passage of goods and services between the different regions of the country and hinder fast access to impacted communities in times of crisis and quick post-emergency recovery. These challenges, limit the transportation of food and primary goods, have perpetuated hunger and poverty throughout the country.

The most vulnerable configurations commonly identified in Haiti are mountain roads, coastal roads, and crossings (bridges and culverts). These configurations are presented schematically in Figure 3.

In the past, Haiti has witnessed serious damage to its main roads and bridges as a **result of the impact of various natural hazards.**

Figure 2: Haiti's Road Network Classification (Source: https://commons.wikimedia.org/wiki/File:Haiti_road_map-fr.svg)



1. Mountain roads:

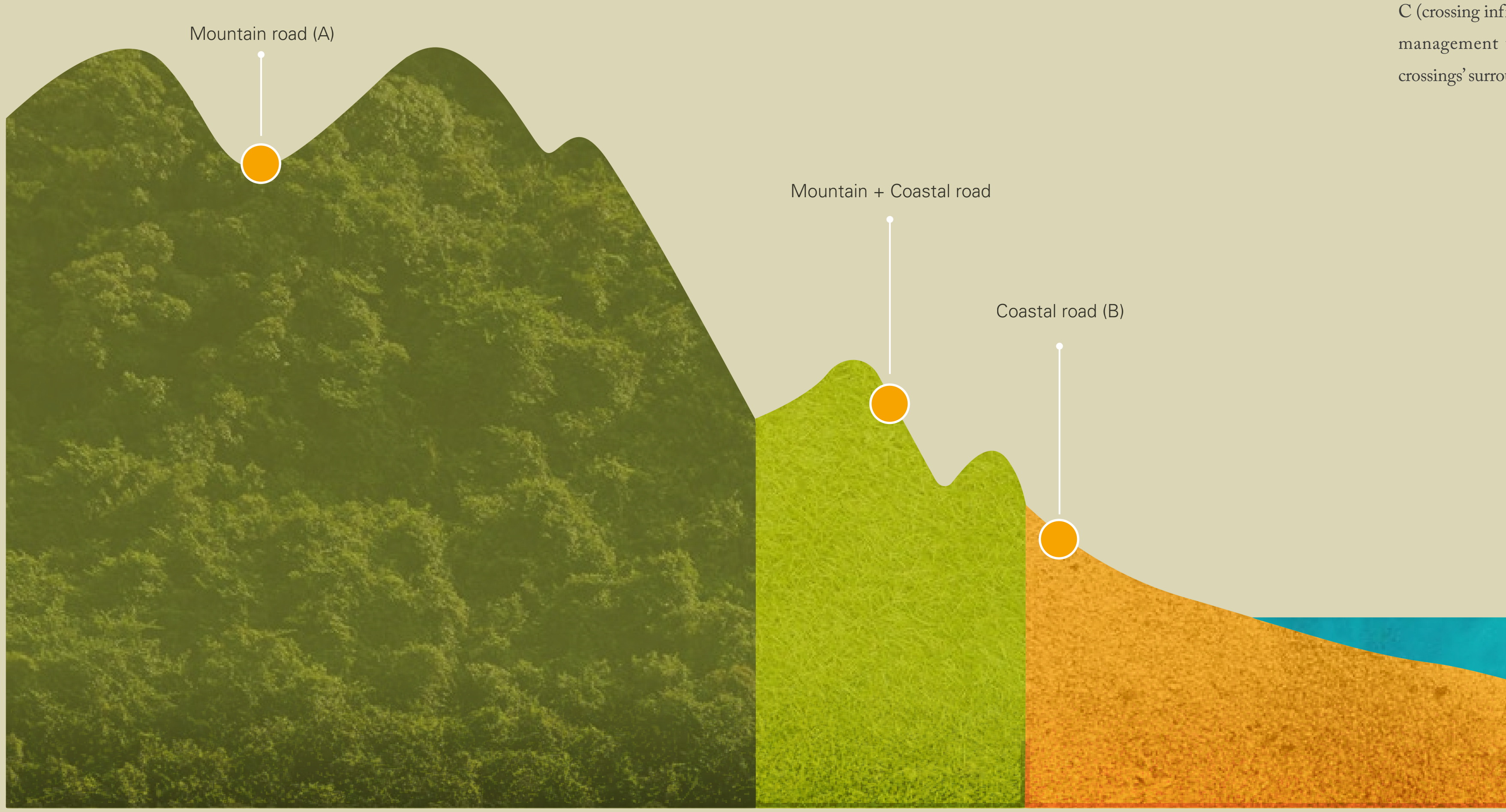
Haiti's mountainous ecosystems have been significantly altered by the severe deforestation process which has resulted in high levels of soil erosion, consequently increasing the risk of slope failure and landslides. To mitigate impacts on mountain roads, NBS aims at providing greater stability to uphill and downhill slopes of roads and redesigning drainage systems.

2. Coastal roads:

A large part of the country's road network is located close to the coast and is therefore exposed to the impact of storm surges and coastal erosion. To reduce these impacts, NBS measures can be used to restore and promote the marine-coastal environment and combined hybrid measures for stabilization and protection.

In Haiti, roads often have configurations (A) and (B). In these cases, there are no one-fits-all solutions that can provide protection against the hazards typically impacting both types of configurations. As such, in this context, the implementation of a combination of appropriate solutions responding to configurations (A) and (B) should be considered.

Figure 3: Road Configurations A and B: mountain and coastal roads

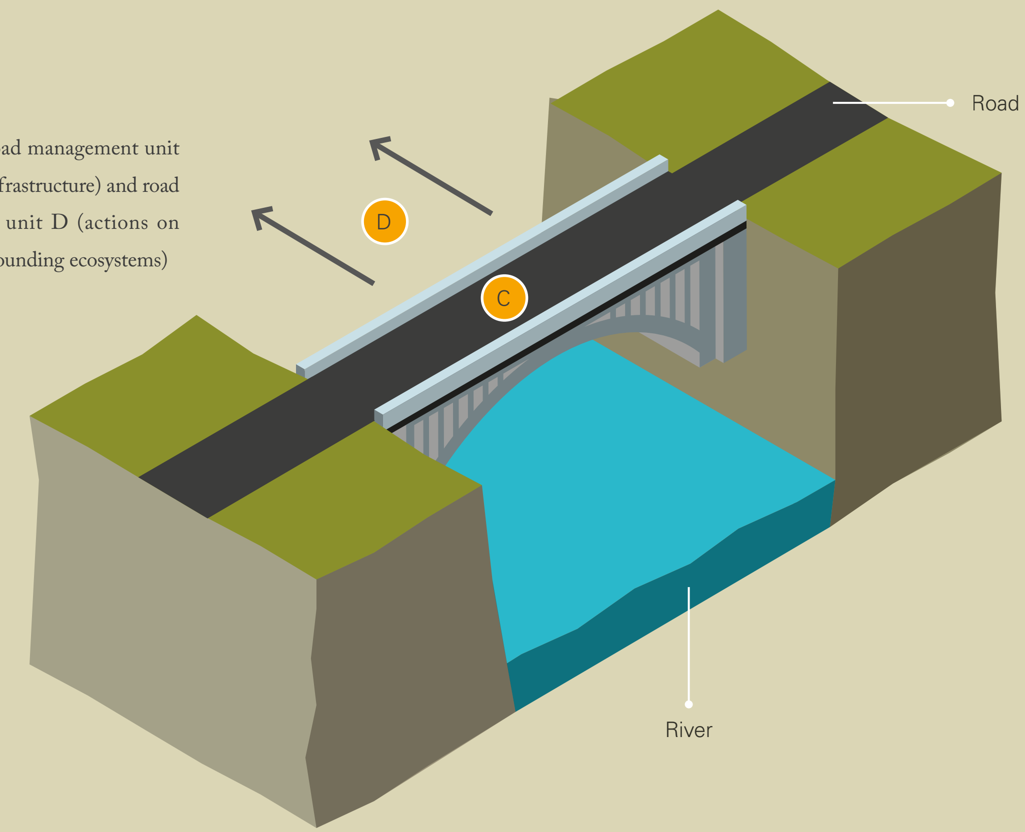


3. Crossings/bridges:

One of the most common problems in Haiti is related to the impact of river flows on crossing infrastructures. In addition, to the increasing and more intense floods, riverbank degradation and the consequent excess sediment that accumulates at the base of crossing infrastructure undermine its stability. At this point, the sediments cause the water speed to increase and thus flow rates end up modifying the structure. In such configurations, NBS can operate both at the specific site of the infrastructure (C), and at the basin level, with actions upstream of the infrastructure (D) (see Figure 4).

One of the most common problems in Haiti is related to the **impact of river flows on crossing infrastructure.**

Figure 4: Road management unit C (crossing infrastructure) and road management unit D (actions on crossings' surrounding ecosystems)



2.4

Impacts of natural hazards and climate change on haiti's road infrastructure

Haiti's road infrastructure is significantly exposed to the impacts of natural hazards and sensitive to the increased frequency and severity of hydro-meteorological hazards associated with climate change.

Among relevant climate change those affecting the transport sector include increase frequency and intensity of extreme events that trigger more intense precipitation events, storm surges, increased temperatures, increased landslide frequency and increases in drought conditions, among other things. Sea level rise increase coastal erosion rates and long-term coastal flooding. There is already evidence of climate change having an impact on road infrastructure: deteriorating pavement integrity, impacting road foundations, eroding road bases, affecting the capacity of drainage and overflow systems to deal with stronger or faster velocity of water flows, and impactingbridge foundations.. A non-exhaustive list of potential impacts of climate change on road infrastructure are presented in Table 1. Some examples of NBS measures that are considered relevant to counteract these impacts in the context of Haiti are presented in Section 6 "Solutions catalogue".

Similarly, projected climate change is expected to have a significant impact on the planning, design, construction, operation, and maintenance of road infrastructure. Overall, climate change presents a significant risk for road authorities, requiring the adaptation principles and strategies to address potential impacts[8].

Although road infrastructure tends to be designed to withstand local weather and climate, designers and engineers typically rely on historical records of climate when designing road infrastructure. However, in the context of climate change, using historical climate data alone is no longer a reliable predictor of future impacts. Most paved roads are usually built to last for 50 years or longer.; Understanding how future changes in climate may affect this infrastructure is important for protecting long-term investments.

Table 1: Potential Impacts of Climate Change on Road Infrastructure ([9], [10]).

Climate Change Projection in Haiti	Potential natural hazard and climate change	Impacts on Road Infrastructure in Haiti
Temperatures are expected to increase by 0.5 to 2.3°C by 2060	Increased temperatures	• More frequent bucking experienced by roads • Deterioration of pavement integrity • Thermal expansion on bridge expansion joints and paved surfaces
Projected increases in temperature, coupled with decreases in rainfall during the critical summer months (June- August) are likely to intensify drought conditions	Increase temperatures and decreased precipitation	• Corrosion of steel reinforcements in concrete structures due to increase in surface salt levels in some locations
	Increase in drought conditions	• Damage to road infrastructure due to increased susceptibility to wider uncontrolled wildfires • Damage to infrastructure due to increased susceptibility to mudslides in areas deforested by wildfires
Sea level is projected to rise between 0.05 and 0.22 m at 2030 in the Caribbean	Sea Level Rise added to storm surges	• Inundation of roads in coastal areas • More frequent or severe flooding of low-lying infrastructure • Damage to roads, and bridges due to flooding, inundation in coastal areas, and coastal erosion • Damage to infrastructure from land subsidence and landslides • Erosion of road base and bridge supports • Bridge scour • Reduced clearance under bridges • Loss of coastal wetlands and barrier shoreline
Hurricane rainfall may increase by 6-17% and surface wind speeds of the strongest hurricanes will increase between 1-8%, with associated increases in storm surge levels.	Increase in intense precipitation events	• More frequent washouts of unpaved surfaces • Increase of flooding and damage to roads and drainage systems due to flooding • Overloading of drainage systems, causing backups and street flooding • Increase in scouring of roads, bridges, and support structures • Damage to road infrastructure due to landslides and flash floods • Deterioration of structural integrity of roads and bridges due to increase in soil moisture levels • Adverse impacts of standing water on the road base
	Increase of storm intensity (more frequent strong hurricanes, Category 4-5)	• Damage to road infrastructure and increased probability of infrastructure failures • Increased threat to stability of bridge decks • Increased damage to signs, lighting fixtures, and supports • Decrease expected lifetime of roads exposed to storm surge
	Increase in wind speed	• Signs, and tall structures at risk from increasing wind speeds

3. NATURE BASED SOLUTIONS (NBS): CONCEPTS AND PRINCIPLES

3.1

Nature-based solutions for infrastructure resilience

Nature-based solutions (NBS) are defined by the International Union for Conservation of Nature (IUCN) as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (2). The NBS framework emerged from the ecosystem approach, which underpins the Convention on Biological Diversity (CBD) and considers biodiversity conservation and human well-being to be dependent on functioning and resilient natural ecosystems[11].

NBS aim to conserve or restore nature to support conventionally built infrastructure systems and can reduce disaster risk and produce more resilient and lower-cost services in developing countries. In the disaster risk management and water security sectors, NBS can be applied as a green infrastructure strategy that can work in harmony with gray infrastructure systems. NBS can also support community well-being, generate benefits for the environment, and advance progress toward the Sustainable Development Goals (SDGs) in ways that gray infrastructure systems cannot.

NBS can be considered an umbrella concept (2) covering a range of ecosystem-based approach that address specific or multiple societal challenges while simultaneously providing human well-being and socio-economic and biodiversity benefits. Approaches under NBS can be classified into five categories, as described in Table 2 and Figure 6: (1) Restorative, (2) Issue-specific, (3) Infrastructure, (4) Management and (5) Protection.

- Related Terminology[60]:
- Coastal green infrastructure
- Natural infrastructure
- Living shoreline
- Natural and nature-based features (NNBF)
- Engineering With Nature® (EWN)
- Building with Nature (BwN)
- Working with Nature (WwN)

Table 2: Description and examples of NBS categories

Category of NBS approach	Description	Types		Examples[12]
Restorative	Technical process that aims to recreate, initiate, or accelerate the recovery of an ecosystem that has been disturbed - degraded, damaged, or destroyed. Restoration activities may not be a primary goal for transportation infrastructure projects, but it can be used as part of compensatory mitigation efforts. [13]	• Ecological restoration (ER) is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed. (SER 2004) • Ecological Engineering (EI) focuses on the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both[14]. • Forest landscape restoration (FLR) is the long-term process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes[15].		• Revegetation: Vegetated buffers that protect water quality in riparian ecosystems from urban or agricultural runoff • Habitat enhancement: • Remediation: Tidal wetlands restoration; • Mitigation: legally mandated remediation for loss of protected species or ecosystems. • Design of tidal creeks • Introduction of particular plant species for salt marsh restoration Use of species that trap sediment for coastal protection of a sandy shore
Issue-specific	Ecosystem-related approaches that vary based on their objective, including Ecosystem-based adaptation (EbA), Ecosystem-based mitigation (EbM), Ecosystem-based disaster risk reduction (Eco-DRR) and Climate adaptation services (CAS).	• Ecosystem-based approaches to adaptation (EbA) use of biodiversity and ecosystem services to help people adapt to the adverse effects of climate change. • Ecosystem-based approaches to mitigation (EbM) use of ecosystems for their carbon storage and sequestration service to aid climate change mitigation. • Ecosystem-based disaster risk reduction (Eco-DRR) reduces disaster risk by mitigating hazards and by increasing livelihood resilience. [16] • Climate Adaptation Services (CAS) are benefits to people from increased social ability to respond to change, provided by the capacity of ecosystems to moderate and adapt to climate change and variability [17]		• Coastal habitat restoration in ecosystems such as coral reefs, mangrove forests, and marshes to protect communities and infrastructure from storm surges • Coastal realignment • Agroforestry to increase resilience of crops to droughts or excessive rainfall (crop diversification to include drought-tolerant varieties) • Integrated water resource management to cope with consecutive dry days and change in rainfall patterns • Sustainable forest management interventions to stabilize slopes, prevent landslides, and regulate water flow to prevent flash flooding • Restoration of terrestrial forests (degraded or deforested landscapes) and vegetated coastal ecosystems (seagrass meadows, tidal marshes and mangrove forests) for carbon sequestration • Coastal roads protection: Restoration of mangroves of salt marshes for coastal protection; artificial reinforced dunes; • Roadside slope protection: Protection of forests that stabilize slopes; use of brush mattresses for slope protection and stabilization; log terracing for erosion protection of road embankments.

Nature based solutions (NBS): concepts and principles

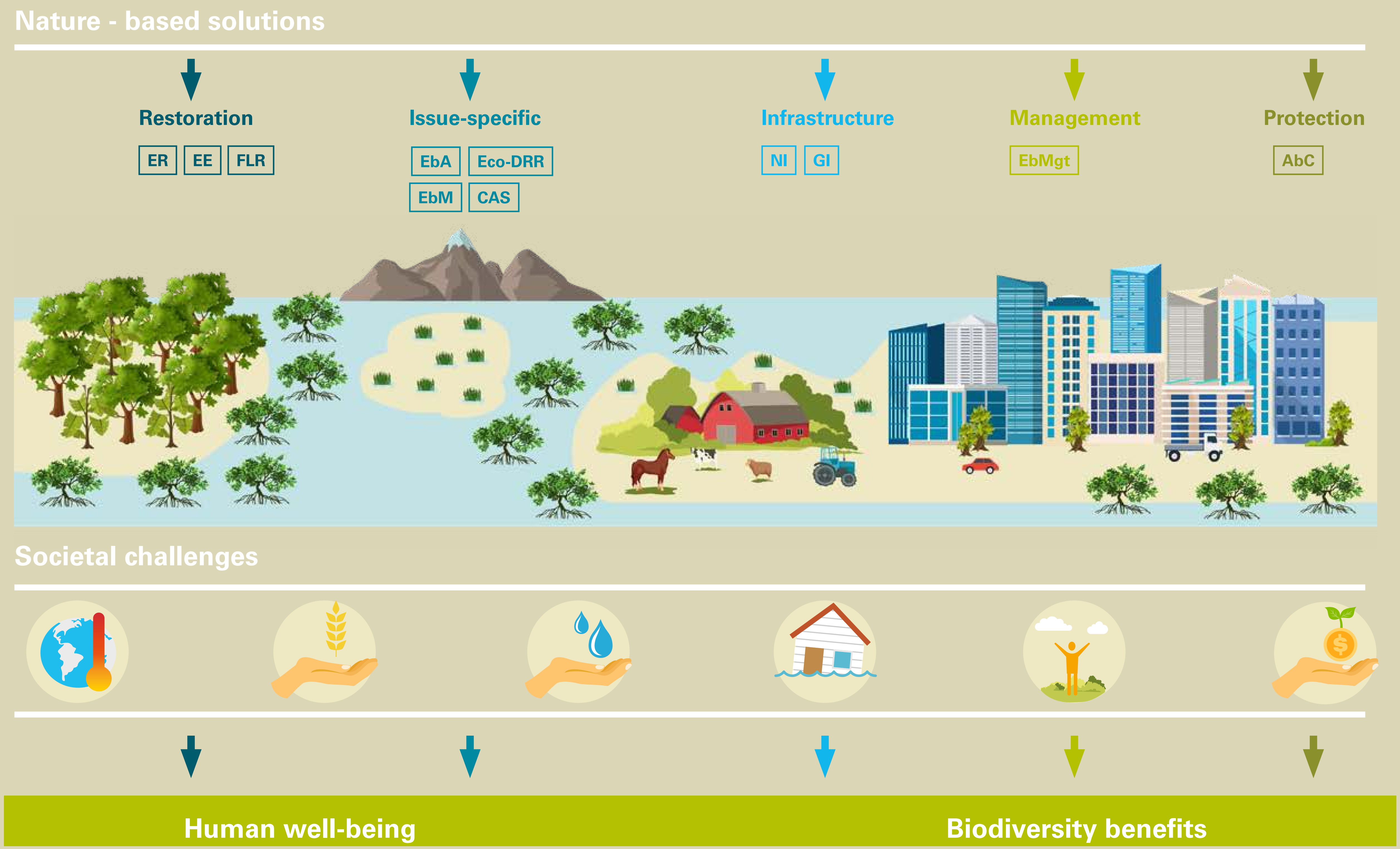
Category of NBS approach	Description	Types		Examples[12]
Infrastructure	These approaches rely on services produced by ecosystems, often utilizing natural landscapes to minimize flood damages, purify and store water, and reduce urban stormwater runoff. Incorporating green infrastructure into road and highway design can protect from the brunt of storm surges and waves and avoiding erosion and sedimentation. Some can adapt to sea level rise by accreting sediment or migrating inland. They can also provide benefits such as recreation opportunities, habitat needed for commercial fisheries, and a healthier environment.	• Natural Infrastructure (NI) manages natural lands, such as forests and wetlands that conserves or enhances ecosystem values and functions and provides associated cobenefits [18] • Green Infrastructure (GI) is natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. GI replicates or mimics the natural functions of a landscape by integrating functions like storage, detention, infiltration, evaporation, and transpiration, or uptake by plants, and are created by human design and engineering. () [19]		• Oyster reefs for wave attenuation • Marsh and dune plantings to prevent erosion • Tide flap on the stormwater outfall to prevent backflow • Bioswales or grassed swales: grassy areas on the side of the road that convey drainage; they can be designed to promote pollutant removal and infiltration of runoff. • Rain gardens: landscaping features planted with vegetation that collect, infiltrate, evaporate, and transpirate runoff. • Wetlands (whether natural or engineered) for water storage and filtering of pollutants

Nature based solutions (NBS): concepts and principles

Category of NBS approach	Description	Types		Examples[12]
Management	Integrated management approach that recognizes the full array of interactions within an ecosystem, including humans, rather than considering single issues, species, or ecosystem services in isolation. It is an approach that works across sectors to manage species and habitats, economic activities, conflicting uses, and the sustainability of resources, and allows for consideration of resource tradeoffs that help protect and sustain diverse and productive ecosystems and the services they provide[20]	• Ecosystem-based Management is an integrated, science-based approach to the management of natural resources that aims to sustain the health, resilience and diversity of ecosystems while allowing for sustainable use by humans of the goods and services they provide.[21 22]		• Integrated coastal zone management • Integrated water resources management
Protection	These approaches cover many management or governance approaches that are applied to specific geographic areas and have objectives and/or outcomes relevant to conservation and sustainable use. They are basically Area-based conservation (AbC) approaches, and include approaches such as Protected Area (PA) management and Other Effective Area-based Conservation Measures (OECMs), but may also apply to areas beyond Pas and OECMs . These approaches need to be assessed on a case-by case basis. Governance of these approaches can be under governments, private actors, indigenous peoples and local communities, or combinations of actors.			• Protected Area (PA) management • Other Effective Area-based Conservation Measures (OECMs).

Ecosystem approach

Figure 5: Conceptual representation of the NBS umbrella concept for five categories of ecosystem-based approaches[24]



Nature based solutions (NBS): concepts and principles

3.2

Nature-based solutions and hybrid interventions

There is a broad range of potential suitable solutions across the spectrum from green/nature-based to hard engineered/gray infrastructure. The combination of these solutions allows drawing from the expertise and solutions from both ends of this spectrum.

Hybrid interventions consist of a combination of nature-based/green, hard/gray, and non-structural interventions that may be used to protect infrastructure, while providing other ecosystem service benefits. It is often the case that the combination of ecosystem-based measures (e.g. restoration of mangrove forests, salt-marshes inter-tidal flats, seagrasses or coral reefs for coastal protection) with hard engineered structures (e.g. breakwaters, revetments, etc.) can extend the lifespan of gray infrastructure, while at the same time supporting fisheries, regulating water quality, and sequestering carbon. "The combined solution can therefore be more comprehensive, robust and cost-effective that of either solution alone"[87].

Given Haiti's vulnerability and the severity and frequency of events affecting the country, most NBS applicable are likely to be integrated with hard/grey infrastructure solutions into hybrid interventions.

Similarly, the implementation of hybrid solutions is very appropriate for Haiti's mountain ecosystems (e.g. for., slope stabilization purposes), where the steep slopes and the high exposure to erosion and landslide hazards make revegetation interventions often insufficient, and thus other strategies must be undertaken.

Key elements of Hybrid Intervention[84]

1. 1. Ecosystems are conserved and/or restored to provide measurable social, environmental, and economic benefits;
2. These interventions include selective integration of a conventional engineering approach; and
3. They provide a climate resilience and/or risk reduction benefit.

The type of solution to be selected depends on some or all of the following factors: i) the project objective, ii) land use considerations in the surrounding environment, iii) ecosystems native to the site, iv) project costs (including monitoring, maintenance and adaptive management), v) desired performance, and vi) local policy and regulations.

The table 3 below lists the strengths and weaknesses of hard, nature-based and hybrid interventions.

Table 3: Comparison between hard interventions, nature-based interventions, and hybrid interventions[63]

Intervention options	Strengths		Weaknesses
Hard interventions (such as sea walls, breakwaters)	• There is a lot of experience in undertaking these interventions. • Expertise and guidance already exist. • Will provide protection as soon as they are built. • Detailed understanding regarding the design standards and protection that the intervention will offer.		• New structures required or structures must be modified to adapt to environmental change. • Has a residual life which weakens over time. • Can have negative impacts on coastal ecosystems and cause reduction in ecosystem services provided by the coastal zone. • Generally, have limited wider benefits apart from storm/ erosion protection. • Can experience more damage from ongoing small storm events compared to nature- based interventions.
Nature-based solutions	• Can provide a wide range of benefits as well as shoreline protection including fishery habitat, water quality, carbon sequestration, tourism enhancement, and recreation. • If ecosystems are restored or replanted, they often get stronger and more resilient over time. • Have the potential to self- recover or repair after both small and larger storm events. • Has the potential to naturally adapt and keep pace with environmental change and sea level rise. • Can be cheaper compared to hard interventions. • Has the potential to engage the local community and stakeholders in protecting, restoring, and enhancing coastal ecosystems that support their livelihood. In the long-term, this builds the adaptive capacity and resilience of coastal communities and ecosystems.		• There is less guidance and best practice available • Hard to predict the level of protection that will be provided • Can provide varying levels of protection geographically • Can take longer for the ecosystem to establish. • Generally, require more space for implementation compared to hard interventions. • Limited data to allow quantification of benefits and comparison of benefit-cost ratios. • Can be more difficult to gain planning approvals for these projects.
Hybrid intervention options	• Capitalizes on the strengths of both hard and nature-based solutions. • Provides opportunities for innovation. • Can be used to provide wider benefits but where there is little space or there is a requirement for immediate protection. • Has the potential to engage the local community and stakeholders in protecting, restoring, and enhancing coastal ecosystems that support their livelihood. In the long-term, this builds the adaptive capacity and resilience of coastal communities and ecosystems.		• Does not provide as many wider benefits as a nature- based intervention. • Requires more research for best practice examples. • Can still have some negative environmental impact.

Nature based solutions (NBS): concepts and principles

Examples of hybrid intervention to protect transport assets that combine typical hard and nature-based solutions are shown in table 4 and schematize in Figure 7, with a list of examples of potential management strategies (NBS/green, hard engineering/grey)) applicable to road infrastructure assets in the context of mountain roads and coastal areas. Detailed examples can be found in section 6 the Factsheet catalogue. The two pilot sites prioritized under this project feature the types of hybrid solutions suitable to the Haiti context (see Section 8. for a case study).

Table 4: Examples of hybrid interventions for mountain and coastal areas

Mountain Areas				Costal Areas		
Hybrid Intervention		Objective		Hybrid Intervention		Objective
NBS/Green	Gray			NBS/Green	Gray	
Slope drainage and revegetation (e.g. restoration of grasslands and/or forests)	Combined with Gabion baskets or check dams	Slope protection for erosion and landslide prevention; manage runoff		Restoration of mangrove forests, salt-marshes or inter-tidal flats	combined with rock revetments or dykes	Protection from coastal erosion and coastal flooding
Planting of local deep-rooted species	With a structured element such as bamboo dams and fences or wall structures	Roadside stabilization and erosion and flood protection; income generation through the selling of the planted grasses (co-benefit)		Dune restoration and beach nourishment	combined with detached (offshore) breakwaters or groyns system	Protection from coastal erosion and coastal flooding; facilitate sediment accumulation
Upper slope: horizontal, vertical, and complementary drainage system, modification of the slope so that vegetation can grow.	Complemented by a system of protective barriers along the road	Slope protection for erosion and landslide prevention and mitigation against the impact of rock falls		Marsh/Mangroves forest restoration and Coral Reefs restoration	Combined with Road elevation Breakwaters construction	Protection of road and bridges from impact of waves
Lower slope: compacted embankment forming green terraces.	Protected with geotextile	Slope protection for erosion control and road base scouring				

Figure 6: Theoretical example of NBS for road protection in Haiti (developed by authors)

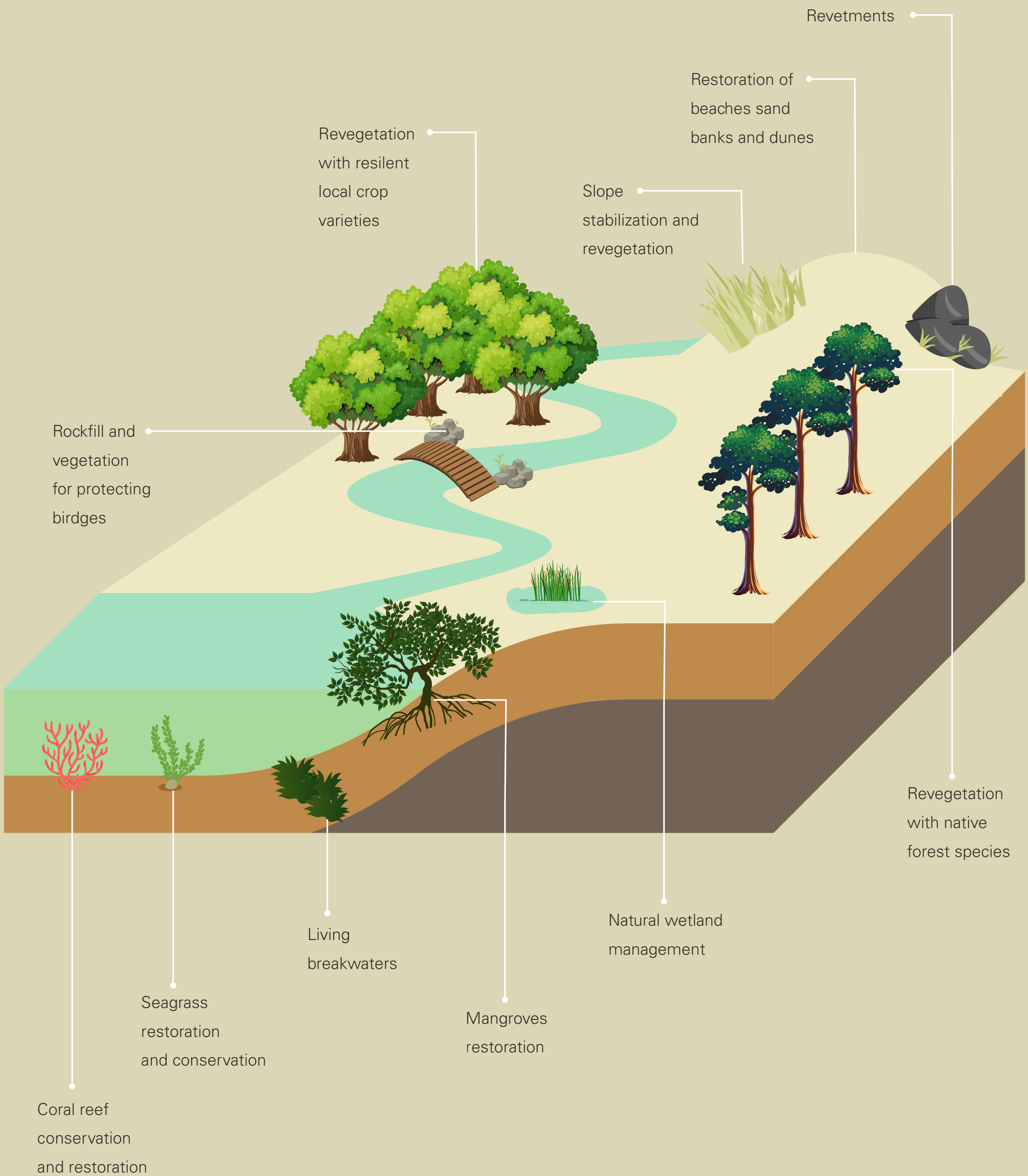


Figure 7: Gravel coastal road highly exposed to coastal erosion and flooding, where vegetated berm provides partial protection

3.3

Principles for implementing nature based solutions

While the term NBS is a relatively recent concept, its application is not; there is already significant evidence of the benefits that these approaches provide in reducing climate risks and contributing to the achievement of the sustainable development goals. These experiences have generated lessons learned and guidance principles. Table 5 summarizes five basic principles that may guide the development of future nature-based interventions during their design, implementation, and maintenance.

Table 5: Summary of the five key principles for NBS[25]

Principle	Description
Principle 1: System-scale perspective	Addressing nature-based solutions for climate change adaptation (EbA) and disaster risk reduction (Eco-DRR) should start with a systemwide analysis of the local socioeconomic, environmental, and institutional conditions. Consider the spatial scale, time scale, and local socioeconomic and institutional context.
Principle 2: Risk and benefit assessment of full range of solutions	A thorough assessment of the risks and benefits of the full range of possible measures should be conducted, covering risk reduction benefits as well as social and environmental effects.
Principle 3: Standardized performance evaluation	Nature-based solutions for disaster risk reduction (Eco-DRR) need to be tested, designed, and evaluated using quantitative criteria.
Principle 4: Integration with Ecosystem conservation and restoration	Nature-based solutions for disaster risk reduction should make use of existing ecosystems, native species, and comply with basic principles of ecological restoration and conservation.
Principle 5: Adaptive management	Nature-based solutions for disaster risk reduction need adaptive management based on long-term monitoring. This ensures their sustainable performance.

3.4

Benefits and co-benefits of nbs and "climate proofing" road infrastructure

NBS offers a major opportunity for innovation with possibilities to deliver multiple long-lasting and tangible benefits to a wide array of societal challenges in a broad range of environmental, socio-economic, and cultural contexts (e.g. river basins - reforestation and green embankments; coastal zones - mangroves and wetlands; and cities - urban parks). These benefits depend on the specific project and setting.

In comparison to purely hard engineered/gray infrastructure solutions, NBS often provide cost and resource-efficiency benefits, and when combined with these structural measures, they often reduce operational and maintenance costs for hard infrastructure, and increase the life-span of such structures resulting in a longer lasting alternative, compared to a purely gray infrastructure. In addition, the conservation and/or restoration of ecosystems offer key co-benefits to infrastructure projects, such as potential of carbon sequestration, biodiversity protection, recreation and tourism or maintenance of soil fertility.

In the context of increased frequency and intensity of hydro-meteorological hazards and climate change, NBS represents an attractive ecological approach for disaster risk reduction and climate change adaptation, while also enhancing the resilience of natural and managed ecosystems and the human settlements next to them. They can also contribute to improving the adaptive capacity of a community by providing community organization training and supplemental support for livelihoods87.

In the transport sector, NBS demonstrates multiple direct benefits and co-benefits for climate proofing road infrastructure, including:

A. Ensuring the sustainability of the infrastructure

NBS can contribute to minimizing offsite sediment delivery from upland areas and thus protect the infrastructure and prolong its lifetime, minimizing operational and maintenance costs. Downstream, sediment loads lead to operational costs for desilting infrastructure such as irrigation canals, hydroelectric power dams and road infrastructure. Vegetative filter strips and reforestation are two NBS approaches used to address this problem. Reforestation practices can also contribute to the reduction of road surface temperatures, therefore reducing the degradation of roads due to high temperatures.

B. Protecting from hazards and climate change effects

When appropriately designed, NBS has high potential to protect infrastructure from hazards such as floods, landslides, and storms. In mountainous areas NBS can reduce the impacts from landslides and rock falls on road infrastructure through the stabilization of degraded slopes. This, in turn, will also help mitigate ongoing sedimentation of streams and prevent additional landslides and mudflows, and further secure the road infrastructure. Revegetation of slopes with deep-rooted native species and forest restoration interventions are some of the NBS practices used in mountain areas for slope stabilization.

Additionally, NBS reduces flooding by increasing infiltration, evapotranspiration, and water storage where precipitation falls. Increasing infiltration also recharges ground water reserves and can benefit aquatic habitats. Another environmental benefit of NBS for stormwater management is that it improves water quality by reducing runoff and allowing runoff to be treated by soils and vegetation. Reducing runoff can provide benefits for mitigating soil erosion, which causes upstream and downstream problems.

In coastal environments, NBS contributes to wave attenuation, therefore reducing the impact of coastal erosion and coastal flooding. Restoration and conservation of coral reefs, salt marshes or mangrove forests are some of the NBS approaches being used in coastal areas for coastal risk reduction.

C. Cost efficiency

NBS are often equal to or less than the initial cost of traditional engineering solutions (e.g. shoreline armoring). In addition, in comparison to conventional hard engineering/grey infrastructure measures, which are not able to adapt and compensate for the various effects of climate change (e.g. sea level rise), one significant advantage of NBS is that some can naturally adapt to parts of these effects. Traditional structural features need to be regularly maintained, after the impact of a disaster and require replacement or retrofitting to achieve similar goals.

When combined with hard engineered infrastructure, NBS often reduce operational and maintenance costs of this infrastructure and increase the lifespan of such structures resulting in a longer lasting and more cost-effective alternative, compared to a purely gray infrastructure. More details on the economic appraisal of NBS are provided in Section 4.

As it is widely recognized and has been previously shown, in addition to enhancing resilience to natural hazards and climate change effects, ensuring the sustainability of infrastructure, and providing cost efficiency benefits, NBS simultaneously facilitate natural ecosystem function, with benefits such as improved water quality, habitat, and fisheries. Specifically, the application of NBS for road infrastructure interventions provides a number of environmental and socio-economic co-benefits, including:

D. Improving water quality and securing access to water for nearby communities

By reducing runoff and increasing infiltration, NBS strategies help to minimize water pollution. This improves water quality and can reduce water treatment costs by 25 percent or more. Planting native plants can help reduce the usage of chemical fertilizers, further improving water quality. This provides public health benefits because people are less exposed to polluted water and drinking water contaminants.

E. Contribute to job creation and support to local livelihoods

In addition to roadside stabilization and erosion and flood protection; revegetation of slopes with deep-rooted native species can contribute to income generation through the selling of the planted grasses. The restoration of mangrove forests will contribute to coastal habitat restoration (e.g. nursery for fisheries), and thus support local livelihoods.

4. THE ECONOMICS OF NBS FOR ROAD INFRASTRUCTURE

The use of conventional road infrastructure protection, such as seawalls, revetments and breakwaters in coastal areas, has often resulted in significant alteration of the function of many shorelines worldwide because of the interaction of these protective structures with natural processes (e.g. reduction in sediment transport, loss of habitats of wetlands and beaches, etc.). More recently, road infrastructure projects often combine NBS with engineered structures into hybrid measures (see Section 3.2).

Selecting NBS rather than hard infrastructure requires being comfortable with a range of effectiveness and the dynamic nature of NBS, and depends on several factors, including their performance over time and an economic justification, at least in terms of risk reduction over the life of the project[26].

Over the past couple of decades, NBS have increasingly been applied for adaptation and/or disaster risk reduction purposes worldwide, addressing in particular the linked challenges of climate change and poverty in poor countries where dependence on natural resources and livelihoods is high. These experiences present growing evidence that NBS often provide low-cost solutions to various climate change challenges. Similarly, it is widely recognized that NBS provides a diversity of other gains (see Section 3.4), which would often place them in an advantageous position compared to other structural measures in the process of prioritization of alternatives.

There is currently very limited literature on the use of NBS to enhance the resilience of road infrastructure and the potential for using NBS for road infrastructure resilience. Some examples where NBS has been used to protect coastal road infrastructure exist.. Certainly, there may be numerous examples spread across regions, where roads and bridges benefit from additional protection or resilience afforded by natural systems, which could be documented. Some other roads and bridges may be potential candidates for the application of NBS. However, better documentation and tracking of NBS applications to address a transportation-related need are needed. The extent to which NBS can be used to protect vulnerable road infrastructure in Haiti (as well as in many other countries) is currently unknown and represents a knowledge gap at this time. A suitable methodology for addressing this knowledge gap, that takes into consideration all associated costs and benefits is therefore needed.

This section aims at providing a brief summary of key economic aspects that underpin the characterization of NBS (based on existing knowledge) to be considered in the assessment and prioritization of disaster risk reduction and climate change adaptation strategies, in an attempt to frame the conversation on the use of NBS to strengthen the resilience of road infrastructure.

Feedback from transportation professionals during the regional peer exchanges underscored the importance of being able to communicate to stakeholders **that nature-based solutions offer some risk-reduction potential, provide multiple benefits, and have reasonable costs**[22]

4.1

Tools for the selection of risk reduction and adpatation strategies

Traditionally, the selection of disaster risk reduction interventions has been based on cost-benefit analyses, where benefits were estimated in terms of reduced impacts or risks avoided. While these analyses continue to be an important tool for assessing the efficiency of disaster risk reduction interventions, with a shifting emphasis from hard engineered measures to NBS, other tools such as cost-effectiveness analysis, multi-criteria analysis and robust decision-making approaches deserve more attention, in order to ensure that investments made to reduce disaster risks are not only cost-effective, but that their benefits reach all members of the population, including the poor an vulnerable, who are often affected disproportionally.

There remains a lack of scientific synthesis and there are several knowledge gaps[28] that make it challenging to comprehensively understand the effectiveness of NBS measures for the specific local contexts, or to appropriately quantify the multiple socio-economic and ecological co-benefits provided by NBS. This often prevents NBS from being widely and consistently implemented and sufficiently mainstreamed into national and international policy processes[29]. To continue informing policy and practice, and improve adaptation, further work is required.

In general, all tools considered for the economic appraisal of risk reduction strategies will require an assessment of benefits and costs of each of the strategies that may be potentially used to meet the climate change adaptation or risk reduction target. Box 4.1 provides the typical steps to be followed in an economic analysis of NBS.

In general terms, for a risk reduction or climate change adaptation strategy to be prioritized above others, and therefore selected, overall benefits (quantitative and qualitative) should be "bigger" than overall costs. A summary of aspects related to the estimation of benefits and costs of NBS is presented in the following sub-sections.

Box 4.1.
Typical steps to be included in an economic analysis of NBS

1. Estimate benefits and co-benefits of NBS strategy:

- Assess primary benefits by estimating the difference in damages/losses with and without NBS over an extended period of time;
- Identify all co-benefits (e.g. habitat, open space, aesthetics, increased property values, improved water quality, etc.), and estimate their value;

---

2. Estimate NBS unit costs and overall strategy costs:

- Research and obtain relevant up-to-date cost information on NBS (e.g. from past projects); network with other communities for cost information;
- Estimate the costs of the overall NBS strategy over the complete life cycle of the NBS (e.g. 20 to 50 years) by summing all associated costs; consider the following costs: i) planning, design and permitting costs, ii) costs of land required for the implementation of NBS, including opportunity costs, iii) capital costs (costs of creation, protection, or restoration), and iv) operation, maintenance and monitoring costs;

---

3. Estimate annualize costs and benefits over a specific time frame:

- Discount the calculated benefits and costs to obtain present values, in order to make a fair comparison of costs (paid in the early years of a project) and benefits (realized year by year over a number of decades);
- Distribute the present value across the years of analysis in order to produce the average benefit or cost in each year (i.e. annualized benefit or annualized cost).
- Estimate annualized net benefits by subtracting annualized costs from annualized benefits;

(Adapted from[30])

4.2

Assessing benefits and co-benefits of NBS

A first step in the economic analysis is the estimation of the total benefit of a climate change adaptation or risk reduction strategy. This should ideally be comprised of the sum of all benefits and co-benefits. The distinction between benefits and co-benefits of project alternatives (e.g. NBS) depends first on the primary objective of the project, and secondly on other aspects such as the strategic priorities of the agency developing the project and those of the communities located in the vicinity or adjacent to the project area.

This Guide is focused on interventions that can strengthen the resilience of road infrastructure to the impact of natural hazards and climate change. Therefore, the benefits to be considered are those related to the efficacy of the intervention to reduce the risk of natural hazards, and/or improve adaptation to climate change effects (e.g., protecting services provided by NBS estimated as damages avoided from reduced flooding); whereas co-benefits are any other relevant benefits that results from the implementation of the specific intervention (e.g., other ecosystem services provided by NBS).

The assessment of the risk reduction and climate change adaptation benefits of various NBS has been the object of numerous research initiatives, particularly over the last decade. Today, there is reasonable consensus on coastal protection services (flood and erosion risk reduction) provided by coastal habitats, and can often-reduce the costs of coastal NBS compared to alternative coastal structures (e.g., submerged breakwaters) for the same level of protection (similar risk reduction benefits)[30]. In addition, these NBS have been reported to be able to keep pace with SLR, on sheltered coastlines. A recent study undertaken on the flood risk reduction benefits of coral reefs across 3,100 km of US coastline estimates the hazard risk reduction benefits of US coral reefs to exceed US$1.8 billion annually[31].

For NBS located in coastal environments, there is, however, a key technical gap on the relationship between the benefits of NBS and time27. On one hand, there is limited literature that describes the ability of NBS to reduce storm hazards as a function of storm duration. On the other, the long- term reliability and performance of NBS are, like all coastal

"On average, **coastal habitats reduce wave heights between 35% and 71%. Coral reefs reduce wave heights by 70%, salt-marshes by 72%, mangroves by 31% and seagrass/kelp beds by 36%',** with coral reefs having the greatest potential for coastal protection (highly effective at reducing wave heights and are also exposed to higher, more powerful waves), followed by salt-marshes, which are almost as effective in terms of wave reduction, but occur in more sheltered environments. Mangroves and seagrass/ kelp beds are about half as effective, with mangroves occurring in the most sheltered environments."[13]

infrastructure, subject to the effects of sea level rise, and therefore, t these NBS will continue to provide equivalent risk reduction benefits and depend on the magnitude of future rates of sea level rise.

As previously noted, NBS provide numerous additional benefits or co-benefits, in the form of water quality improvements, sediment management, resource production, carbon sequestration, job creation and tourism and recreational services, to name a few. However, while the wide-reaching and potentially long-lasting risk reduction and adaptation-related benefits of NBS, of coastal NBS, have been quantified in terms of monetary values, many of the socio-economic and ecological co-benefits provided by NBS are non-monetary, and therefore not accounted for in traditional CBA. Quantifying the total ecosystem services of NBS is critical for demonstrating the advantage position of NBS in comparison with traditional engineering measures; however, the following considerations should be noted:

- While co-benefits may be difficult to monetized, there is currently a growing body of literature related to quantifying ecosystem services ([32], [33], [34]); although, few unified studies that draw on wide sets of data and characteristics. To try to place a value on ecosystem services, the benefit transfer method may be used[35]. This method uses economic values for ecosystem services in one location to approximate the value in a different location.
- There is also a lack of information concerning the role of ecosystem services and how they might best be leveraged as part of transportation planning or impact mitigation (3).

Table 6 provides a (non-exhaustive) list of risk reduction benefits provided by some NBS that may be integrated as part of road infrastructure projects in coastal and inland/ mountainous environments, as well as a list of socio-economic and ecological co-benefits of these measures. All these benefits should therefore be fully assessed as part of the prioritization of appropriate risk reduction strategies for the reduction of risk to road infrastructure as part of Step 3 specifically. Step 3.2 (see Section 5); the economic assessment methodology should ideally consider the annual benefits related to all these aspects over an extended period of time.

A couple of considerations regarding the benefits associated to NBS should be noted:

- Table 6 shows the benefits of each of the individual NBS. However, it should be noted that according to recent studies, the combination of NBS is shown to yield benefits beyond those achieved individually (e.g., oyster reef in combination with marsh vegetation had a greater impact on reducing wave height than each of these measures individually[36], and the combination of corals, seagrasses and mangroves achieved more protective services than any individual habitat or combination of two habitats[37].
- In addition, given that some NBS seem more effective at reducing the risk of some hazards under low to moderate intensity events, combining NBS with traditional engineered structures may address some of these shortcomings and address the factors that may have contributed to their degradation over time, while simultaneously enhancing the resilience of both the infrastructure and the ecosystem, thus yielding the greatest benefits over time.

Table 6: Risk-reduction and climate change adaptation benefits and socio-economic and ecological co-benefits of NBS

Type of NBS	Benefits for DRR & CCA	Strengths & weaknesses	Co-benefits
Coastal areas			
Coral Reef/Oyster Reef Restoration	• Coastal flood risk reduction => wave attenuation through transmission, breaking and energy dissipation, thus protecting from wave and storm surge impact, in particular under extreme event conditions; protection from tsunamis and SLR; • Coastal erosion risk reduction => protection from waves and tides; due to the reduction of wave height, reefs can also modify sediment erosion and deposition patterns.	Oyster reefs are more effective in low wave energy environments.	• Habitat conservation/restoration and biodiversity enhancement. • Resource production • Tourism and recreation;
Mangrove Forest Restoration	• Coastal and riverine flood risk reduction => wave attenuation and reduction of wave run-up and storm surge, as well as reduction of tsunami run-up, thus reducing coastal and riverine flooding. • Coastal erosion risk reduction; • SLR mitigation;	The benefits of mangroves change as water levels increase. When water levels are within the root structure, mangroves are effective at reducing wave action and wave run- up, but as water levels increase, mangroves are more effective at reducing storm surge than they are at reducing wave action.	• Improvement of water quality and sediment management; • Mitigation of salt intrusion; • Habitat conservation/restoration and biodiversity enhancement. • Carbon storage & sequestration; • Resource production; • Tourism and recreation;
Coastal Wetland (Salt Marshes) Restoration	• Coastal and riverine flood risk reduction => wave height and water velocity attenuation, and reduction of flood depths in the marsh, resulting in increased protection against waves and storm surges; • Coastal erosion risk reduction => minimization of net sediment loss and increased sediment stabilization;	The capacity of marsh vegetation to provide these benefits changes with the water level. When marshes are completely submerged, and water levels are above the tops of the marsh plants, they enhance flood depth reduction but are less effective at attenuating waves.	• Improvement of water quality and sediment management => natural filters that remove pollutants for water purification; sediment nutrient storage; • Habitat conservation/ restoration and biodiversity enhancement. • Carbon storage & sequestration; • Resource production; • Tourism and recreation;
Beach nourishment & Dune Restoration/ Revegetation & Pocket Beaches (beach stabilization along sheltered shorelines)	• Coastal flood risk reduction => protection from wave and storm surge impact, in particular under extreme event conditions; protection from tsunamis and SLR; • Coastal erosion risk reduction => protection from strong winds, waves and tides; sand retention and stabilization by vegetation. • Reduction of wind and salt spray on adjacent infrastructure	Wider beaches, beaches with higher berm elevations, and beaches with larger volumes, provide more protection to upland infrastructure.	• Improvement of water quality and sediment management => water infiltration, cleaning and storage; protection of inland resources from saltwater intrusion. • Habitat conservation/ restoration and biodiversity enhancement. • Tourism and recreation;

The economics of NBS for road infrastructure

Type of NBS	Benefits for DRR & CCA	Strengths & weaknesses	Co-benefits
Inland/mountain areas			
River Floodplain Restoration Dike modification/ removal along rivers Re-meandering of watercourse	• Riverine flood risk reduction => peak water flow and downstream flood risk reduction through increased flood capacity: water storage and slow release of water and sediment; facilitates seasonal river dynamics.		• Improvement of water quality and sediment management => Reduction of surface flow velocity and sediment management; reduction of environmental pollution, increase of sediment storage and reduction of soil erosion; • Habitat restoration and biodiversity enhancement. • Carbon sequestration; • Resource production; • Tourism and Recreation;
Forest Conservation / Forest Restoration	• Riverine and pluvial flood risk reduction => Rainwater interception and infiltration, reducing the impact on banks along drainage lines, reducing peak flows, and reducing the impact of riverine floods downstream; • Soil erosion and landslide risk reduction => Soil stabilization and reduction of erosion in riparian zones and steep slopes; • Reduction of soil subsidence;		• Air and soil pollution mitigation; • Habitat restoration and biodiversity enhancement. • Carbon sequestration;
Terracing	• Pluvial flood risk reduction => Runoff reduction and soil erosion control;		• Increase of stormwater storage capacity; • Improvement of soil and water quality (reduce groundwater and river pollution) and sediment management; • Habitat creation/restoration and biodiversity enhancement. • Resource production; • Tourism and recreation;
Bio-Retention areas: Detention Ponds, Infiltration trenches, Bio-retention basins	Pluvial flood risk reduction => Increase stormwater collection, infiltration and storage capacities, resulting in reduction of peak water flow and storm flooding reduction; Increase of soil stabilization and prevention of soil subsidence;		• Improvement of water quality and sediment management => Removal of water and soil pullutants. • Habitat creation/restoration and biodiversity enhancement; • Carbon sequestration;
(Inland) Wetland Restoration	Reverine and pluvial flood risk reduction => Stormwater flow attenuation, water infiltration, sediment and pollution removal and water table stabilization;		• Improvement of water quality and sediment management => removal of water pollutants, reduction of stream erosion. • Increase storm water storage capacity => groundwater recharge, stormwater storage; • Habitat creation/restoration and biodiversity enhancement; • Carbon sequestration; • Resource creation, local economy stimulation and job creation; • Tourism and recreation;

The economics of NBS for road infrastructure

4.3

Assessing costs of NBS

The next step in the economic analysis is the estimation of the costs associated with each option. The costs of NBS strategies should be estimated over the complete cycle of the NBS (e.g. 20 to 50 years) to do a fair assessment of costs with respect to benefits. The majority of NBS costs occur in the early years of the project; however, benefits take time to emerge, and it is therefore important to take a long-term perspective (e.g., 20 to 50 years) in decision-making. Because the value of NBS benefits adds up over time, it may take years to recover the initial cost.

It is important to consider all costs associated to NBS. These should include i) planning, design and permitting costs, ii) costs of land required for the implementation of NBS, including opportunity costs, iii) capital costs (costs of creation, protection, or restoration), and iv) operation, maintenance, and monitoring costs.

While limited, some general references for unitary costs of NBS can be found in existing literature (see Table 7[38]). Therefore, researching relevant up-to-date cost information on NBS (e.g. from past projects) is particularly useful. Networking with communities that have experience implementing NBS measures could be another key source of cost information. While general information may be available on effectiveness and unit costs of NBS, it is always necessary to keep in mind that the feasibility of each option will strongly depend on the local circumstances. Estimating the costs of implementation of NBS remains a technical gap, as costs can vary across regions based on geographical location, setting, implementation method, site accessibility, availability of experienced contractors, and the nature of the permitting requirements[27]. A better understanding of the costs of NBS in transportation settings is needed.

Another technical gap relates to the cost of long-term maintenance of NBS. Some maintenance costs for several types of NBS have been reported. For beach nourishment projects, the United Kingdom (UK) environment suggests that the maintenance costs could be close to nothing[39]. Some authors argue that with an appropriate design, NBS should be able to adapt to changing conditions over time (e.g. growing to keep pace with SLR), thus reducing the maintenance costs. However, the existing literature presents conflicting information regarding whether the maintenance costs of NBS are more or less than those of traditional engineered approaches[27]. What seems certain is that NBS should be regularly monitored to ensure the long-term reliability and performance of the intervention in achieving the intended outcomes and desired co-benefits.

Table 7: Capital and Maintenance costs and moderate Benefit-Cost ratios of several types of NBS

Type of NBS	Reported implementation (capital) cost	Reported annual maintenance cost	Empirical evidence of estimates of b/c
Coastal environment			
Coral Reef Restoration	$165,000/ha (median)[40, 41] (also $542,500/ha[42])	For MPAs, $12 M/year for the Great Barrier Reef[43]	13.6 – 15. 5[44]
Oyster Reef Restoration	$66,800/ha[6]		7.34[45]
Mangrove Forest Restoration	$9,000/ha (median) [Range: $1,413-42,801/ha[35]]	Globally: $7-85/ha/yr[46] ($5,000[47]-11,000[48]/ha/yr in Florida, 10% of initial investment ($85/ha) in Indonesia[49]	41[26]
Coastal Wetland (Salt Marshes) Restoration	$85,000-230,000/ha[42] ($67,000/ha[35])	$25/m/yr in NL[50]	6[26] – 8.72[40]
Beach nourishment	$3-21[36]/$m^3$ (also $2-58/$m^3$ globally[51], $4.7-17.6/$m^3$ in the USA[42], $3-8/$m^3$ in NL[52], $15.5–37.5/$m^3$ in THAI[53])	Vary from almost nothing to several million dollars per km, although costs are usually at the lower end of this range[54].	0.28 – 1.68[40]
Dune Restoration/ Revegetation	$7,636-13,888/ha[44]	For dune restoration, the following figures are reported: $333-2,526/ha/yr[55]	

Type of NBS	Reported implementation (capital) cost	Reported annual maintenance cost	Empirical evidence of estimates of b/c
Inland/mountain environment			
River Floodplain Restoration Dike modification/ removal along rivers Re-meandering of watercourse	$27,200/ha [$130-360,000/ha][56] $1-100/m^3 $18-1,200/m or river section recovered	0.5 – 1.5% of total investment costs[57]	
Watershed reforestation	$2,207/ha [$189-$5,665/ha][61]	Vary widely depending on location and type of trees.	
Forest Conservation / Forest Restoration (Tropical Forests)	$3,450/ha[37]	Vary widely depending on location and type of trees.	
Terracing	$1,080/ha/yr[58]	$242/ha/yr	
Bio-Retention areas: Detention Ponds Infiltration trenches Bio-retention basins	For various types[59]: $60/m^2 $74/m^2 $534/m^2	0.5 – 10% of construction costs	
(Inland) Wetland Restoration Wetland Connection to watercourse	$33,000/ha[37] $1,000/ha/yr (median) [Range: $6-70,000/ha/yr][60] $2,400-300,000/ connection[51]	$785/ha/yr (over a 40-yr period) over a restoration cost of $10,022/ha[44].	

For comparison purposes, Table 8 provides some references of capital and maintenance costs of hard engineered structures traditionally used for the protection of coastal areas. In general, the present low-cost alternatives to traditional hard engineered structures for coastal areas, for reference purposes, and examples of benefit-cost ratios have also been included in Table 7 based on some recent studies undertaken for distinct types of coastal adaptation strategies in the United States (US). For instance, , except for some beach nourishment interventions undertaken in the Western Gulf of Mexico, all the other NBS were reported to have positive benefit-cost ratios compared to hard engineered structures. It should be noted that the NBS benefits considered in these, and other studies tend to refer exclusively to the protection services offered by coastal ecosystems (e.g., savings in damages during storm events, reductions in erosion), and not the additional co-benefits that these ecosystems offer. Therefore, it is expected that when some of these additional co-benefits are quantified and included in the assessment, the benefit-cost ratios may be even higher.

The costs of the overall NBS strategy would then need to be estimated by summing all associated costs, based on the unitary costs identified. In order to make a fair comparison of costs (which are paid in the early years of a project) and benefits (which are realized year by year over a number of decades), the overall costs would need to be discounted and converted to "present value" terms. Finally, to obtain the average benefit or cost in each year (i.e. annualized benefit or annualized cost), the present value should be distributed across the years of analysis.

Table 8: Capital and Maintenance costs and moderate Benefit-Cost ratios of hard engineered structures for the protection of coastal areas

Type of hard infrastructure	Reported implementation (capital) cost	Reported annual maintenance cost
Sea Wall	\$0.4-27.5[61] million/km per 1 m height	1-2% per annum[55]
Sea Dike	\$0.9-69.9[55, 62, 63] million/km per 1 m height	1-2% per annum[55]
Breakwater	\$2.5-10.0[26] million/km	1% per annum[55]

4.4

Key summary factors to consider when assessing benefits and costs of NBS

In summary, the following factors should be considered when assessing benefits and costs of NBS for the selection of adaptation or risk reduction strategies:

- NBS, coastal habitats such as coastal wetlands, reefs, and mangrove forests near coastal roads, but also beach nourishment and dune restoration projects, can protect road infrastructure from wave and storm surge impacts on sheltered shorelines. Similarly, forest restoration, slope revegetation or wetland restoration approaches, can also protect road infrastructure from runoff and peak water flows or soil erosion.
- Some of these NBS have been successful in providing protection services for decades while at the same time providing other ecological benefits more typical of these natural ecosystems than of engineered structures[27]. However, for NBS located in coastal areas, more research is needed on the relationship between the benefits of NBS and time, assessing the ability of NBS to reduce storm hazards as a function of storm duration, and the long- term reliability and performance of NBS in relation to future sea level rise.
- In medium-to-high energy environments, hybrid approaches combining NBS with some form of structure are often used to attenuate waves and/or stabilize shorelines[27].
- It is important to understand how effective an NBS is in reducing risk (e.g. reducing wave heights in coastal environments). Site- specific design of NBS is, therefore, critical to achieve the intended outcomes and desired co- benefits. For this purpose, learning from previous mistakes of projects is the key to achieving outcomes and benefits. Common mistakes in the design and implementation of NBS and hybrid measures are presented in Box 4.2.
- NBS can provide a variety of important wide-reaching and potentially long-lasting adaptation-related benefits, as well as socio-economic and ecosystem-related co-benefits, despite the various trade-offs

NBS, coastal habitats such as coastal wetlands, reefs, and mangrove forests near coastal roads, but also beach nourishment and dune restoration projects, **can protect road infrastructure from wave and storm surge impacts on sheltered shorelines.**

and associated challenges, such as the time taken for benefits to emerge.

- The true value of NBS is typically greater than what can be monetized because the value of co-benefits is hard to express in monetary terms. While the estimation of the value of co-benefits is an active line of research, co-benefits that cannot be monetized should be described and included in the decision-making process.
- Current literature provides some references of costs associated with the implementation and maintenance of NBS in diverse settings. Many of the references available are associted with road infrastructure projects related to NBS in coastal areas. It should be noted, however, that these costs may vary significantly based on the specific context and setting, site accessibility, implementation methods and nature of the permitting requirements.
- Non-economic factors such as legal challenges or public outreach needs can increase the resources needed to implement a strategy.
- In general, a lack of quantitative information on the relative costs and benefits of NBS is one principal factor limiting their use. A better understanding of the costs of NBS transportation settings is needed.
- Most case studies emphasize the challenges of fully measuring financial and economic costs and benefits and highlight the need to go beyond monetary values to better reflect the benefits of NBS.
- Because the majority of NBS costs occur in the early years of the project, while benefits make take time to emerge, it is important to take a long-term perspective (e.g., 20 to 50 years) in decision-making. The value of NBS benefits adds up over time, thus it may take years to recover the initial cost.
- Monitoring NBS interventions is the key to planning for adaptive management, but also for assessing the performance of the interventions over time. The lifespan and effectiveness of any intervention will depend on the severity of future events.

Box 4.2.
Common mistakes in the design and implementation of NBS and hybrid measures for the protection of road infrastructure (with emphasis on coastal roads)[27]

1. With regards to the engineered structure:

- Under- or over- designing structures for their intended application;
- Using non- traditional structures (e.g., alternatives to rock breakwaters) whose performance is not well understood;
- Placing structures in locations that may actually exacerbate shoreline erosion or storm flooding, or impact adjacent ecosystems (e.g. by restricting tidal circulation and therefore impairing the movement of fish);
- Using loose or under- sized materials that may shift under typical wave conditions in coastal environments;
- Improper timing of construction relative to growing or spawning seasons of the target habitats (e.g. constructing an oyster reef one month too late may delay recruitment by an entire year); and
- Unintended or anticipated adverse effects.

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2. With regards to NBS:

- Selecting and using inappropriate vegetation (e.g. non-native species or invasive species), in particular with respect to the ecological setting and elevation;
- Using inappropriate fill material for marsh, beach, or dune establishment in coastal environments, leading to poor ecological function and reduced physical performance;
- Placing vegetation at inappropriate tidal elevations;
- Planting vegetation outside the local growing seasons, which may not coincide with a particular phase of the project schedule;
- Failing to address the site- specific physical coastal processes (e.g. understanding water levels and waves, local geomorphology, sediment characteristics, SLR projections, etc.)

5. GUIDELINES FOR PLANNING AND IMPLEMENTING NBS FOR STRENGTHENING ROAD RESILIENCE

The methodology for designing and implementing NBS for the protection of road infrastructure presented in this Guide is the result of a comprehensive review of several guiding documents available in the literature, applied to the specific context of the transport sector. It is comprised of a series of phases and steps, which guide the experts in the decision making process towards using NBS to strengthen the resilience of road infrastructure.

The overall process described may be applied to several different contexts or sites; however, it should be noted that the process may need to be adapted to the specific project taking into consideration the site conditions, size of the project, etc. Furthermore, for emergency projects, for which a solution may need to be determined very quickly, some steps of the process may have to be taken at a prominent level while using proxy data rather than gathering new data.

Including the local community in the decision-making process (using appropriate communication and stakeholder engagement strategies) is vital to the successful selection of a sustainable solution which provides wider benefits to the population and the surrounding ecosystems. Stakeholder Engagement Plan should be developed at the start of a project and updated throughout the project implementation process.

The methodology for the planning and implementation of NBS applied to the context of the transport sector comprises five iterative steps (Figure 9):

To enhance the understanding of the methodology, a practical example of the application of this methodology is presented in **ANNEX 5**.

Figure 9: Summary of the steps for planning and implementation of NBS

STEP 1.
Situation analysis to define problem and scope of intervention

This first step focusses on assessing the ecological and social system and relevant processes at the project site, specifically in terms of the characteristics of the ecosystem, economic assets, population, and infrastructure, and defining the scope and problem to be addressed with the adaptation interventions.

STEP 2.
Climate hazard vulnerability and risk assessment

This step focuses on the development of the climate change and climate hazards risk assessment, and the identification of potential impacts and vulnerabilities of people, ecosystems, and infrastructure, and comprises a series of sub-steps involving the development of climate hazard, exposure, and vulnerability analyses.

STEP 3.
Identification and prioritization of NBS options

This step focuses on the identification of suitable NBS measures with the potential to reduce climate risks and impacts. Towards this end, the methodology proposes a series of considerations for the identification of NBS measures and presents an overview of different approaches that can be used for their prioritization, such as Cost-Benefit Analysis and Multi-Criteria Analysis.

STEP 4.
Design and implementation of the NBS options

The methodology for this step provides the necessary considerations to design and implement the selected NBS measures, taking into consideration the stakeholder engagement, detailed activities, geographical scope, and available resources.

STEP 5.
Monitoring, evaluation, and maintenance of the NBS options

Lastly, for this final phase, a description of the monitoring process of NBS is provided, including examples of performance indicators and guidelines on the maintenance of NBS.

1
- 1.1 Define the site and scope of the intervention
- 1.2 Assess the current state of the road infrastructure
- 1.3 Assess the current status of the ecosystems

2
- 2.1 Hazard and Exposure Assessment
- 2.2 Vulnerability Assessment
- 2.3 Assess climate and hazard risk and potential impacts

3
- 3.1 Identify potential NBS or hybrid interventions options
- 3.2 Screen intervention options with technical, social, environmental and economic criteria

4
- 4.1 Undertake detail design of selected interventions
- 4.2 Prepare implementation management plan and pre-implementation surveys

5
- 5.1 Identify performance evaluation indicators
- 5.2 Selection of monitoring methods
- 5.3 Operations and maintenance of NBS

5.1

Step 1. Situation analysis to define scope and problem

Objective

To identify what the specific problem is and determine the scope of the intervention. To make a rapid analysis of the current state of the road infrastructure and conditions of the environmental, economic, and socio-cultural elements.

Stakeholder engagement

Stakeholder engagement is a key element in the overall process and should be considered from the early planning stages. This engagement will contribute to strengthening the development of assessment aim, scope, and delivery at the beginning of any assessment, and will also increase the likelihood of successful delivery. Stakeholder consultations can ensure that the needs of diverse groups are acknowledged and taken into consideration.

Effective methods of early engagement include the delivery of stakeholder workshops and briefing sessions with key decision-makers and groups or individuals who are likely to provide input to the assessment and take ownership of the outcomes. The most effective forms of communication vary between groups. For example, government departments may have formal, pro-active mechanisms for consultation, whereas engaging with local communities may take a more informal approach.

Information needed

To conduct this baseline analysis and determine the scope of the intervention, site-specific information is needed. Resources like maps, reports, plans, and aerial photographs are generally available through key stakeholders/actors, such as government agencies; in the case of Haiti, the National Geo-spatial Information Center, CNGIS (*Centre National de l'Information Géo-Spatiale*), the National Buildings and Public Works Laboratory (*Laboratoire National du Bâtiment et des Travaux Publics), the Interministerial Committee for Territory Development (Comité Interministériel d'Aménagement du Territoire),* are three key agencies from which relevant information could be collected. Table 9 shows a list of common types of information that may need to be gathered for the project, and where this information may be found.

Outcome

Selected site for intervention and an identified set of objectives which are tailored to the specific baseline conditions.

Table 9: Example of type of information to be collected in Phase 1

Type of information	Relevant information	Where it could be found
Climate and hazard susceptibility information	• Climatological/weather data from weather stations: rainfall, temperature, wind; • Climate change projections. • Susceptibility of area to flooding, hurricanes, storm surge, and earthquakes. • Historical events and impacts in the project area.	• Met services • Disaster Preparedness and Emergency Agencies and related agencies/actors • Civil protection services
Physical environment	• Geology and geomorphology, soils, vegetation cover and land use (agriculture, urban, others): Types of rocks and geologic faults; Direct and indirect surveys for soil and / or rock characterization • Detailed Geological Survey. • Data on waves, currents, tides, sea level, rainfall, wind patterns, • Hydraulic and hydrological information, such as watercourses and watersheds; surface hydrology, estuarine/marine receiving water quality; • Digital terrain models: topography, bathymetry; and drainage (from LiDAR or other surveys); • Regional maps: Forest Cover Map, Terrestrial Ecosystem Map Soils and Geology Map.	• National Land Agencies • Ministries of Environment and Natural Resources • National Spatial Data Agencies • Water Resources Agencies • Geology divisions/departments

Bio-ecological environment	• Vegetation information
	• Inventory, attribute information and evaluation of:
	  • Terrestrial and marine ecosystems, such as forests, wetlands, salt marshes, mangrove forests, beaches, coral reefs, and other sensitive habitats;
	  • Rare or endangered species, species of commercial importance, and species with the potential to become nuisances or vectors.
		• Forestry Departments
		• Ministries of Environment and Natural Resources
		• National Environment Protection Agencies

Type of information	Relevant information	Where it could be found
Physical Infrastructure data	• Inventory, attribute information (e.g. height, length, location georeferenced, etc.) and evaluation of the condition of coastal assets, including roads, drains (gullies and canals), rivers, dyke system, coastal infrastructure, transportation infrastructure, utility infrastructure, water resources infrastructure, telecommunications networks, etc.	• Ministries of Infrastructure and Public Works • National Works Agencies • Water Resources Authorities • Coastal Management Divisions/Departments
Socio-economic data	• Economic base activities and extent • Livelihoods such as fisheries, aquaculture, tourism and recreation, economic resources, economic threats and opportunities, growth projections, etc. • Mapping of social infrastructure in targeted areas, population (past, present and future), land use, planned development activities, employment, recreation and public health, community perception of the development, vulnerable occupants. Identification of pressures from natural and anthropogenic sources, and consideration of ecological, cultural and economic values where relevant. • Critical facilities: (a) Emergency Shelters, (b) Emergency Services such as police stations, hospitals, and fire stations, (c) other critical facilities such as schools, banks, public buildings, aged homes, infant homes, national monuments, (d) bridges, coastal roads and properties; and (e) populations at risk.	• Ministries of Economy • Ministries of Local Government • Social Development Departments • Statistical Offices • Disaster Preparedness and Emergency Agencies

Key activities

1. Define the site and scope of the intervention

In order to define any intervention options, road authorities should decide which roads and/ or locations should be included in the assessment. Road authorities should prioritize the sites to be assessed by focusing on critical roads and sites located in hazard prone areas that are of the greatest value to the transportation network and the public. The assessment could even focus on a particular geographic location if that area is of high importance to the economy of the country. Identifying the relevant roads and sites to be assessed can also help to narrow the scope of the assessment. Stakeholder's input should be used to inform and/or validate the list of prioritized sites. Some of the key hazard related criteria proposed for site selection include:

- Slope stability
- Sedimentation risk
- Erosion
- Hill slope gradien
- Topography
- Terrain
- Geomorphic process
- Risk to resources of interest
- Undermining in areas adjacent to the roads
- Undercutting in transversal and complementary drainage structures

In addition to these hazard susceptibility criteria, other criteria such as socio-economic importance (i.e. in relation to connectivity), physical vulnerability (e.g. status of the road), or operational importance (i.e. in relation the usage of the specific road) could also be considered. It should be noted that the prioritization exercise is often a challenging task in data scarce contexts.

2. Assess current state of the road infrastructure

This step seeks to conduct an overview assessment for road infrastructure. For this, each road may be subdivided into sections of similar hazard exposure based on a series of recognizable attributes. These may include but not limited to:

- a unique identifier for the road segment or road system
- length of road segment or road system
- estimated or year the road was built
- road condition or known construction method used to build road (e.g. bulldozer, backhoe)
- traffic volume
- degree of revegetation occurring on the road
- location if different from base maps
- any observed instability indicators
- any anticipated erosion problems (hazards)
- interpreted slope stability (hazards)
- materials used for the road construction
- Weakening of the road embankment and road foundation by standing water

Box 5.3
Guiding questions for assessing the status of ecosystems (Step 1.2)

- Which are the ecosystems identified in the intervention site and what is their current status?
- What are the characteristics of these ecosystems? What are the ecosystem services they provide?
- What is the importance of these ecosystems (for example, do they generate benefits that another ecosystem cannot generate)?
- What current uses and benefits do the actors at the intervention site perceive from the ecosystems and what economic activities are generated there?
- What economic activities are carried out by the population in the area/around the area? (e.g. agricultural activities, sowing and harvesting of water, recovery of pastures, forestry activities)
- Is there any difference in the level of access to these resources by different groups (men/women, youth/elderly)?
- Are there activities of special importance for women/men/youth?
- Are there plants or animals of special importance for women/men/youth?

3. Assess the current status of the ecosystems

This step aims to analyze if there are ecosystems that currently play a role in climate change and hazard protection (e.g. flooding, landslides), and understand how these ecosystems can further contribute to reducing the risk from such hazards. Ecosystem health should be measured by indicators such as species diversity, abundance, and connectivity. Historical changes and trends in the ecosystem should be assessed to obtain a first impression of the ecosystem's stability and resilience, and to gain understanding of its original regulatory and provisioning services. The potential for expanding the risk reduction services of these ecosystems through conservation or restoration efforts should then be qualitatively articulated. It is also important to assess the socio-economic context of the area, to better understand the relationship between the socio-economic elements and the ecosystems in the area. The following activities are required for this step:

- Identify the key ecosystems and their processes in the selected site
- Assess the current state and processes of the main ecosystems at the intervention site, taking into account the size, type of the ecosystem, key plant and animal species of importance (endemic, threatened, under pressure, under management, among others) and endangered species.
- Define the socio-economic elements relevant to the intervention site to better understand the link with the ecosystems.

Case Study

Prioritizing Climate Resilient Transport Investments in a Data-Scarce Environment: A Practitioners' Guide

This Practitioners' Guide[64] aims to provide guidance for the prioritization of climate resilient investments in road infrastructure by presenting a general methodology, a conceptual framework, and a case study of the process that was conducted in Belize. It specifically addresses environments where data is scarce, but there exists institutional memory that can be harnessed. It makes use of existing data, draws on expert knowledge, and actively engages with key stakeholders, to identify and prioritize key national investments using a participatory and data-informed process.

The conceptual framework presented in the Guide consists of six modules, which may be implemented both in parallel and iteratively:

a. Definition of objectives and scope of the prioritization process
b. Understanding of the governance context and establishing the institutional arrangements for the process
c. Collation of data, focusing on identifying and bringing together existing data, and collection of data, focusing on the creation of new data to fill the data gaps
d. Evaluation of criticality
e. Assessment of risk/exposure from climate-related hazards;
f. Informed decision making

The process in Belize involved determining (a) socioeconomic importance of road sections and (b) flood susceptibility of the primary and secondary road network. Road stretches critical for access to public services such as hospitals and schools, movement of economic products and services, and use in evacuation routes as well as those that provide access to the socially vulnerable were assessed through a participatory Multi-Criteria Evaluation (MCE) process. Representatives from over 35 ministries, municipalities, private sector

The process in Belize involved determining (**a) socioeconomic importance of road sections and (b) flood susceptibility of the primary and secondary road network.**

organizations, civil society, nongovernmental organizations (NGOs), and academic institutions determined the most important criteria for assessing the critical road stretches. Once these were established, the participants developed indicators to evaluate the criteria and scored each indicator, which enabled quantitative analysis of the road network. Flood susceptibility was analyzed using a combined approach of field inspections and collection of information on past events. Incorporating the outputs from these processes, a cutting-edge geospatial model was then developed based on network analysis.

Through this process, four key areas were identified that were the most critical and were highly susceptible to flooding. The results of this process were adopted by the Government of Belize as a strategic plan and was used to coordinate investments that were implemented with various donors, including the World Bank. This process was successful in Belize because the ministry responsible for national development planning provided strong leadership throughout the process. This is essential if the results of such a prioritization processes are to be integrated into national processes.

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5.2

Step 2. Climate vulnerability and risk assessment

Objective

This phase seeks to guide the identification of climate change and natural hazards and assessment of the risks they present to resources and road infrastructure. The choice of interventions partly depends on the risks that are prevalent within the selected site.

Information needed

Information regarding past disasters and their impacts in the selected site, information on climate change projections for various climate change scenarios, topographical and geological maps.

Stakeholder engagement

The engagement of stakeholders should already be undertaken from the data gathering stage, to ensure that the most up-to-date and best data available for the selected site is used.

Outcome

A vulnerability and risk profile in current and future climate scenarios covering hazards, exposure, and vulnerabilities.

Key activities

1. Hazard and Exposure Assessment

Once a road authority has taken the first step to define the assets and/or locations for inclusion in the assessment (for example, critical assets only, all assets located in a specific region etc.), the intensity and extent of the hazards as well as the exposure to the impacts of the various natural hazards can be evaluated. This exercise may be developed by road authorities in collaboration with the Disaster/Emergency management agencies or related actors. Exposure may be categorized through the assessment of existing exposure levels – based on historical and recent events and observations, local and technical knowledge, and existing research. The choice of scale of analysis and the most pertinent level of accuracy is important:

- **Regional scale (**region serviced by the road network) is considered when the hazard may affect most or all the territory. It is also the only scale of analysis where all the regional stakes related to the road network are integrated in the assessment. Authorities responsible for various sectors co-operate to reduce the risk.
- **Network scale** is necessary to identify the main vulnerabilities of a road network before focusing on critical sections, nodes, or structures. Both regional and network scales tend to be considered as part of the development of strategic and systems planning, taking into consideration various climate change scenarios and qualitative analyses (e.g. expertise) of hazard impacts and exposure.
- **Section scale** is conducted prior to the network scale consolidated approach when critical sections are already known (high levels of traffic, no alternative route, sensitive ecosystems), or after having identified the vulnerable sections through the network approach to refine the analysis.
- **Structure scale** orientation is considered when the focus lays on analyzing critical points of a section, such as a viaduct, a tunnel, a node (interchange), etc. These critical points may have been identified through a prior assessment at the network and/or section scales. As the analysis focuses on a single asset, a comprehensive and technical (quantitative) approach may be feasible. The following matrix (Table 10) can be used to identify the exposure of specific assets and/ or locations.
- **Assess impact probability**. Impact probability relates to the likelihood of a climate hazard occurring within a given timeframe. Due to the uncertain nature of climate change, assessing probability of occurrence of climate hazards can be difficult. However, approximations can be made using climate change projections, evidence of past events and vulnerability levels. A process for assessing and scoring the probability of climate change/hazard risks facing highway networks, assets, locations, and operations is set out in Table 11.

Table 10: Matrix for assessment of exposure to roads.

	Extreme Tempera- ture	Drought	Mean Rainfall	Storms/ Extreme Rainfall	High climatic variability	Sea Level Rise and/ or Storm Surge
Asset/ Location/ Operation A						
Asset/ Location/ Operation B						
Asset/ Location/ Operation C						
Asset/ Location/ Operation D						

Note: Exposure can be scored as followed: X = No or negligible exposure now and/or in the future; 1 = Low exposure now and/or in the future; 2 = Medium exposure now and/or in the future; 3 = High exposure now and/or in the future.

Table 11: Description and scales of probability of impact.

Probability of impact	Definition	Score
Likely / Almost Certain	Fairly likely to occur (probability greater than 50%)	3
Unlikely	Possibly occurring (probability less than 50%)	2
Rare / Highly Unlikely	Low, but not impossible (low, but noticeably greater than zero)	1

2. Vulnerability Assessment

Vulnerability to climate change and natural hazards is the propensity or predisposition of an area/ecosystem/population/asset to be negatively affected by their impact. Vulnerability is explained by two factors: 1) sensitivity, and 2) adaptive capacity. **Sensitivity** is the degree to which a system is affected, by climate or hazard-related stimuli.

- **Assess the level of sensitivity using:**
  a. Experience of recent and historical events – for example, road flooding in a certain location may have led to greater widespread environmental and economic damage than similar flooding levels in another similar area.
  b. Geographical location – for example, road assets located on slopes are likely to be more sensitive/susceptible to landslide and scour. In comparison to those located in flat regions, and areas of a network that act as major links between large urban areas that will suffer a higher level of disruption during extreme weather events than areas of the network in lesser populated and urbanized areas; and/ or,
  c. Asset condition and design life – for example, poorly maintained and poor condition sections/segments of the network are likely to be more sensitive to the impacts of extreme weather than recently constructed or well-maintained areas or assets. Table 12 provides an example to help assign the high, medium, and low levels of sensitivity. The level of sensitivity to be assigned to a specific asset should be informed by current levels of sensitivity.
- **Assess the level of adaptive capacity.** Adaptive capacity can be a difficult concept to quantify and evaluate due to a range of internal and external factors. For instance, whilst an asset, location or operation may be highly exposed and sensitive to hazards (thus, having a high vulnerability level), it may have an enhanced capacity for adjusting to impacts and therefore its overall vulnerability is considered to be lower when adaptive capacity is considered. *Table 13* provides an example to help assign the high, medium, and low adaptive capacity levels. The level of adaptive capacity assigned should be informed by current levels of sensitivity.
- **Determine overall level of vulnerability.** Through the combination of the adaptive capacity and sensitivity ratings, it is possible to identify whether the road is vulnerable, to what degree, and to which climate/hazard variables. Assets having high sensitivity and low adaptive capacity will have a higher vulnerability to the climate/hazard variable than those with a low sensitivity and high adaptive capacity. Those with low vulnerability to the climate variable are less likely to require adaptation strategies to be put in place to protect them. The Vulnerability Matrix shown in table 14 provides an example of how sensitivity and adaptive capacity can be combined to determine the overall vulnerability level.

Table 12: Description of sensitivity level of road infrastructure.

Level of Sensitivity		Description of Sensitivity Level to Infrastructure (example)
3	High	Permanent or extensive damage requiring extensive repair
2	Medium	Widespread infrastructure damage and service disruption requiring moderate repairs. Partial damage to local infrastructure.
1	Low	Localized infrastructure service disruption. No permanent damage. Some minor restoration work required.
0	Negligible	No infrastructure service disruption or damage.

Table 13: Description of level of adaptive capacity.

Level of adaptive capacity		Description of adaptive capacity of Infrastructure (example)
3	High	There is an operational contingency plan for emergency, which is adopted to avoid infrastructure damage and related disruption of road traffic.
2	Medium	There is a contingency plan for emergency, it is operational but needs to be updated. Stakeholders
1	Low	There is no contingency plan for emergency but there is awareness and plans to prepare a plan.
0	Negligible	There is no contingency plan for emergency nor plans to be prepared. Awareness of stakeholders are also limited.

Table 14: Assessing overall level of vulnerability for road infrastructure based on adaptive capacity and sensitivity assessment.

Adaptive capacity	Sensitivity		
	Low	Medium	High
Low	4 (Medium)	5 (High)	6 (Extreme)
Medium	3 (Low)	4 (Medium)	5 (High)
High	2 (Very Low)	3 (Low)	4 (Medium)

Box 5.4
Guiding questions for assessing the level of adaptive capacity

- Is the asset, location or operation able to accommodate changes in climate? For example, has the asset been designed with climate change in mind? Is the network/ asset in a good condition?
- Are there any barriers to an asset's, location's, or operation's ability to accommodate for, and adapt to, a changing climate? For example, constrained resources; political will; ownership uncertainties/disputes; a lack of defined roles and responsibilities; a lack of community integration and education?
- Is the road network already facing (non-climatic) challenges that will limit the ability of highway networks to accommodate changes in climate? For example, there may be a strong requirement to upgrade existing roads to meet growing traffic levels and resources are focused on this.
- Is the rate of projected climate change likely to be faster than the adaptability of the system? For example, will the assets design life be reduced as a result of the increasing pressures posed by climate risks? Will assets, locations, and operations, which have an inbuilt ability to adapt to a changing climate, be able to do so prior to the asset, location or operation reaching threshold limits?
- Are there already efforts and processes underway which aim to address climate change impacts related to the network? For example, are there plans, programs or strategies in place to enhance adaptive capacity? Are there contingency plans in place for the temporary/ permanent failure and/or loss of an asset/location or operation?

3. Assess climate risks and potential impacts

This step seeks to enable experts to understand where to quantify the risks posed to road networks and assets in a simple, accessible, iterative, and yet robust and holistic way following risk assessment principles. Experts will be able to rank their assets, locations, and operations according to the level of risk probability and/or severity. This approach will identify where the most significant risks are expected to occur and shall prepare the experts for the identification of the adaptation responses. Section 2.3 describes in detail the list of potential impacts on road infrastructure due to increased temperature, prolonged and heavy rains, and sea level rise. These impacts should be further assessed for their level of severity and probability.

- **Assess the impacts severity**. Severity relates to a judgement of severity (flooding of a road, heat damage to a bridge, a landslide in a particular location etc.) if it were to be realized, regardless of the probability of occurrence. Severity is assessed by the user based on knowledge, estimation, and evidence of past similar events (at a similar scale, at the same or similar asset, or at the same or similar location) and can be scored using a Severity Scale. Criteria and the associated metrics within the Severity Scale should be tailored according to local needs and priorities. Defining scoring criteria and metrics is ideally done in a workshop setting with key stakeholders to identify important criteria to be used to assess consequences. Table 15 presents an example showing the severity scale for different criteria.
- **Determine level of risks.** Considering the results of the level of exposure, vulnerability and potential climate/hazard impacts, the level of risk can be estimated to be either low, medium, or high. The Scale of Risk levels in Table 16 shows how the combination of the risk components can lead to various levels of risk.

Defining scoring criteria and metrics is ideally done in a workshop setting with key stakeholders to identify important criteria to be used to assess consequences.

Table 15: Severity scale for assessing impacts.

Score Criteria	1 (Low)	2 (Medium)	3 (High)
Population and communities	Between 1-2% of the population affected	Between 2-5% of the population affected	Between 5-10% of the population affected
Economic impact	Less than US $1m	Between US $1m and $5m	More than US $5m
People and employees	Employees within a major office affected	Employees within a function affected (e.g. within maintenance)	Employees within a Business Unit affected
Society	Regional disruption of essential services, social practices and events	Regional disruption of essential services, social practices and events	National disruption of essential services, social practices and events
Stakeholders and Supply Chain	More than one stake-holder or element of supply chain affected	One group of stakeholders or elements of supply chain affected	More than one group of stakeholders or element of supply chain affected

Table 16: Severity scale for risk based on exposure, vulnerability, and climate hazard impacts

Climate hazard impacts	Exposure	Level of vulnerability	Risk
High	High	High	High
High	High	Medium	High
Medium	Medium	Low	Medium
Medium	Low	High	Medium
Medium	Low	Medium	Medium

Box 5.5
Geographical factors to consider when identifying future climate change risk types include but are not limited to:

- **The presence of water bodies:** coastal areas may need to consider sea-level rise
- **altitude:** Areas at higher altitudes may be more concerned with extreme weather events such as high wind speeds and increased precipitation levels associated with an increased frequency and magnitude of storms associated with climate change;
- **land-use:** Areas which are heavily urbanized may be focused on damage to highway drainage systems and road and pavement fabrics whereas more rural areas may be concerned with access and over-reliance on road structures as a result of a lack of redundancy;
- **topography:** Topography is likely to be a major consideration for national road authorities especially in regard to excess surface water runoff associated with flood events exacerbated by climate change;
- **soil and geology:** This will be a consideration for authorities who have previously experienced landslides and will be a factor in flood risk; and,
- **accessibility:** Some geographical locations may have poor access and/or transportation links that may be further affected and limited by climatic variables such as extreme weather events, including flooding.

Case Study

Development of a vulnerability map of the road infrastructure in Haiti

Vulnerability maps of the road network in Haiti were developed in the framework of the project "Development of Design and Guidelines, and Capacity-Building for the Adoption of Ecosystem-Based Solutions to Protect Infrastructure Assets in Haiti as a decision-making tool to identify such areas where the road infrastructure is more exposed to climate/hazard threats and where a Nature-Based or Hybrid solution may be needed.

Steps in the analysis

Step 1. Spatial information

To produce the vulnerability maps, it is necessary to obtain and process geospatial information from various sources and at different scales. More information on the methodology is presented in Annex 3 "Methodology for producing vulnerability maps in Haiti and results".

Step 2. Analysis of the information

The analysis was performed for each road classification (communal, departmental, and national). For each one, an affectation buffer (area of influence) of 200 m was generated.

Three analysis products (indicators) were obtained, including the level of exposure to climate threats and the indirect effects that could affect the infrastructure assets in Haiti.

- **Coastal proximity.** The vulnerability is due to the exposure of the roads and change in the sea level (i.e. storm surge) caused by tropical storms and hurricanes. The impact on the roads is reflected in floods and the undermining of the embankment. For the coastal proximity indicator, the following values were taken into consideration (Table 17).
- **Slope grade.** The vulnerability is due to the exposure of the roads to landslides and erosion of the slopes. The material can slide due to meteorological events, saturation of the material and sliding due to gravity, earthquakes, among others. The impact on the roads is the obstruction of material. For the slope grade indicator, the following values were taken into consideration (Table 18).
- **Crossings.** The vulnerability is due to the exposure of the roads due to an increase in the water flow and potential associated floods. The increase in the flow of rivers and bodies of water is due to rains, storms, hurricanes, among others. Road damage is reflected in bank erosion, flooding and obstruction of roads, and damage to bridges. For the crossing indicator, the intersection between the roads and the 150 m hydrology buffer was taken into account.

It is important to mention that for a more specific analysis, it is necessary to know other factors and conditions of the site. For example, the type of soil and rock, on which the stability of the slopes depend, the existence of functional drainage works, and the existence of works in slopes. However, in the absence of more detailed data, through the indicators previously mentioned, a first assessment of the vulnerability of Haiti's road infrastructure may be determined.

The three indicators were integrated to obtain vulnerability indices. These values range from null, low, medium to high risk (Table 19).

Table 17: Values of the coastal proximity indicator.

Level	Index	Description
Null	0	Areas with an altitude greater than 30 m.a.s.l.[65]
Low vulnerability road	1	Areas with an altitude between 20 and 30 m.a.s.l.
Medium vulnerability road	2	Areas with an altitude between 10 and 20 m.a.s.l.
High vulnerability road	3	Areas with an altitude between 0 and 10 m.a.s.l.

Table 18: Values of the slope grade indicator.

Level	Index	Description
Null	0	Areas with a slope between 0 and 5°.
Low vulnerability road	1	Areas with a slope between 5 and 25°.
Medium vulnerability road	2	Areas with a slope between 25 and 40°.
High vulnerability road	3	Areas with a slope greater than 40°.

Table 19: Vulnerability indices for infrastructure assets.

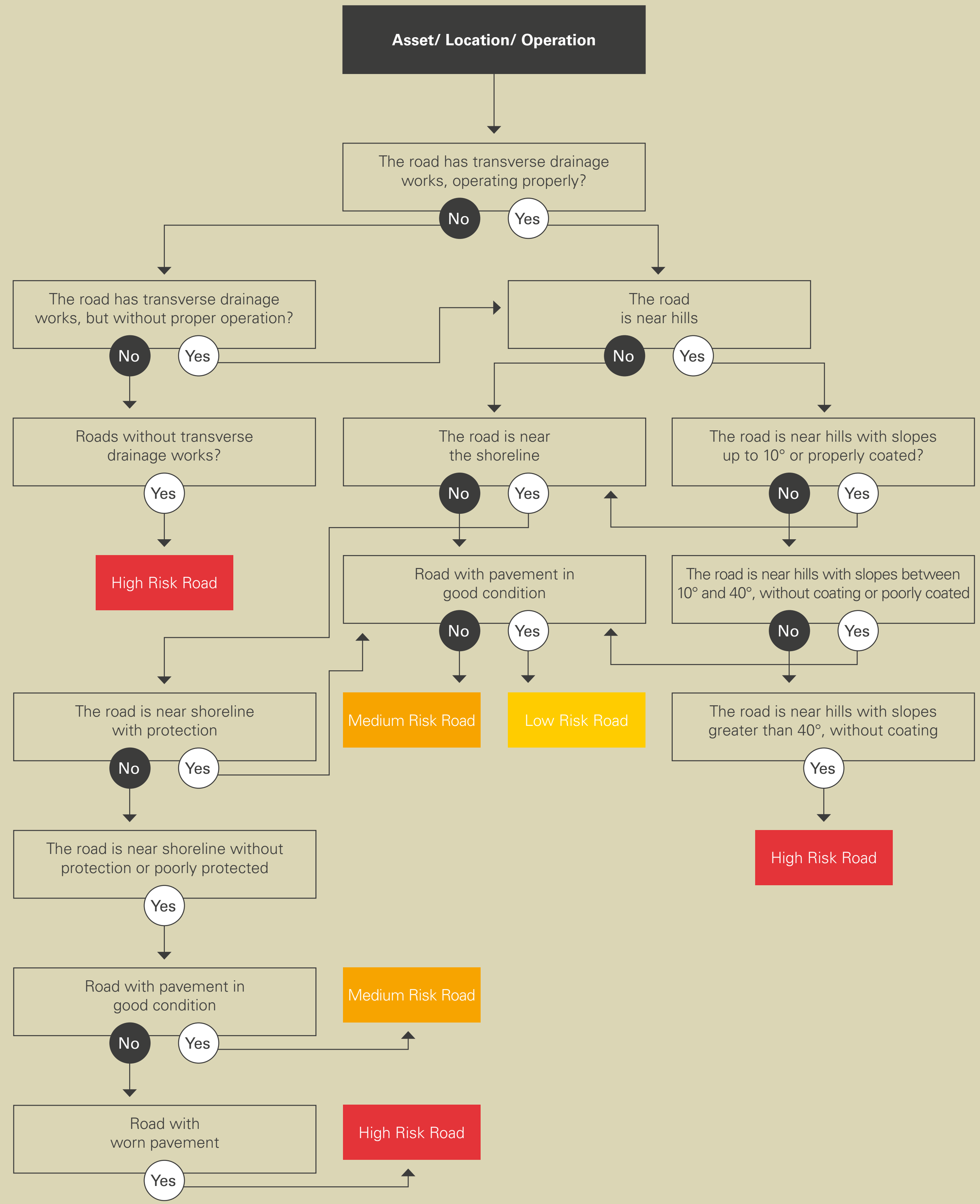
Level	Index	Description
Null	0	• Roads exposed to hills with slopes between 0 and 5°. • Roads far from crossings and water bodies. • Roads far from the shoreline or with an altitude above 30 m.a.s.l.
Low vulnerability of the road	1	• Roads exposed to hills with slopes between 5 and 25°. • Roads near crossings and water bodies (less than 150 m). • Roads near the shoreline with an altitude between 20 and 30 m.a.s.l.
Medium vulnerability of the road	2	• Roads exposed to hills with slopes between 25 and 40°. • Roads near crossings and water bodies (less than 150 m). • Roads near the shoreline with an altitude between 10 and 20 m.a.s.l.
High vulnerability of the road	3	• Roads exposed to hills with slopes greater than 40°. • Roads near crossings and water bodies (less than 150 m). • Roads near the shoreline with an altitude between 0 and 10 m.a.s.l.

Results from the analysis for Grand'Anse department

The Grand'Anse department has approximately 225 km of main roads of which 43 km are Community/Tertiary Routes, 121 km are Secondary/Parrish Routes, and 59 km are National Routes. The resulting map is shown below. Figure 10 shows a decision tree which aims to support the process of the assessment of risk to the road infrastructure.

Vulnerability map: Grand'Anse department

Figure 10: Decision tree for the identification of intervention options depending on the level of risk to the road.



5.3

Step 3. Identification and prioritization of nbs options

Objective

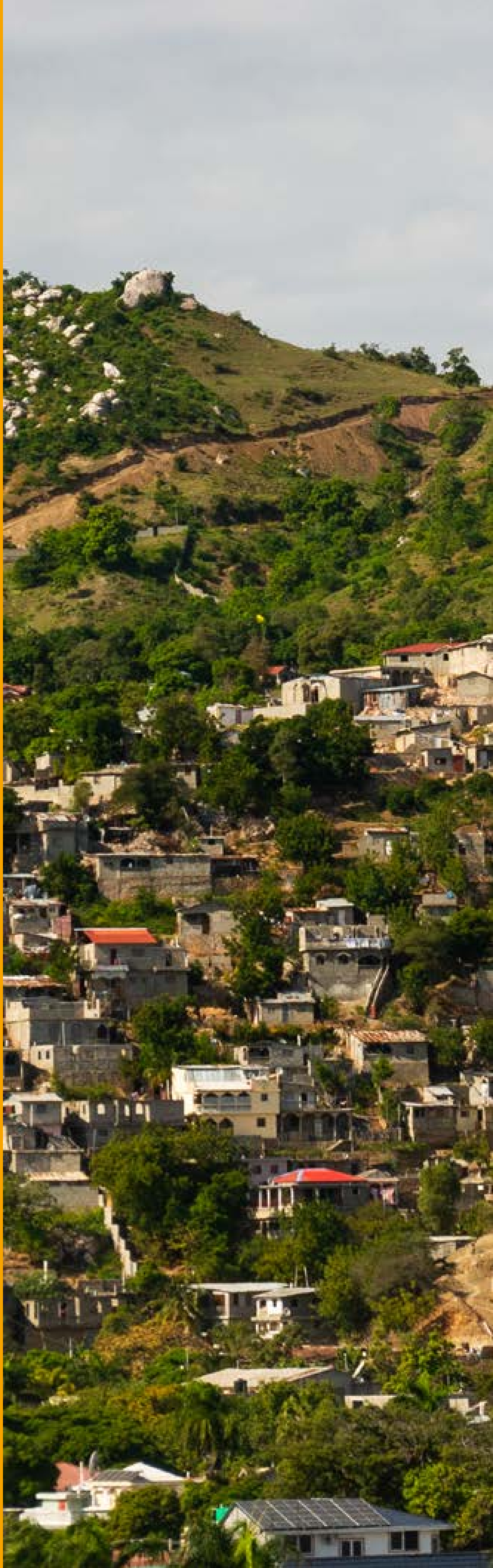
Identify possible strategies to reduce flood risk, landslide and other climate risks and evaluate whether nature-based solutions are a suitable alternative or valuable addition to conventional options. Wherever possible, prioritize nature-based solutions by evaluating trade-offs and limitations, more detailed actions are provided while using methods for appraising the value of the NBS.

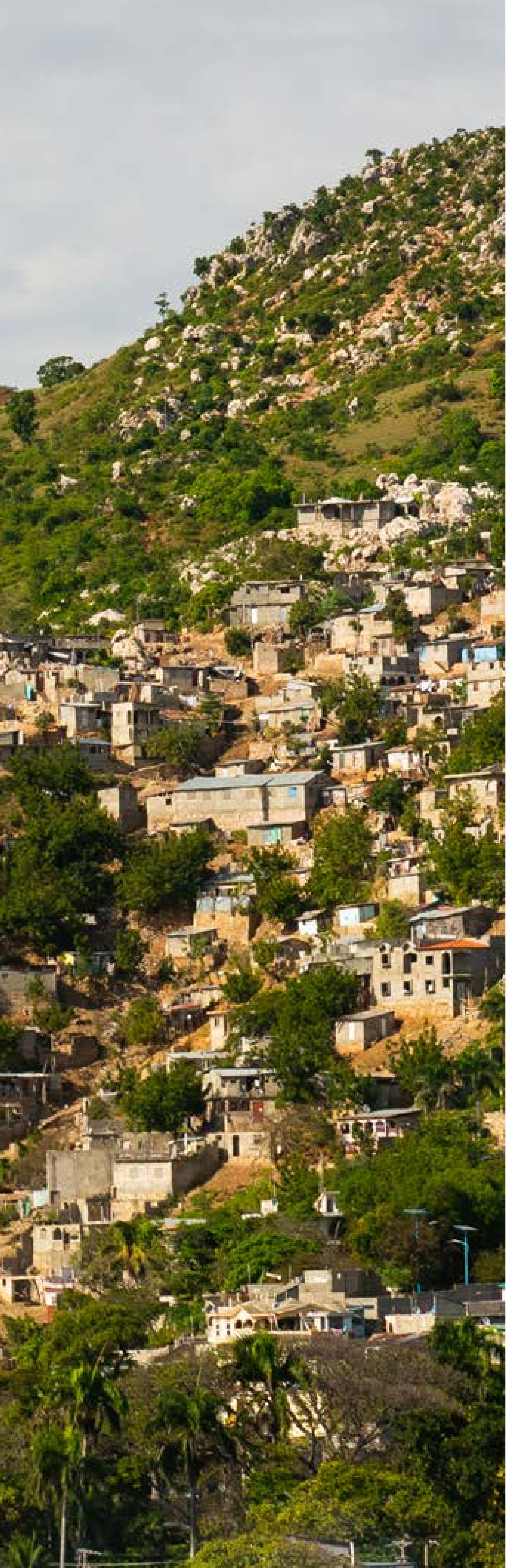
Stakeholder engagement

Make use of the multi-stakeholder group to validate the best options and develop a business case.

Outcome

A concise list of interventions which are technically, economically, socially, and environmentally feasible, with approximate costs for comparison.





Key activities

1. Identify potential nature-based or hybrid intervention options

Based on the risk assessment taken, this step aims to identify possible nature-based or hybrid solutions to address the specific risk. It should be noted that non-structural measures (such as early warning systems and spatial planning) and various combinations of nature-based, conventional, and non-structural measures may be needed to address the specific risk. Conservation, expansion of an existing ecosystem, or restoration of a destroyed ecosystem should be considered to see how they can contribute to reduce floods or landslide risk. In addition, previous projects and possible NBS should be looked at for lessons learnt and preliminary cost estimates. Factors may influence the stability and performance of vital ecosystems that should be assessed. Finally, how NBS can be integrated into the wider system management should be assessed, and a list of feasible NBS/hybrid options and accompanying measures should be developed.

An example of an exercise that could be undertaken with stakeholders for the identification of NBS for road infrastructure resilience in Haiti is included in Annex 5.

Depending on the level of risk of the selected site, NBS measures may deliver different management approaches to climate risk. In coastal areas, coastal management approaches as part of which NBS may be considered[66]:

- **Build:** The intent of this is to maintain the current position of the coast and maintain or increase the level of protection using nature-based, hybrid or hard interventions.
- **Protect:** The intent of this is that existing interventions are used to provide the necessary protection, rather than building or implementing new interventions.
- **Accommodate:** The intent of this is to modify or retrofit existing or adjacent interventions that are already in situ to improve overall scheme performance; and
- **Retreat:** The intent of this to review and/or adopt new planning tools to enable the coast to accommodate sea level rise and storm surge inundation events.

Examples of the application of these coastal management approaches to road infrastructure are presented in Table 20.

Table 20: Examples of coastal management approaches applied to road infrastructure

Coastal Management Approach	Example applied to road infrastructure
Build	Planning beach nourishment interventions, groyns systems, detached breakwaters, wooden piles, in order to build a coastal barrier for coastal assets (e.g. coastal roads) against wave action and coastal erosion
Protect	Retrofitting a revetment that is protecting a coastal road from wave action; restoring coral reefs, mangrove forests, wetlands or dune systems that serve as a buffer for a coastal road;
Accommodate	Raising the level of a road to accommodate for projected sea level rise
Retreat	Planning a new climate-resilient further inland taking into consideration the required set-back limits.

2. Prioritize the identified options with technical, social, environmental, and economic criteria

After a number of NBS/hybrid options has been identified, each option will be screened on the basis of technical, social, environmental and economic criteria to prioritize the most feasible and cost-effective options. This screening process should be conducted through a participatory process with stakeholders. Two main methodologies can be used to prioritize between intervention options: a) Multi-Criteria Analysis and b) Cost-Benefit Analysis. Key steps include:

- Consider multiple values and benefits, including non-monetary, in the selection of criteria to capture the full value of different NBS and hybrid options. Stakeholders could already be engaged in the criteria selection process.
- Identify a scoring and weighting system, assign scores and weights to the proposed criteria and use the criteria to rank NBS and hybrid options.
- Prioritize and short-list NBS and hybrid measures based on the agreed-upon criteria.
- Make use of the multi-stakeholder group and consult other rights holders to validate the best options and develop a business case.
- Analyze the costs, benefits, impacts and trade-offs of different risk management scenarios, and the costs of inaction, to capture gains or losses in ecosystem functions and services provisioning that have an impact on adaptation and disaster risk reduction and resilience (e.g. consideration for wetlands).

The two methodologies are differentiated by their complexity, type of analysis (qualitative or quantitative) and by the resources and inputs required to use them.

- **Multi-Criteria Analysis** - the analysis is made on the basis of qualitative information that allows to classify a range of NBS/hybrid options according to pre-selected criteria. This analysis allows prioritization to be performed with a limited amount of quantitative information. Selection criteria should be defined with the participation of all stakeholders participating in the planning process.
- **Cost-Benefit Analysis** - the analysis is based on quantitative information to estimate and compare all the costs and benefits of the various NBS/hybrid measures considered, to provide information on which of the identified measures generate the greatest direct, indirect and positive externalities/benefits associated with the reduction of risks associated with the impact of natural hazards and climate change. The benefits perceived by the population using ecosystem services will be related to the ecosystems where NBS will be implemented.

At the end of the prioritization process, a short list of selected NBS and/or hybrid options suitable for the specific site will be available. A list of examples of NBS and hybrid solutions is included in the Solutions Catalogue (Section 7).

Case Study

Selection of Pilot Sites in The Grand South Haiti

The Grand South of Haiti, the Tiburon Peninsula or the Southern Peninsula is home to the Grand'Anse, Nippes, Sud, and Sud-Est and part of the Ouest Departments of Haiti. The main economic activity of this region is agriculture, and it accounts for 85% of national corn production, 37% of national fruit production, 34% of the country's cattle, pigs and goats, and 30% of chickens, ducks, turkeys, s and guinea fowl. Each year, the exports of the peninsula, just for the sector 'essential oils', represent at least USD $25 million.

Despite the importance of this, there is only one form of terrestrial communication between the peninsula and its main cities with the capital of the country, Port-au-Prince.

Route Nationale 2 (RN 2) is the southern cross-country interdepartmental highway in the Haitian Highway System. The principal cities that RN-2 connects to includes (from west to east) Les Cayes, Aquin, Miragoâne, Léogâne, Petit-Goâve, Gressier, Carrefour, and Port-au-Prince. It is 186 km (118 miles) long from Port-au-Prince to Les Cayes.

The RN 2 connects with the Route Departmental 25 (RD 25) and reaches the west end of the Tiburon peninsula.

This road system is a two-lane road in both ways that connects approximately 3.5 million people (30% of total population in Haiti), many of which live in sub-urbanized or rural areas, without access to other means of communication and exchange of food, materials, or services. Since it is the only communication route in the south of the peninsula with the capital of Haiti, many efforts and maintenance

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Route Nationale 2 (RN 2) is the southern cross-country interdepartmental highway in the Haitian Highway System. The principal cities that RN-2 connects to includes (from west to east) **Les Cayes, Aquin, Miragoâne, Léogâne, Petit-Goâve, Gressier, Carrefour, and Port-au-Prince.**
It is 186 km (118 miles) long from Port-au-Prince to Les Cayes.

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have been carried out over the years. However, these efforts have not been sufficient since the vulnerability of these infrastructures to meteorological risks is extremely high.

During the visit to the sites on the south coast of the southern peninsula, we were able to observe series of engineering works for the maintenance and protection of these infrastructures. A large part of the work is collapsed or unfinished due to poor planning and lack of financial resources.

In total, eight sites were visited during field missions, as potential sites for NBS solutions, selected by the World Bank Team and the the Unité Centrale d'Exécution (UCE) of the Ministère des Travaux Publics, Transport et Communications of the Government of Haiti for its criticality and vulnerability. The objective of the field visits was to prioritize the top two sites for NBS implementation. Details of each sites can be found below.

Out of those, 2 sites (site 1 and 4) were selected after a field visit inspection and based on several criteria:

- There were places where different measures could be proposed, so that when extrapolating such actions, they would be applied in a greater variety of sites
- Measures could be executable and applicable in time, cost, and result
- The execution of the measures could be done using endemic vegetation and materials easily found in Haiti
- Public administrations of Haiti agree and find it necessary actions in these locations

During the visit to the sites on the south coast of the southern peninsula, we were able to observe series of engineering works for the maintenance and protection of these infrastructures. **A large part of the work is collapsed or unfinished due to poor planning and lack of financial resources.**

Table 21: Identification of Pilot Sites in Haiti

Sites	Initial Diagnostic	Proposed Solutions
Site 1 is located on RN 2 in the section of Des Zanglais, Saint-Louis-du-Sud commune, Aquin Arrondissement, Sud Department of Haití.	No transverse drainage works are observed in this section. The main problem observed is to the undercutting slope and to the erosion in the upper slope, which causes risks of block landslides.	Hydrological evaluation, determination of slope protection structures and their complementary drainage works and the need for cross-sectional works. Definition of coastal protection structures and a compact embankment
Site 2 is located on RN 2 in the section of Solon, Saint-Louis-du-Sud commune, Aquin Arrondissement, Sud Department of Haití.	Possible landslide, lack of drainage work, observation of cracks on the road and intercalations of limestone and fractured and altered marls.	Hydrological evaluation, determination of the need for cross-sectional road works and laundry on the slope
Site 3 is located on RN 2 in the section of Solon, Saint-Louis-du-Sud commune, Aquin Arrondissement, Sud Department of Haití	The lack of an appropriate resource management program causes contamination of soil, air and water. The accumulation of waste also causes the generation of flood risks, the lack of maintenance and therefore the capacity for the flow to be discharged.	Hydrological evaluation, Definition of a gutter maintenance program
Site 4 is located on RD 25 in the section of Blactote, Tiburon commune, Chardonnières Arrondissement, Sud Department of Haití.	The probability of eroding and sliding down the slope to the road, generating impacts on mobility and road infrastructure, lack of transversal additional drainage work, the undercutting slope and the upper slope erosion, generation of erosion.	Hydrological evaluation, definition of the need of cross-sectional works, of coastal protection structures and a compacted embankment
Site 5 is located on RD 25 in the section of Blactote, Tiburon commune, Chardonnières Arrondissement, Sud Department of Haití.	The soil is not fixed (mainly by plant roots), so it is susceptible to eroding and sliding down the slope , erosion of the coast caused by waves , high deforestation level , There are no transversal drainage works or laundries that discharge the runoff partially ,block detachment	Hydrological evaluation, Definition of slope protection structures, coastal protection structures and the need of cross-sectional works on the road. Possible modification of the slope
Site 6 is located on RD 25 in the section of Cosse, Les Anglais commune, Chardonnières Arrondissement, Sud Department of Haití.	great speed of runoff and erosion of the drainage and slope stabilization systems implemented, emerging of fractured and altered sedimentary Vulcan origin,	Hydrological evaluation, Restoring the gabion wall, Hydraulic review of existing drainage works, Definition of the existing ditches along the way of the existing drainage work and energy dissipating structures
Site 7 is located on RD 25 in the section of Cosse, Les Anglais commune, Chardonnières Arrondissement, Sud Department of Haití.	Lack of appropriate drainage systems, ditches are observed in both margins, range, and damages of the structure at the discharge site, lack of maintenance.	Hydrological evaluation, Restoring the gabion wall, Definition of Hydraulic review of existing drainage works and energy dissipating structures, Laying of pavement.
Site 8 is located on RD 25 in the section of Boury, Torbeck commune, Cayes Arrondissement, Sud Department of Haití.	deforestation of the basin above generation of large runoffs and erosion of the banks of the riverbanks, reduction of the hydraulic capacity of the cross section of the channel.	Hydrological evaluation of the river basin, Hydraulic review of the bridge, rectify (dredge) the cross-section upstream and downstream of the bridge will be defined, Define the works of protection of the margins of the channel

Guidelines for planning and implementing nbs for strengthening road resilience

5.4

Step 4. Design and implementation of nbs interventions

Objective

This phase seeks to guide the detailed design and implementation of the selected NBS/hybrid measures.

Stakeholder engagement

At the design stage process, it is important that the stakeholders are engaged in the selection of criteria for the prioritization of interventions, as well as in the validation of the selected interventions. For this process, their roles, and responsibilities, need to be clearly identified.

Outcome

A short list of detailed interventions which are technically, economically, socially, and environmentally feasible, with approximate costs for comparison.

Key activities

1. Undertake detailed design of selected interventions

The design variables necessary for this step will be taken from the results of the hazard assessmentsto Step 2. Using these variables, the details of the different measures (length, size, type of materials to be used, etc.) will be identified. It is important to consider the principles and safeguards for the selected NBS and hybrid options throughout the design and implementation stages. A list of potential solutions can be found in section 3 and in the NBS Solutions Catalogue in section 7. The selection of the intervention should be based upon a revision of:

- The exposure of the site to environmental loads such as wind, waves, currents, water levels.
- Land use (current and future).
- Type and condition of the foreshore.
- Geotechnical issues such as depth and type of founding material, and its susceptibility to erosion.
- Environmental status of the site and its surroundings; and
- The availability of material supply.

2. Prepare implementation management plan and pre-implementation surveys

The implementation management plan will be based on the type of material to be used for the specific intervention site. If purely NBS solutions are considered, then restoration or conservation management plans will be developed. If a combination of NBS and hard engineered structures is envisioned, then construction management plans will be required. As part of this step, additional surveys that may be required prior to the start of implementation will be undertaken.

Box 5.6
Relevant stakeholders in Haiti to be engaged in the design and implementation of NbS interventions include:

- Ministère des Travaux Publics, Transports et Communications (MTPTC)
- Ministère de l'Environnement (MDE)
- Ministère De L'agriculture, Des Ressources Naturelles Et Du Développement Rural (MARNDR)
- Ministère de la Planification
- Ministère de l'Intérieur
- Ministère de Tourisme
- Réseau d'agents/volontaires de la protection civile
- Conseil d'Administration de la Section Communale (CASEC)
- Collectivités territoriales
- Organisations d'agriculteurs et riverains
- Organisations de pêcheurs et riverains

Case Study

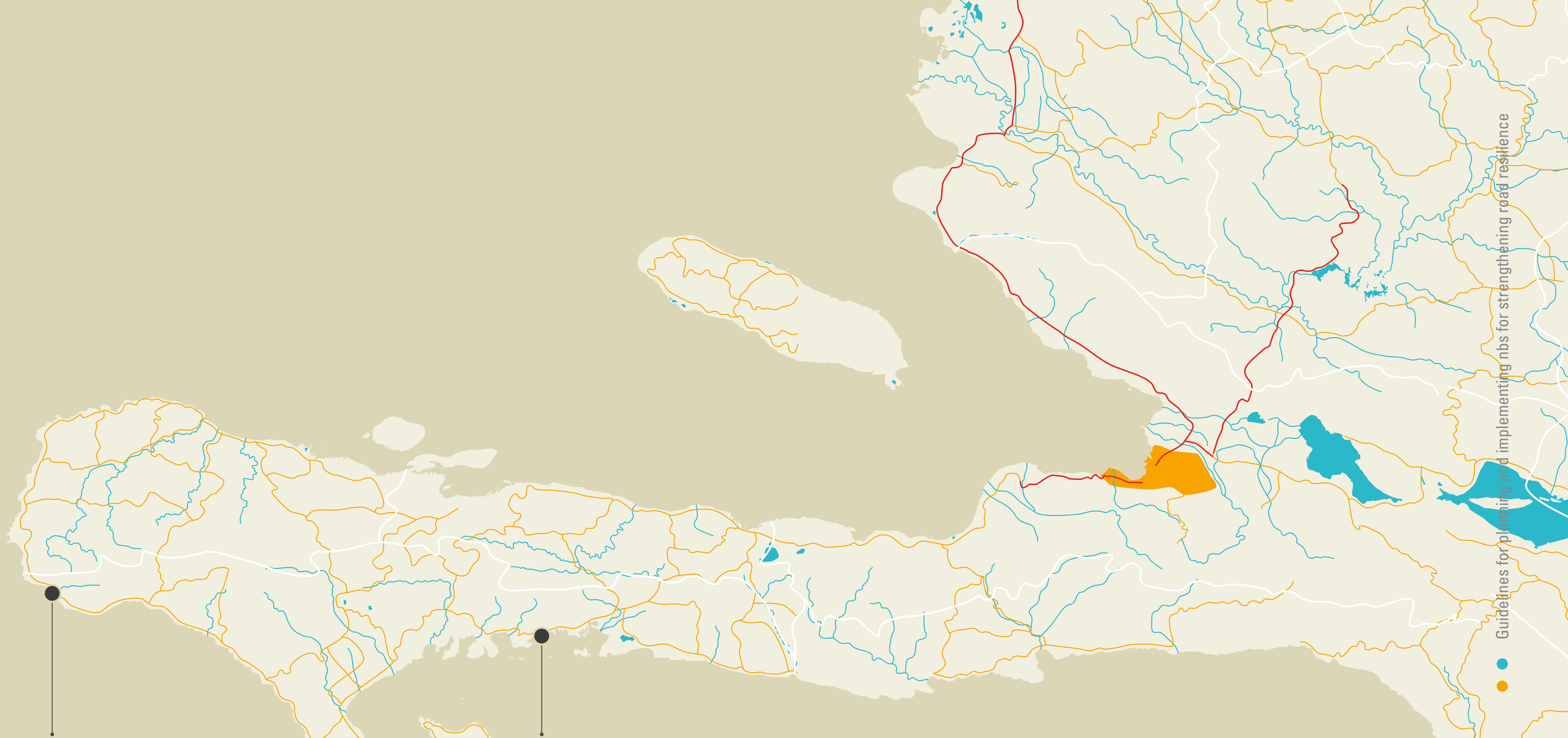
Design Packages for Two Pilot Sites in Haiti

Two sites in the South of the country were selected as pilot sites for the design of NBS as described in case studies of Step 2 and 3.

- Site 1: RN2 in the section of Des Zanglais, community of Saint-Louis-du-Sud.
- Site 4: RD25 in the section of Blactote, community of Tiburon.

From the initial diagnostics it was clear that both sites presented similar problems. The solutions proposed are the same for both sites:

- Hydrological evaluation of the site to analyze the effects of runoff from inland basins.
- Definition of the slope protection structures, and their complementary drainage works such as gutters and ditches.
- Determination of the need for cross-sectional works on the road.
- Definition of coastal protection structures to prevent erosion.
- Definition of a compacted embankment (which could be reinforced with geotextile) in the lower slope, according to "Specifications Pour Couche", compacted to 100% of its PVSM forming green terraces, which should be protected with geotextile to prevent erosion.

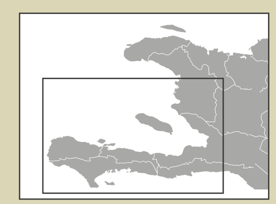


Site 4. Blactote

Site 2 is located is at approximately 4.1 km from Tiburon, on the coastline of the Tiburon Peninsula. The probability of eroding and sliding down the slope to the road, generating impacts on mobility and road infrastructure, lack of transversal additional drainage work , the undercutting slope and the upper slope erosion , generation of erosion

Site 1. Des Zanglais

Site 1 is located on the coastline of the Baie Anglaise, 20-23 meters from the beach front to the south and 2-3 meters from the foot of the mountain
No transverse drainage works are observed in this section. The main problem observed is the undercutting slope and to the erosion in the upper slope, which causes risks of blocked landslides.



From the initial diagnostics it was clear that both sites presented similar problems. **The solutions proposed are the same for both sites**

Guidelines for planning and implementing nbs for strengthening road resilience

Final solutions adopted

According to what has been observed in the field and engineering analysis, the **upper slope** (mountain side) is considered stable under static drained conditions, even under the effects of erosion. Under saturated static conditions, the slope is at an incipient state of fault. Under seismic conditions, the slope shows unstable behavior. The slope fault in the two previous conditions will occur at its top.

As such, with a view to protect the upper slope in the most critical situation (saturated conditions), the following measures were proposed:

- To cut and profile the slope to an inclination of 38 ° (1.28: 1 - H: V) for site 1 and 30 ° (1: 0.6 - H: V) for site 2.
- To include complementary drainage works (gutters, canals) to reduce pore pressure
- To install a protection system against erosion and promotion of vegetation growth based on willow spilling revetments.

Similarly, the lower or coastal slope is stable under static and dynamic conditions, as well as saturated and drained. However, it is exposed to the effect of erosion from the waves. The following measures were therefore proposed to protect the seaward side of the road:

- Construction of an embankment with the material that results from the actions developed in the upper slope
- Construction of a revetment with a slope 2: 1 (H: V).
- Mangrove revegetation

Figure 17: Final design in Site 1, Des Zanglais

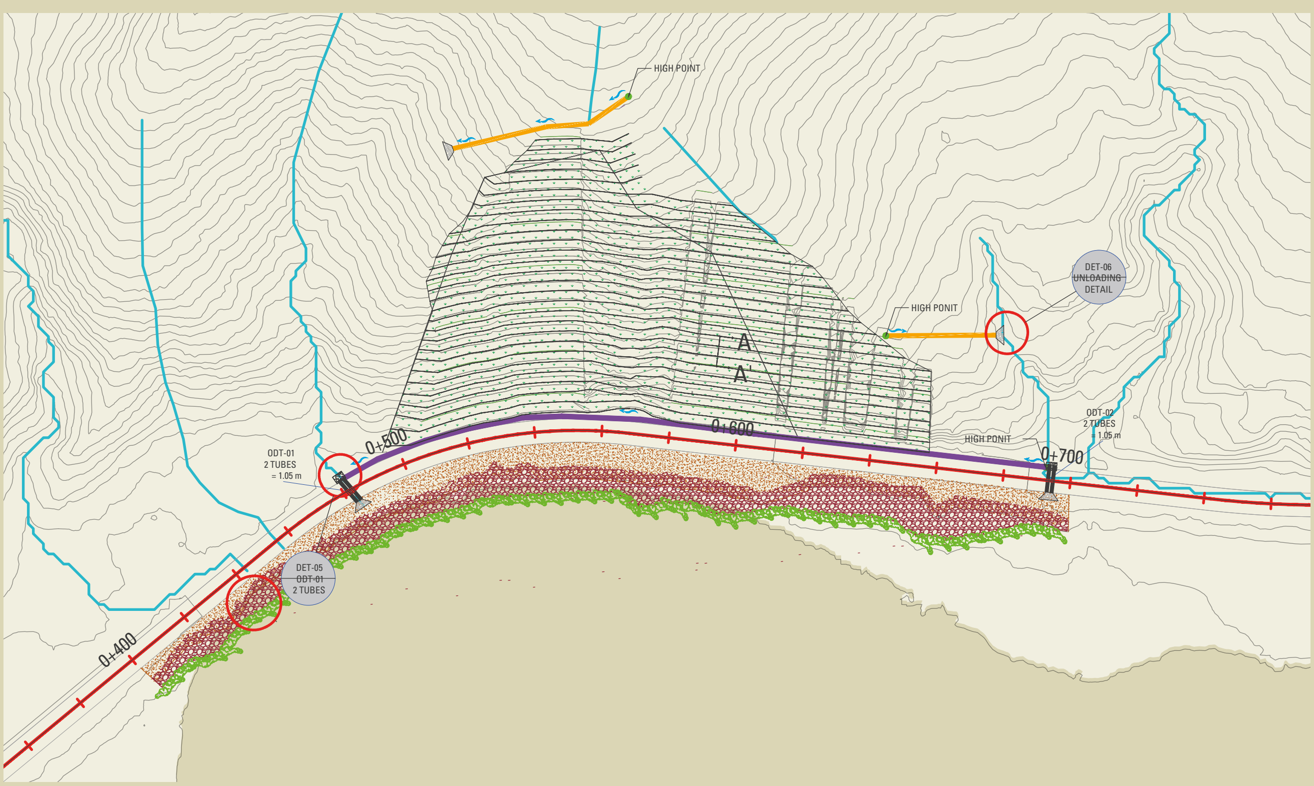


Figure 17 and figure 18 depict the **plan views of the final designs envisioned for both sites.**

Figure 16: Illustration of costal slope protection

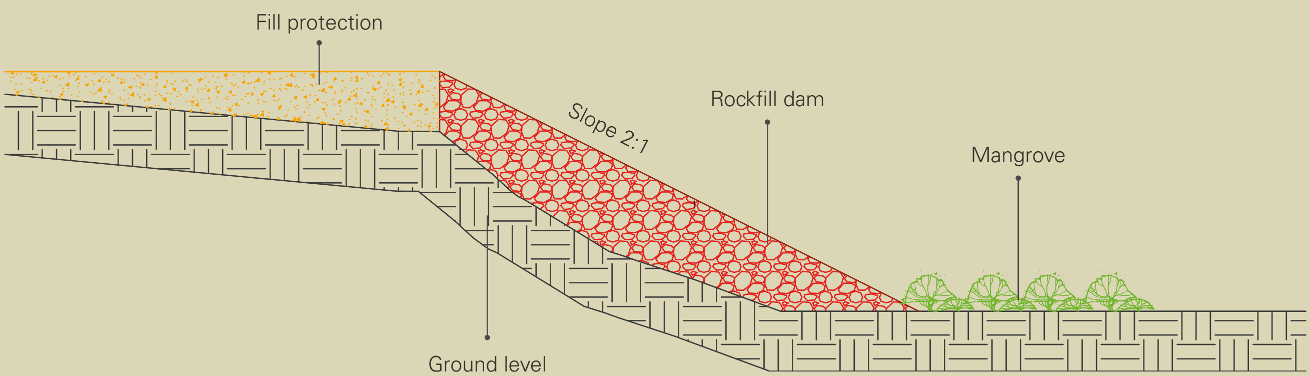
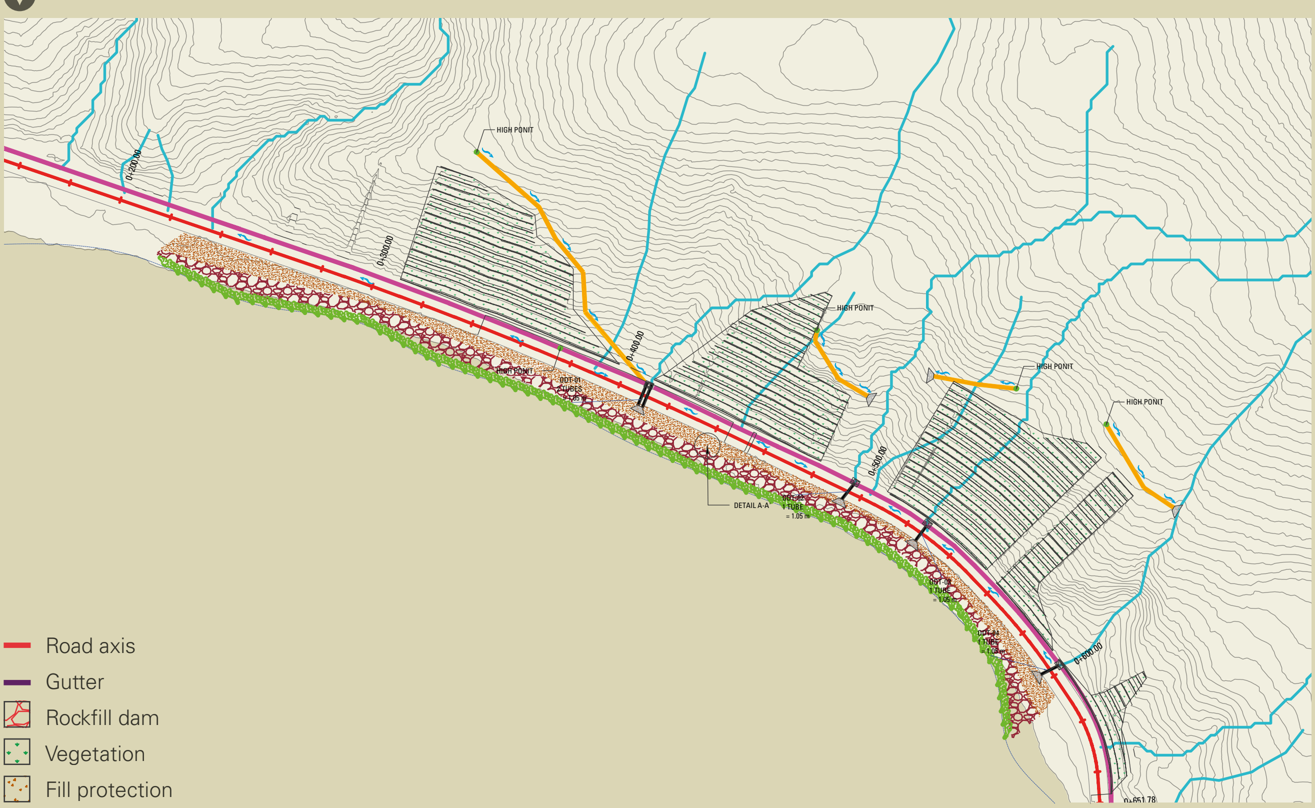


Figure 18: Final design in Site 2, Blactote



5.5

Step 5. Monitoring, evaluation and maintenance of nbs interventions

Objective

Monitoring activities during and after the implementation of NBS are needed to assess the achievement and effectiveness of foreseen outcomes. Monitoring and evaluation are also needed to record lessons learned for future use and replication of successful practices.

Stakeholder engagement

Stakeholder engagement for the monitoring, evaluation, and maintenance of NBS is crucial. Local communities can be involved in the monitoring processes by using simple and affordable methods and equipment. Furthermore, stakeholders can also be involved in the co-management of NBS measures through conservation approaches (e.g. Payment for Ecosystem Services, PES[67]). Awareness raising will be needed to increase the capacity and understanding of local communities of the importance of NBS and their maintenance and management benefits.

Outcome

A monitoring and evaluation framework that is realistic, operative, and iterative, including a standardized protocol for data collection and evaluation, and information generated on outcomes and impacts of interventions.

Key activities:

1. Identify performance evaluation indicators

After the implementation of NBS, it is important to be able to monitor its effectiveness. This will inform the kind of maintenance required to improve the performance of the solution to meet expected outcomes for road resilience. Therefore, key performance factors and evaluation indicators should be defined and agreed at design stage and should be monitored following the implementation of the NBS.

For the evaluation of solutions, three types of indicators are recommended to accurately measure their performance: 1) process (how to do it?), 2) the output (are measurable products achieved?), and 3) the outcome (are the goals achieved?). It is important that the indicators reflect the measure implemented and the level of reduction of the hazard it aims to mitigate. Table 22 shows a list of example indicators for measures for coastal protection. The identification of performance indicators depends on the type of solution implemented and the site-specific context.

After the implementation of NBS, it is important to be able to monitor its effectiveness. This will inform the kind of maintenance required to improve the performance of the solution to meet expected outcomes for road resilience.

Table 22: Example of indicators related to measures for coastal protection.

Objective of adaptation measure	Measure	Type of indicator	Indicator
Protection of beach and dunes from erosion associated with sea level rise and storm surge, and protection of the coastal road infrastructure assets located in the hinterland	Beach nourishment	Output	• Volume of sand gained/lost on beach and in dunes • % of road disruption (e.g. in number of days that the road is not operational)
	Dune restoration	Process	• Recession/accretion of shore in m/year
		Outcome	• % of areas affected by soil erosion / soil quality degradation • % of road disruption (e.g. in number of days that the road is not operational)
	Mangrove restoration	Outcome	• % of land exposed to wave action and flood risk
	Managed coastal realignment	Outcome	• % of road disruption (e.g. in number of days that the road is not operational) • Number of people directly affected (evacuated, relocated, injured or ill) by floods per 100 000 population
	Coastal slope stabilization	Outcome	• % of road network protected from extreme weather conditions/events • % of road disruption (e.g. in number of days that the road is not operational)

Box 5.7
Mangrove restoration monitoring

Mangrove restoration areas can be located across the nearshore/shoreline /hinterland zones and therefore monitoring of mangroves must be considered on an integrated coastal zone management scale and within spatial coastal zone planning. Mangrove afforestation areas are often located in Protected Areas, and therefore it is also critical that the monitoring plan is integrated into the management plan for the area. The following performance factors and evaluation metrics need to be considered:

Vegetation width, height, density, structure, age, stiffness, orientation to storm direction, continuity, health of root system, length.

Forest width and density of exposed root systems – this is most important for effectiveness in terms of wave attenuation

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Water depth

Sediment composition – need continued source of sediment - Predation of seedlings/transplants of young trees

Monitoring of NBS for road infrastructure requires using methods for ecological, social and infrastructure monitoring. Many of the methods that are currently used for monitoring are quite complex and require expensive equipment and specialist scientific skills. However, there are community-based monitoring methods, which are affordable and easy to use. In addition to monitoring, Payment for ecosystem services (PES), are interesting co-management approaches (where monitoring is embedded) that have the added value of generating economic benefits for local populations.

The role of communities in monitoring processes is particularly important. Therefore, special emphasis is provided in this Guide regarding suitable methods for monitoring, which engage community groups and require simple techniques and affordable equipment. Some of this monitoring methods include:

- **Visual inspection of ecosystems and infrastructure:** This method aims to observe the state of the ecosystem (e.g. growth of vegetation, survival of mangrove seedlings), the natural fluctuation of the beach morphology in coastal areas (e.g. level of coastal erosion) or slopes in mountainous areas, and to understand long-term and seasonal changes. In parallel, it is important to observe the road infrastructure that the NBS protects and document any changes in its status.
- **Beach profile surveys in coastal areas:** The key aim of this method is to quantitatively establish beach response to storm events, beach recovery rates, long-term volume changes and areas of potential erosion. It can be undertaken using a range of technology including traditional levelling. Ideally, it should be georeferenced using appropriate GPS.
- **Photographs:** the key aim of this method is to document the change and state of ecosystems and infrastructure. Photography is a useful monitoring technique that is based on the establishment of a series of locations from which to take repeatable photographs approximately at the same time of the year and similar conditions (e.g. tidal conditions); in the case of coastal areas, preferably close to low tide.

Table 23 shows a recommended monitoring program for ecosystem and infrastructure monitoring in coastal areas.

Table 23: Proposed monitoring program for monitoring of ecosystems and infrastructure in coastal areas

Monitoring	Visual Inspection	Beach Profiles surveys	Photography
During the first two years following construction	Twice per year	Twice per year	Twice per year
Year 3 onwards	Annual	Twice per year or to be redefined	Annual
Following storm events	As soon as possible following a storm event		

Table 24: Examples of the key elements included in a management plan for mangrove restauration.

Results	Restauration of mangroves
Activities	Raise awareness among local residents on the need to conserve mangrove remnants.
Project phase	During all phases of the intervention
Performance indicators	No extraction activity is recorded in the natural formations of mangroves.
Calendar	From the beginning of the implementation of the restoration plan
Estimated cost	USD 10,000

Table 25: Description of routine maintenance requirements for different interventions in coastal areas.

NBS option	Maintenance requirements
Beach Nourishment	Recharge with additional material to replace material lost through erosion and sediment transport. Recharge of material needs to be in line with the material that was originally used as part of the design and to the design slope and crest heights that were defined in the design.
Mangrove restoration	Removal of loose fouling materials (e.g. fishing nets, garbage, loose sea-weed fronds).
Breakwater	Replace missing rock armor and reposition rock that has been moved out of place to maintain 3 contact points.
Beach vegetation planting	Weeding and removal of any invasive species. Depending on the species planted, some may need cutting back or trimming more regularly. Beach vegetation can often also trap rubbish, either left by beach users or brought in by the tide. Regular maintenance to tidy the beach is therefore likely.

3. Operations and maintenance of NBS

Following the implementation of the NBS, it is important to prepare a management plan to provide guidelines for the operation and maintenance of NBS. It is recommended that the management plan covers the following sections:

- Introduction to the NBS and its characteristics
- Baseline information for the ecosystem including, for example, water levels, beach morphology, sediment properties (grain size etc.), sediment transport and ecosystem sensitivities for coastal areas.
- A table including the project results, expected activities, project stage, when the activity will be performed, performance indicator, timeframe, and estimated cost. An example of such table is provided in table 24 *f*or the case of a mangrove restauration intervention.

The management plan for NBS needs to consider two types of maintenance: (i) regular maintenance and (ii) after event maintenance of NBS.

- **Regular maintenance** involves the regular maintenance and monitoring of the completed project, which should include pro-active measures to prevent deterioration by providing maintenance on a routine basis. Regular maintenance should be included in the project budget and should be considered in the selection of suitable interventions, as certain interventions have much costlier maintenance requirements and therefore can alter the economic assessment of the option. Table 25 presents the routine maintenance required for a list of NBS interventions in coastal areas.
- **After event maintenance:** This involves maintenance or repair following storm events. For example, in coastal areas this could entail the replacement of dislodged rocks from a breakwater or, in some instances, or a repetition of a beach nourishment exercise following a storm.

Regular maintenance should be included in the project budget and should be considered in the selection of suitable interventions, as certain interventions have much costlier maintenance requirements and therefore can alter the economic assessment of the option.

6. STAKEHOLDER ENGAGEMENT

6.1

Stakeholder engagement and NBS

Stakeholder engagement is the practice of interacting with, consulting, involving, and collaborating with project stakeholders to the overall benefit of the project, the communities, and the ecosystems. It is essential to include a variety of approaches including consultation, communication, negotiation, compromise, and relationship building to ensure the full engagement of the different types of stakeholders to capitalize on their support towards sustainable and efficient solutions, or to prevent the occurrence of negative impacts (e.g. sand/rock extraction for construction practices, cutting of mangrove trees for fuel, etc.)

In the context of NBS, best practice in stakeholder engagement involves the implementation of NBS interventions through participatory processes at community and landscape level. These processes will only be successful if raising awareness and capacity building activities are held, and communication strategies are developed properly. These approaches are explained in table 26.

Table 26: Approaches for stakeholder engagement

Participatory processes	Key element to meaningful consultation and participation. These processes must begin early in the project identification and planning process to gather initial views. They must encourage stakeholder feedback and engagement in the project design and implementation, ensure transparency, and respond to feedback.
Awareness raising	Aimed to increase sensitivity over the importance of implementing and maintaining NBS over time and the protection of infrastructure and how it benefits local communities and ecosystems. This can be done through campaigns, publications, media products, volunteering activities, among others, considering the whole community: businesses, local authorities, schools, NGOs, academia, civil society.
Capacity building	Aimed to increase technical knowledge related to NBS, understanding that sensitivity and engagement need to have a technically solid basis. Local authorities, technical staff and communities, need to know how the NBS work, how they are designed, what are the risks they entail, including environmental and social issues, what are the O&M requirements and how to respond to unexpected contingencies.
Communication strategies	Closely related to the three aspects above, these strategies should take the form of a plan that determines the best moment and the best way to reach consensus on decisions with stakeholders. A communication strategy should consider aspects such as dialogue modalities, target groups, language, culturally appropriate messages, identification of sensitive subjects at the local level, transparency.

6.2

Stages for stakeholder engagement

The coordination of NBS activities, from planning through to implementation and monitoring, across different levels of government, and with different sectors and actors, will be needed to achieve their objectives. Stages for stakeholder engagement are schematized in the diagram below (Figure 0).

The first step is the Identification of stakeholders. The quality of this identification can affect the scope and scale of the NBS strategy, as well as help determine which options will be the most appropriate. In the context of NBS, the stakeholders will typically include local communities, local economic actors, implementing partners of the project, local authorities ("départements", "arrondissements," "communes," "sections communales"), local academic institutions, local technical staff, and national-level policy and decision makers. In the context of Haiti, these could be the Ministry of Environment, the Ministry of Tourism, and the Ministry of Planning.

Within the economic actors, it is essential to consider that numerous economic activities take place in Haiti. The coastlines of the country host activities such as fishing, local trade, tourism, harvesting of mangrove forests. In the hinterland, agriculture activities face the constraints related to the mountainous environment - 80% of the territory being mountainous with more than 75% of slopes greater than 20% and highly affected by deforestation and consequent erosion -, except for the agro-pastoral activities that take place in the Plateau Central. Some of the stakeholders are organized in associations such as e.g. fishers' associations and cooperatives of vetiver producers. It is fundamental to incentivize the private sector to be involved in NBS.

The above diagram indicates the kind of tools that can be used for promoting participation in every stage: participatory rural appraisal, mapping, workshops. The toolkit at the end of this section, provides some resources for exploring the different methodologies.

Additional tools that may be used for stakeholder engagement include social media, ad virtual tools, focus groups, questionnaires, and surveys, learning alliances, and living labs.

Some of the stakeholders are organized in associations such as e.g. fishers' associations and cooperatives of vetiver producers. **It is fundamental to incentivize the private sector to be involved in NBS.**

Figure 20: Stages for stakeholder engagement

1.
Identification of stakeholders

NBS stakeholders include multipe group: communities, economic actors, governments.

2.
Understanding livelihoods and ecosystems

Discussions, participatory rural appraisal exercises, livelihood and resource mapping, participatory hazard mapping, stakeholder interviews.

3.
Design

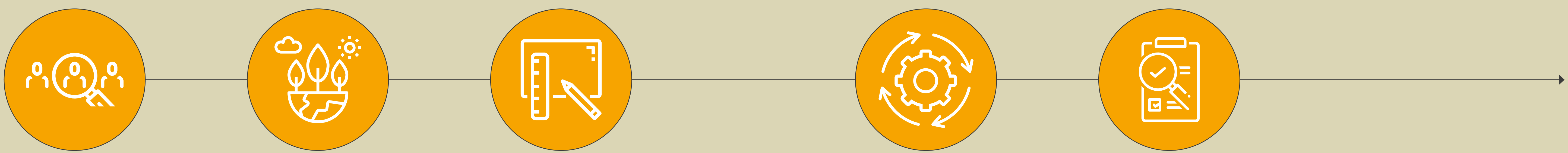
Participatory processes during hte desing stage for the selection of criteria to prioritize measures and validation of interventions. Periodic workshops that include capacity building and analysis of E&S issues.

4.
Implementation

Continuous information sharing and consultations, agreement on lifetime of intervention, capacity building. Involvement of stakeholders in the implementation of measures.

5.
Monitoring and evaluation

Flexibility to changes during works, based on stakeholder needs an emerging information. Involvement in O&M.



6.3

Identification of relevant stakeholders

Stakeholders, at various levels and stages, are crucial to the success of an adaptation project, and as previously described, they should be involved from the planning stages throughout the overall process. Stakeholders can include national and local government institutions, communities, non-governmental organizations, research institutes or the private sector. The level of participation of the stakeholders will depend on the phase of the process and the specific stakeholders involved: consultation, management, coordination, implementation, monitoring and evaluation.

An in-depth stakeholder analysis and development of multi-stakeholder processes and participatory mechanisms are key to achieving ownership and sustainability of the NBS interventions.

Table 27 shows an example of potential stakeholders and their roles for the implementation of NbS interventions.

Table 27: Stakeholders and their roles in the implementation of NbS interventions.

Stakeholders	Roles
National government and ministries (e.g., agriculture, health, environment, education); early warning systems and disaster prevention institutions	• Implement sectoral policies, programs and plans • Build capacity and develop effective mechanisms to solve local problems • Ensure technical capacity • Provide budget for interventions • Oversee the implementation of the interventions
Local governments	• Develop local capacity • Finance local plans and programs promoting NBS interventions
Research centers and universities	• Address knowledge and information gaps needed for the design and implementation of NBS interventions • Develop protocols and guidelines for the implementation of the NBS interventions • Participate in the monitoring and evaluation of NBS measures
Local environmental/ development NGOs	• Facilitate the organization and the participation of local people and • Develop capacity (e.g., technical, financial, human, institutional) • Strengthen local institutions such as community groups
Local communities	• Participate in the implementation, management and monitoring of the NBS measures to be implemented

6.4
Recommendations

Experiences of engaging stakeholders in NBS in Haiti and in other parts of the world have shown that this process will be more successful if the following aspects were integrated in the stakeholder engagement process:

- Identify, inform, and involve local intervention structures in the implementation of NBS.
- Involve all neighboring communities' upstream and downstream mountain ecosystems and all communities living in or depending on coastal ecosystems.
- Work with local organizations trusted by the communities can help to build social cohesion.
- Assign resources to cope with logistical challenges if communities are dispersed and served by poor infrastructure.
- It is important that the project team should be ready to question assumptions about livelihood strategies through an inclusive discussion with members of all parts of the community, including women, youth, and minority groups.
- Obtaining and showing results in the short term (months) is of great importance for maintaining the motivation of the community and the decisive factors of the NBS.
- Communities are motivated by the exchange of best practices with communities from other parts of the country or other countries. It is therefore important to identify best practices and organize activities in which stakeholders can show examples to follow, can learn from others, and can create networks for collaboration.

It is important that the project team should be ready to question assumptions about livelihood strategies through an **inclusive discussion with members of all parts of the community, including women, youth, and minority groups.**

Box 6.1
An example of how the vision of the communities on the choice of species can be key to success of the NBS – the case of vetiver

Technically, planting vetiver is one of the best options for slope stabilization in Haiti. However, vetiver is, at the same time, one of the most exported products of Haiti because of its interest for the perfume industry and a very important source of income for a large number of small farmers. Many of them depend on vetiver for their livelihood. It is therefore important to work with communities on the relevance of selecting vetiver for revegetation of slopes, to ensure the sustainability of the protection measure. A possible intermediate solution could be the promotion of sustainable vetiver cultivation. There are several initiatives in the country that help make the vetiver sector more sustainable: preserving resources (soil, water, etc.), improving and diversifying producers' incomes, and strengthening the capacities of stakeholders in watershed management.

Box 6.2
Gender aspects in stakeholder engagement

To achieve active involvement of both men and women, it is essential to:

- Use of inclusive language in all instances of calls and outreach, to explicitly address men and women.
- Establish meeting schedules considering the possibilities of participation of men and women.
- Establish specific schedules for meetings with women as targets.
- Impulse to give women a voice in participatory processes, so that they can make their needs visible.
- Organize ad hoc care spaces so that women can participate in meetings and activities (considering the structure of the sexual division of labor).
- Always extract data and results disaggregated by sex.
- Identify employment opportunities for women within the framework of the project activities and in the long term. It is important to remember that the 1987 Constitution, amended in 2011, establishes the principle of a quota of at least 30% of women in all activities of national life, particularly in the public services.

Case study

NBS and stakeholder engagement in the context of works on the Les Cayes - Jérémie road

1. Context

As part of the road infrastructure rehabilitation program for the integration of the territory, implemented by the Haitian Government and financed by the Inter-American Development Bank (IDB) and the Canadian International Development Agency (CIDA), the Departments of the South and Grande-Anse benefited from the project to rehabilitate National Road 7 (RN7) linking the towns of Les Cayes and Jérémie.

Within the Haitian government, the Ministry of Public Works, Transport and Communications (MTPTC) is responsible for transport infrastructure and was the project owner through the Central Execution Unit (UCE).

The Les Cayes / Jérémie road project extends over a length of approximately 79 km.

There are many valuable protected areas; and agriculture and agroforestry are the main activities along the stretch. The project includes some good examples of interventions related to the participation of local communities and the implementation of some NBS measures for slope protection. These aspects are described below.

The location of the road on the mountain side means that there are several very steep slopes. Therefore, erosion control is an extremely important measure. Although Nature-Based Solutions were only applied to a small portion of the slope section, their application a few years later was confirmed to be satisfactory.

In this project, the slope protection work considered the planting of trees and shrubs, vetiver, and the construction of dry walls with stones. These walls make it possible to retain sediments and strongly limit erosion, as well as limiting the impact of potential landslides. Especially in cases where erosion processes are evident, instead of planting, the walls should be built first. These will begin to capture sediment and then trees, shrubs and vetiver can be planted.

Within the framework of plantation and embankment protection actions, there were several successful actions to engage local communities:

Figure 22: Les Cayes / Jérémie Project location.
Source: SMi – BID, March 2013

Lot 1
Lot 2

- **Consultations, awareness-raising:** in addition to formal and informal public consultation sessions with local communities before initiating the works, during and after the construction phase, training sessions on tree planting techniques and awareness-raising sessions on environmental protection were held for the community.
- **Those responsible for the actions:** the grassroots organizations were responsible for the implementation of the planting project.
- **Consideration of community opinion for species selection:** surveys were conducted in each locality. They showed people's interest in fruit trees, in addition to forest trees.
- **Purchases in the community:** producers who own nurseries and many others have benefited from purchases of species for the planting project. In the same way, the project aimed to integrate all small businesses in the area to carry out the work.
- **Involved population:** in addition to local representatives, the population affected by the embankment works at the various localities along the section has actively participated in the project, thus ensuring better long-term care on the part of the entire community.
- **Generation of employment at the local level:** employment of the inhabitants of the communities on the construction site was promoted.
- **Employment of women:** special effort was made to identify employment opportunities for women from the communities in the project and to achieve the target of 30% women defined by law in Haiti. For example, they worked in the catering of all the staff, as the project managers decided to promote their employment instead of contracting a large company. To a lesser extent, they worked carrying stones, water, and driving trucks and bulldozers.

2. Nature-Based Solutions, 7 years later

Thanks to the continuous/regular monitoring undertaken by the UCE in the field, it is possible to affirm that the revegetation works, and the dry-stone installations carried out in 2012 are still in good conditions, 7 years later. Not only have the communities preserved the spaces with the afforestation done, but also the works continue to guarantee protection against erosion. The pictures below show the state of the various developments as of February 2020.

Figure 23: Nature-Based Solutions along Les Cayes-Jeremie road (source: UCE)

3. Lessons learned: the importance of being able to adapt the consultation methodology in restrictive situations

Communication with project stakeholders must be maintained and nurtured, even in crisis contexts where circumstances may prevent consultations from taking place in the usual way.

This has happened, for example, in the case of the consultation process of the Regional Development Project of the Boucle Centre-Artibonite, BCA[64]. This process was affected by the coronavirus (COVID-19) health crisis, during which mobility was limited and face-to-face contact with the different actors was not possible during that period.

Restrictions on mobility were applied after initial contact with local actors. The next step required a second visit to present the action plans developed with the inputs of the first one, but this could not be carried out.

The World Bank, in its technical note prepared specifically for this exceptional situation[65], indicated that, given the growing concerns about the risk of spread of the virus, there was an urgent need to adapt the approach and methodology for stakeholder consultation and participation. Several options for process development were proposed by the WB.

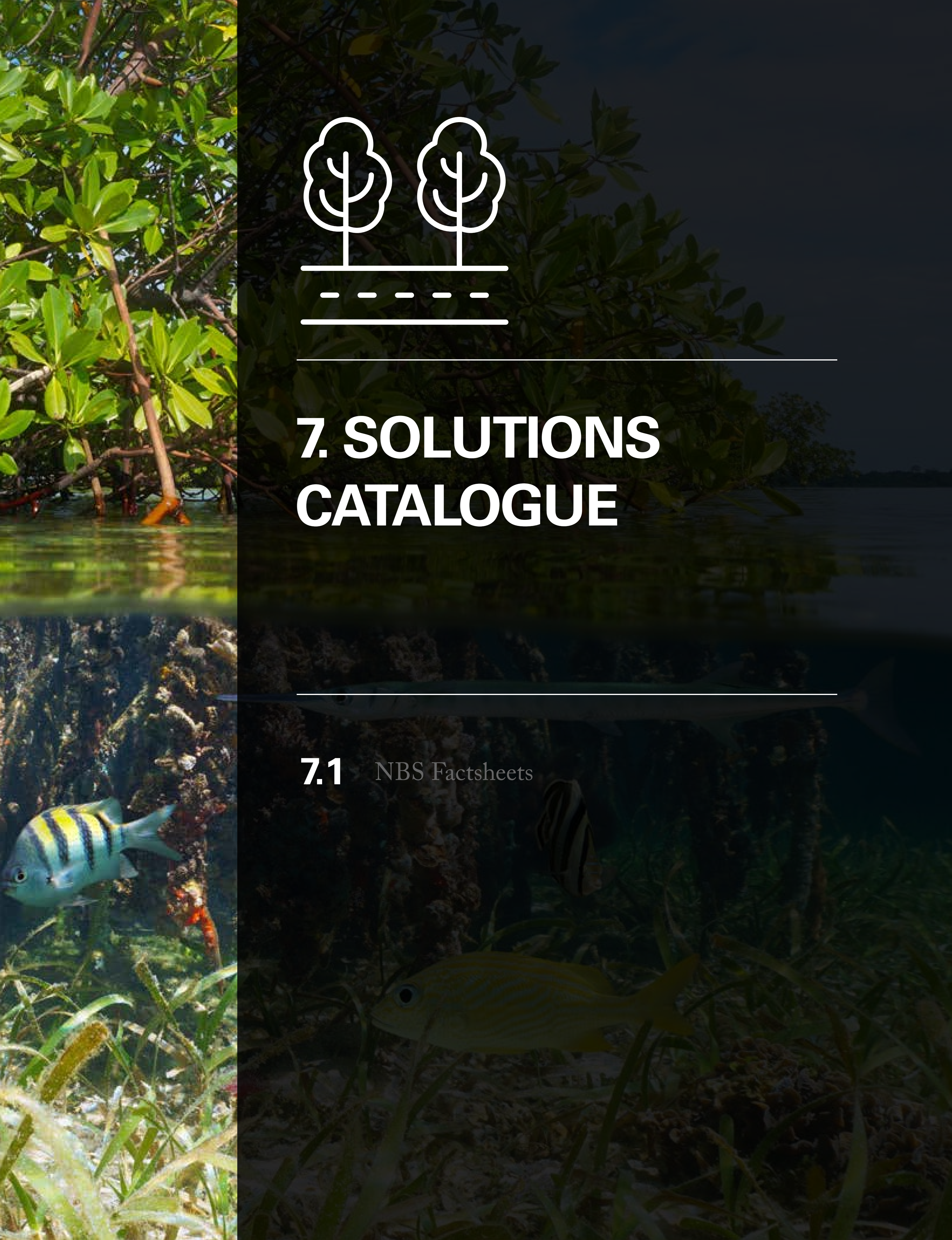
In the case of the BCA project process, it was necessary to assess the level of ICT penetration among key stakeholder groups to determine the type of communication channels that could be used effectively in the context of the project. Options included the use of the Internet (videoconferencing, instant communication applications, e-mail) and telephone calls. In the case of BCA project stakeholders, the working group determined that Internet exchanges with local authorities could be considered, but with interruptions; with local communities, the telephone would be the only viable option. The table below (table 28) shows the analysis of alternatives that was carried out to allow the process to continue.

Communications were carried out satisfactorily with all local stakeholders. It should be noted that the flexibility of the consultation methods made it possible to continue the process and maintain an open telephone channel, the potential of which was used by both the management team and the stakeholders consulted.

However, one of the lessons learned is that a first face-to-face contact was still necessary to generate trust. For the population consulted, it would not have been the same to receive telephone calls without first meeting the project team in person. The project team also committed to organize a public consultation once the state of emergency was lifted, to compensate for the lack of direct connection during this period.

Table 27: Stakeholders and their roles in the implementation of NbS interventions.

Approach/ Tools	Analysis	Applicability
Public meetings	Prohibited by the Haitian Government and the UTE	Not applicable
Small meetings	Stakeholders lack PPE[66] against COVID-19. Small meetings and field missions prohibited since the declaration of the state of health emergency.	Not applicable
Online Meetings and discussion groups	Technologies are not accessible for the Town Hall, the management committee, or the stakeholders.	Not applicable
Traditional communication channels (TV, newspapers, radio and others)	Not suitable for stakeholder consultations. On the one hand, stakeholders are scattered throughout the territory and local radio stations have limited coverage. On the other hand, such communications may jeopardize the security of the stakeholders.	Not applicable
Email and Instant Messaging	Instant messaging is used to communicate with certain stakeholders who have this technology (e.g. MDOD, Town Hall, Management Committee). However, some stakeholders only have internet data available very rarely and in limited quantity. This technology is not accessible to all the impacted parties concerned.	Applicable for exchange of documents and images. Unsuitable for long discussions.
Telephone calls	They make it difficult to confront different ideas and do not allow for group interaction. Nevertheless, they do allow for an in-depth discussion with each specific PAP[67]. They also guarantee the confidentiality of data and do not compromise the security of the PAPs.	The most used method of consultation during the health emergency generated by COVID-19.



7. SOLUTIONS CATALOGUE

7
SOLUTIONS CATALOGUE

This section provides a description of tested NBS that may be used for the protection of road infrastructure. While interventions need to be tailored to the specific local context, and despite the wide range of contexts in terms of exposure to hazards, ecosystem health and human systems that exist, these NBS have been found relevant for Haiti's context.

A list of 16 Solutions are identified and summarized in the following table including information on its most relevant road configurations, objective, type, scale, material, implementation cost, co-benefits, and risks. Additional information on economic cost of NBS can be found in section 4. Subsection 7.2 provides fact sheets with the description of the solutions that are considered the most relevant for Haiti in terms of highest risks, local ecosystems, and local capacity and resources for implementing the solutions.

NBS1.
Slope stabilization: general principle

NBS2.
Slope stabilization with natural materials

NBS3.
Slope stabilization with hybrid materials

NBS4.
Revegetation with native forest species

NBS5.
Restoration with resilient local crop varieties

NBS6.
Mangroves conservation and restoration

NBS7.
Coral reef conservation and restoration

NBS8.
Living Breakwaters

NBS9.
Oysterbreak systems and shoreline protection units

NBS10.
Restoration of beaches, sand banks and dunes

NBS11.
Seagrass restoration and conservation

NBS12.
Natural wetland management (morass, swamps, and wetlands)

NBS13.
Coastal slope stabilization with hybrid materials

NBS14.
Managed coastal realignment

NBS15.
Rockfill and vegetation for protecting bridges' piles and abutments

NBS16.
Riverbank works for bridge protection

Although the different categorizations are presented in a certain order, it is important to keep in mind that all ecosystems are linked. Everything that happens in one of the systems has a direct influence on the others. For example, poor management of upper watershed areas (for example, poorly planned drainage), can generate significant negative consequences on the coastline or directly in the marine ecosystem. In summary, "recognizing the interconnectivity of systems is fundamental to the design and effectiveness of the NBS"[72].

In each of the solutions of the catalogue, guidance is provided on whether they are fully based on the use of biodiversity and ecosystem services (ecosystem-based adaptation, EbA, or Ecosystem disaster risk reduction, Eco-DRR), or if they are hybrid options that seek to capitalize on the characteristics of both hard and natural approaches.

Comprehensive approach

Although different NBS solutions could be cited separately, it should be noted that the best solution is likely to be a combination of several NBS, hard engineered and non-structural measures, which would in turn result from an intensive territorial/land use planning process.

Thus, it is recommended to adopt, in all cases, a comprehensive perspective. For this, it is necessary to consider the following two types of approaches, valid for the 4 vulnerable configurations or Road Management Units identified: Multiple Lines of Defense and Upstream Management. These are described below.

Multiple lines of defense: Involves using environmental features (barrier islands, marshes) to complement hard infrastructure (levees and flood gates) as well as non-structural measures (raised homes and evacuation routes). The increased number of interventions which are used within a scheme is likely to increase the overall resiliency to extreme events. The figure 24 below presents a representation of how some of the interventions can be aligned and complement each other (GoJ 2017) as part of a multiple lines of defense approach.

Upstream management: Management from the upper watershed areas and hinterland to the nearshore is critical. Given the close inter-connections between land, water and coastal systems in Haiti, the integration of upstream activities with coastal area management is essential to foster effective cross-sectoral coordination in the planning and management of land, water, and coastal uses.

NBS	Road Configuration	Objective	Type	Intervention Scale		Materials	Cost	Co-benefits	Risks for sustainability
NBS1 Slope stabilization: general principle	A: Mountain	Protect infrastructure from landslides and erosion by slowing water velocity and facilitatingwater infiltration.	Ecosystem-based / hybrid	landscape / road's right-of-way				Biodiversity (if species are native), environmental conditions	Lack of attention to soil quality in the revegetation process. Selection of varieties that are attractive to animals (livestock or wildlife) or for an economic activity (e.g. vetiver). Selection of varieties that are not adapted to the specific site conditions.
NBS2 Slope stabilization with natural materials	A: Mountain D: Crossing (riverbanks)	Protect infrastructure from landslides and erosion. The natural method that is mostly used for anchoring the different structures are the live or dead hardwood stakes.	Ecosystem-based	landscape / road's right-of-way		Coconut, jute, or other organic fiber grids; Straw rolls; Fascines; Logs / wattles (timber logs or logs made of organic fibers such as coconut fiber or straw -"straw wattles").		biodiversity, environmental conditions	Lack of maintenance, especially in the first stage after installation.
NBS3 Slope stabilization with hybrid materials	A: Mountain D: Crossing (riverbanks)	Protect infrastructure from landslides and erosion. The grey method that is mostly used for anchoring the different structures are wires and hooks.	Hybrid	landscape / road's right-of-way		Synthetic anti-erosion geomats or geogrids; Terraces; Geocells; Gabions; Riprap; Stone revetment; Riprap.	$1,080/ha/yr[65]	biodiversity, environmental conditions	Extreme events
NBS4 Revegetation with native forest species	A: Mountain	Helps stabilize slopes. Native plants are adapted to native soils, provide wildlife habitat, can adapt better to climate disruptions/	Ecosystem-based	landscape / road's right-of-way			$3,450/ha[37]	biodiversity, environmental conditions	Lack of attention to soil quality in the revegetation process. Selection of varieties that are attractive to (livestock or wildlife) or for an economic activity (e.g. vetiver). Selection of varieties that are not adapted to the specific site conditions.

Case study – design package developed for two pilot sites in Haiti

NBS	Road Configuration	Objective	Type	Intervention Scale		Materials	Cost	Co-benefits	Risks for sustainability
NBS5 Restoration with resilient local crop varieties	A: Mountain	Restoration of ecosystems adjacent to roads that can provide protection against erosion, while also, having the advantage of being economically valued by local communities.	Ecosystem-based	landscape / road's right-of-way				economic value	Lack of attention to soil quality for the development of vegetation. Selection of varieties that are not adapted to the specific site conditions. Selection of varieties that have no market conditions.
NBS6 Mangroves conservation and restoration	B: Coastal	Coastal protection. Mangroves reduce wave energy, reduce storm surge and flood depth .	Ecosystem-based	landscape			$9,000/ha (median) [Range: $1,413-42,801/ha[35]]	Provides numerous goods and services to the marine environment and to human communities: fisheries, firewood, timber and plant products; sequestration of greenhouse gases; sinks for inorganic nitrogen and phosphorus; biodiversity; tourism.	Exposure to plastic pollution and other human waste; conversion to unsustainable aquaculture. Overharvesting for charcoal and firewood for sale in urban markets. Unprotected mangrove seeding vulnerable to predation by goats.
NBS7 Coral reef conservation and restoration	B: Coastal	Protection from wave damage to other habitats, coastal communities, and infrastructure. Coral reefs can supply and trap sediments and attenuate waves.	Ecosystem-based	landscape			$165,000/ha (median)[35,36] (also $542,500/ha[37])	Biodiversity, provision of essential ecosystem services and habitat for valuable fish species and other marine organisms. Ecotourism.	Pollution, invasive species, overfishing, eutrophication, damage from shipping and tourism activities, climate change and natural hazards.
NBS8 Living Breakwaters	B: Coastal	Reduce wave energy by creating a barrier, most often underwater, between open water and the shoreline.	Ecosystem-based	landscape		Intentionally designed to incorporate natural habitat components while still providing protection to the coastline (e.g. harvested oyster shells).		Biodiversity, provision of essential ecosystem services and habitat for valuable fish species and other marine organisms. Fishery production. Tourism.	Pollution, invasive species, eutrophication, damage from shipping and tourism activities, climate change

Case study – design package developed for two pilot sites in Haiti

NBS	Road Configuration	Objective	Type	Intervention Scale		Materials	Cost	Co-benefits	Risks for sustainability
NBS9 Oysterbreak systems and shoreline protection units	B: Coastal	Reduce wave energy, thus reducing damage from wave action, and reduce erosion.	Ecosystem-based / hybrid	landscape		Important to check characteristics such as strength and permeability.	$66,800/ha[6]	Stimulate oyster growth and thereby increase the biodiversity in the immediate area.	Depend on design considerations (e.g. area of frontages to be protected, current, tide and surge water levels and obstructions on seabed.
NBS10 Restoration of beaches, sand banks and dunes	B: Coastal	Protection from storm surge and waves and sea level rise.	Ecosystem-based / hybrid: combined with groynes, offshore breakwater, artificial coral reef creation	landscape			$7,636-13,888/ha[44]	Biodiversity: Beaches provide value for the residents and help to support the local tourism economy.	To achieve a successful restoration, it is essential to eliminate the influx of public to the area where the action is carried out. It is necessary to carry out a series of works to protect the dune line, including fencing, adapting accesses, building walkways and information signs.
NBS11 Seagrass restoration and conservation	B: Coastal	Attenuate waves and stabilize sediments (most reliably in shallow waters and low wave energy environments).	Ecosystem-based	landscape				Biodiversity, refuge for calcifying organisms, key habitat (spawning, nursery and feeding grounds). Carbon sinks: as biomass increases with ocean acidification, carbon sequestration is increased. Fishing.	Pollution brought by rains, sedimentary erosion created by cyclonic swells affects certain species of seagrasses, exposition due to low barometric tides. Impact from anthropogenic pressures (e.g. use of fishing gear; anchorages and boat propellers; removal of meadows from bathing areas for the "well-being" of tourists; impact from the extraction of coral or sand; development of infrastructure, indirect pollution from domestic, agriculture and industrial activities).

Case study – design package developed for two pilot sites in Haiti

NBS	Road Configuration	Objective	Type	Intervention Scale		Materials	Cost	Co-benefits	Risks for sustainability
NBS12 Natural wetland management (morass, swamps, and wetlands)	B: Coastal	Act as "buffers" and thus perform important functions related to the protection of communities, ecosystems, and assets (sediment and erosion control; storm water runoff reduction through infiltration).	Ecosystem-based	landscape			$85,000-230,000/ha[42] ($67,000/ha[35])	Recreation, water quality, nutrient transformation, and removal; reduction of human impacts by limiting easy access; biodiversity, and a barrier to invasion of exotic species. Reduction of water temperature, pollution reduction, enhanced access to water for local communities.	Pollution. Impacts from direct human activity on the ecosystem.
NBS13 Coastal slope stabilization with hybrid materials	B: Coastal	Protect infrastructure from coastal erosion by waves, currents, and wind.	Hybrid	landscape		Revetments; Groynes; Adjustable timber groynes; Gabions; Sandbag structures; Sediment-filled geotextile material tubes		Biodiversity, fishery habitat.	Revetments can disrupt natural shoreline processes by cutting-off inshore supply of materials and can also destroy shoreline habitats and reduce the width of inter-tidal beaches. Climate events can affect short-term structures such as gabions and sandbags.
NBS14 Managed coastal realignment	B: Coastal	Flood risk management. Face sea level rise, storm surge.	Ecosystem-based / hybrid	landscape / road's right- of- way				Biodiversity, fishery habitat, mitigation of loss of intertidal habitat, carbon sequestration and storage, recreational use.	Option that is often of high political and social controversy. The schemes frequently suffer from a lack of public acceptance. It is also likely to be highly disruptive and expensive if relocation of coastal infrastructure is required. Care should be taken to ensure that if infrastructure is abandoned rather than relocated, nearby areas do not become isolated, thus leading to increased poverty.

Case study – design package developed for two pilot sites in Haiti

NBS	Road Configuration	Objective	Type	Intervention Scale		Materials	Cost	Co-benefits	Risks for sustainability
NBS15 Rockfill and vegetation for protecting bridges' piles and abutments	C: Crossings	Protection against local scour of piles and abutments due to water and sediment erosion.	Ecosystem-based / hybrid	Road's right- of-way				Biodiversity.	Extreme events can damage the implemented solution.
NBS16 Riverbank works for bridge protection	C: Crossings	Protection against local scour of piles and abutments due to water and sediment erosion.	Ecosystem-based / hybrid	Road's right- of-way		Channeling dikes (built with a soil or sand embankment that should preferably be protected with rock and at least with grass or vegetation. Filters may be required or the granulometry may need to be varied to avoid loss of fine material); Spurs (built with rocks, gabions, wood, or bamboo).		Biodiversity, in the case of revegetation.	Extreme events can damage the implemented solution.

Case study – design package developed for two pilot sites in Haiti

7.1

NBS FACTSHEETS

In this section, a series of fact sheets have been developed for each of the NBSs that have been considered relevant to the Haitian context. They are intended to provide a quick overview of the basic principle of the protection that ecosystems can provide to the road network in each case.

NBS1

Slope stabilization: general principle

NBS objective

Protect infrastructure from landslides and erosion. This consists of revegetating the slopes to slow water velocity and facilitate water infiltration. In general, a combination of measures is desirable. Especially in areas with steep slopes, it is important to reduce the slope and, if this is not possible, install stabilization structures such as gabions, riprap, retaining walls, which can be combined with grids or rockfill geotextile sheets. Then, revegetation is promoted to bring further stability. Slope drainage is also an important consideration in this context. See different combination of options in the table below and subsequent factsheets.

Type of NBS

Ecosystem-based / hybrid

Increases potential with other NBS

Combination of measures in table 29 below

Intervention scale

Landscape / road's right-of-way

Co-benefits

Biodiversity, environmental conditions

Risks for sustainability of NBS

Lack of attention to soil quality in the revegetation process. Selection of varieties that are attractive to goats and other livestock or for an economic activity (e.g. vetiver). Selection of varieties that are not adapted to the specific site conditions.

O&M considerations

Stabilization and revegetation of exposed slopes must be carried out as work on the roads progresses. All protection and/or stabilization works must be subject to periodic visits and detailed inspections followed by corrections in the event of anomalies detected, whether these are due to normal ageing or to stresses related to the type of phenomenon that justifies the presence of the protection work. It should be noted that projects are not finished with germination of the plants, but with at least 70% cover of long-term vegetation.

Example of Haitian experience

Slope stabilization through revegetation during the rehabilitation works of the route Cayes - Jérémie (see case study on p. 63). Also, solutions have been proposed by TYPSA for two pilot sites in the South, in the framework of the project "Development of Design and Guidelines, and Capacity-Building for the Adoption of Ecosystem-Based Solutions to Protect Infrastructure Assets in Haiti" (see case study in Section 7).
Several options can be considered for slope stabilization. In the selection of the suitable options, the first aspect to consider is the quality of the soil. Then, depending on the slope and type of soil, among other factors, revegetation may or may not need a stabilization support. On the vulnerable Haitian roads, it is highly likely that a combination of the following three types of measures will be needed.

Soil preparation →	Stabilization support →		Revegetation
	Based on nature	Hybrid	
General principle **without a good soil quality and a good preparation, the rest of the measures are unlikely to thrive. Includes fertilization, making of holes, installation of watering systems.**	Coconut or other organic fiber grids Straw rolls Fascines or Rolls of plant residues Logs / wattles Anchorage: hard wood stakes	Synthetic grids Terraces Geocells Gabions Stone revetment Riprap Anchorage: wires and hooks	**General principle** UGeneral principle: Use plant stakes or plant native species with strong roots to stabilize the slope. Native plants foster biodiversity and need less inputs. **Methods:** • Manual • Hydroseeding

Specific studies in each context must be developed to find the appropriate measures.

NBS2

Slope stabilization with natural materials

NBS objective

Protect infrastructure from landslides and erosion. Solutions that provide erosion protection, during the period it takes for the roots and shoots of native plants to colonize and stabilize soils, based on natural materials. The natural method that is mostly used for anchoring the different structures are the live or dead hardwood stakes.

Coconut, jute, or other organic fiber grids: They control erosion in furrows and gullies on slopes, helping germination and root formation. They are commonly adjusted with live stakes or plant establishment systems to establish long term live barriers. Their high resistance allows them to be used in some cases to replace rockfills. The coconut fiber rolls can be mixed with other products or erosion control systems.

Straw rolls: rolls of straw packed in synthetic nets. Their purpose is to capture and maintain the sediments on the slope, being useful for temporary stabilization.

NBS objective

Fascines: or rolls of plant residues from deforested areas on slopes susceptible to erosion. Used with plant stakes or native species with strong roots will help to stabilize the slope.

Logs / wattles: can be timber logs or logs made of organic fibers such as coconut fiber or straw ("straw wattles"). Effective and economical alternative to silt fence and straw bales for sediment control and storm water runoff. Can be placed and staked along the contour of newly constructed or disturbed slopes. Fertile topsoil, organic matter, and native seeds are trapped behind logs/ wattles and provide a stable medium for germination. Straw wattles also retain moisture from rainfall.

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right-of-way

Increases potential with other NBS

Hydraulic and erosion control products.

Implementation cost:

$1,080/ha/yr[65] and $242/ha/yr for annual maintenance cost (these costs are for illustration based on cost for Terracing)

Co-benefits

Biodiversity, environmental conditions

Risks for sustainability of NBS

Lack of maintenance, especially in the first stage after installation.

O&M considerations

All protection and/or stabilization works must be subject to periodic visits and detailed inspections followed by corrections in the event of anomalies detected, whether these are due to normal ageing or to stresses related to the type of phenomenon that justifies the presence of the protection work.

NBS3

Slope stabilization with hybrid materials

NBS objective

Protect infrastructure from landslides and erosion. Solutions that provide erosion protection, during the period it takes for the roots and shoots of native plants to colonize and stabilize soils, with the incorporation of non-natural materials. The grey method that is mostly used for anchoring the different structures are wires and hooks.

Synthetic anti-erosion geomats or geogrids: Flexible and permeable blankets, made of synthetic fibers held together by flat meshes or three-dimensional wefts. With the same functionality of the organic geogrids, they act as soil protection, facilitating the development and reinforcement of vegetation. A good option for steep slopes is the composite turf reinforcement matting.

Terraces: to slow the speed of the water and promote plant growth. Terraces prevent erosion by shortening a long slope into a series of shorter, more leveled slopes which allow water to move more slowly and soak into the soil. Terraces can be constructed from pressure treated lumber, natural stone, or masonry products such as modular blocks. Building techniques will vary depending on the material used.

NBS objective

Geocells: three-dimensional structures that allow confining granular materials and soils. They are sheets of high-density polyethylene, welded by ultrasound, with the purpose of improving the foundation of a road, confining fertile soil to vegetate a slope or a layer of gravel to cover an erodible channel or even creating a stable mass of soil to work as a retaining wall under gravity. Good performance for erosion control on steep slopes and as a lining for high-flow channels.

Gabions: Stone filled wire mesh racks. Placed at the foot of the slide, they help to stop its evolution towards the road.

Riprap: This technique involves placing rough, angular natural stone on the slope surface. The stones are placed so that they interlock and form a tight, dense barrier that will protect the slope from erosion. This type of Riprap should only be used for slopes less than 66% (34 degrees). Steeper slopes require larger anchored stones or different techniques.

Stone revetment: consider dry stone revetment.

Riprap: Drainage spurs and riprap at the foot of the slide to counter the advance of materials on the roadway.

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right-of-way

Increases potential with other NBS

hydraulic and erosion control products.

Co-benefits

Biodiversity, environmental conditions

Risks for sustainability of NBS

Extreme events

O&M considerations

All protection and/or stabilization works must be subject to periodic visits and detailed inspections followed by corrections in the event of anomalies detected, whether these are due to normal ageing or to stresses related to the type of phenomenon that justifies the presence of the protection work.

NBS4

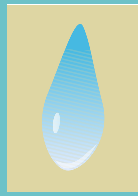
Revegetation with native forest species

NBS objective

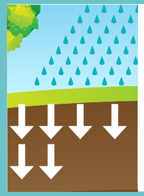
Vegetation helps stabilize slopes in many ways. Native plants adapt to native soils, provided that wildlife habitat can adapt better to climate disruptions and interact with each other in ways hybrid/exotic plant communities cannot. At each site, it is necessary to analyze the specific characteristics of the vegetation (volume and density of foliage, size, height of vegetation cover, presence of different layers of vegetation cover, type, depth, diameter, density, cover and resistance of the root system, among others).

Please refer to Annexes 4, for consulting the list of species suitable for NBS in Haiti.

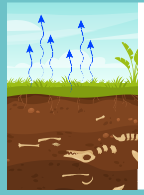
Schematically we can draw the effects of vegetation on the stability of a slope:



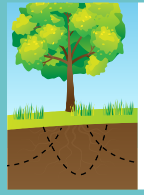
Stops part of the rain



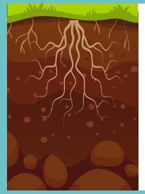
Inceases infiltration



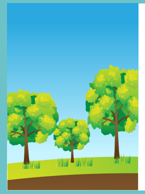
Pumps out the humidity of the soil



Roots reinforce the soil, increasing resistance to cutting

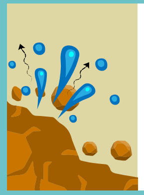


Anchors the surface soil to deeper layers



Increases weight on the slope

Transfers wind force to the soil



Stops the soil particles, decreasing the susceptibility to erosion

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right-of-way

Implementation cost

$2,207/ha [$189-$5,665/ha][61] or $3,450/ha[37] (Tropical Forest) with annual maintenance varying widely by location and type of trees.

Co-benefits

Biodiversity, environmental conditions.

Increases potential with other NBS

Hydraulic and erosion control products

Risks for sustainability of NBS

Lack of attention to soil quality in the revegetation process. Selection of varieties that are attractive to goats and other livestock or for an economic activity (e.g. vetiver). Selection of varieties that are not adapted to the specific site conditions.

O&M considerations

Stabilization and revegetation of exposed slopes must be carried out as work on the roads progresses. All protection and/or stabilization works must be subjected to periodic visits and detailed inspections followed by corrections in the event of anomalies detected, whether these are due to normal ageing or to stresses related to the type of phenomenon that justifies the presence of the protection work. It should be noted that projects are not finished with the germination of the plants, but with at least 70% cover of long-term vegetation. In most cases, it is recommended that seeding be done prior to installation of blankets. Straw or hay mulch may be added after seeding. All check slots and other areas disturbed during installation process should be re-seeded. Where conventional seeding techniques cannot be used due to the difficulty of access or the steep slopes, hydroseeding of herbaceous and woody species can be considered.

Example of Haitian experience

Slope stabilization through revegetation during the rehabilitation works of the route Cayes - Jérémie (see case study in Section 6.3). Also, solutions have been proposed by TYPSA for two pilot sites in the South, in the framework of the project "Development of Design and Guidelines, and Capacity-Building for the Adoption of Ecosystem-Based Solutions to Protect Infrastructure Assets in Haiti" (see case study in Section 8).

NBS5

Restoration with resilient local crop varieties

NBS objective

Productive species should also be considered for the restoration of ecosystems adjacent to roads. While they do not necessarily possess the benefits of native plants in terms of biodiversity, there are many that may be well adapted to the environment and can provide protection against erosion, while also, having the advantage of being economically valued by local communities. These communities can obtain resources from them and therefore will be more likely to maintain them over time.

Please refer to Annex 4 for consulting the list of species suitable for NBS in Haiti.

Solutions catalogue

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right-of-way

Co-benefits

Economic value.

Increases potential with other NBS:

Hydraulic and erosion control products

Risks for sustainability of NBS

Lack of attention to soil quality for the development of vegetation. Selection of varieties that are not adapted to the specific site conditions. Selection of varieties that have no market conditions.

O&M considerations

Stabilization and revegetation of exposed slopes must be carried out as work on the roads progresses. All protection and/or stabilization works must be subject to periodic visits and detailed inspections followed by corrections in the event of anomalies detected, whether these are due to normal ageing or to stresses related to the type of phenomenon that justifies the presence of the protection work. Planting distances will depend on the needs of each species (e.g. citrus fruits will need between 5.5 and 7.5 m distance, while mangoes will need 8 to 10 m), different geographical and agro-ecological areas. On the plain, the trees will be planted closer together depending on the slope. The steeper the slope, the shorter the distance between the trees. These factors, together with the definition of planting periods and care needs, must be endorsed by a specialized technician. Straw or hay mulch may be added after seeding

Example of Haitian experience

Slope stabilization through revegetation during the rehabilitation works of the route Cayes - Jérémie (see case study in Section 6).

NBS6

Mangroves conservation and restoration

NBS objective

Coastal protection. Mangroves reduce wave energy, reduce storm surge and flood depth[73]. The roots of mangroves limit coastal erosion and protect communities and infrastructure from tropical storms.

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right of way

Increases potential with other NBS

seagrass beds and coral reefs' health and preservation. Revetments can be effective when used in front of the mangroves to facilitate growth of new plants.

Red mangrove *(Rhizophora mangle)*
Black mangrove *(Avicennia germinans)*
are the most suitable species for restoration in Haiti. Mangrove forests are found along major estuaries, especially along the north coast, east of Cap Haitien, and on the east coast south of Gonaïves. Populations are also found at Fort Liberté, in the north-east of the country. Please refer to Annex 4 – List of species suitable for NBS in Haiti: dune, beach and coastal

Co-benefits

productive ecosystem that provides numerous goods and services to the marine environment and to human communities: fisheries, timber, firewood, charcoal, and plant products; sequestration of greenhouse gases; sinks for inorganic nitrogen and phosphorus; biodiversity; tourism.

Risks for sustainability of NBS

exposure to plastic pollution and other human waste; conversion to unsustainable aquaculture. Reductions in mangrove cover are observed globally, with evidence of severe trends in some countries of the region. Mangrove loss in Barbados has been drastic, including local extinction of two species[74]. Key factors for successful sustainability and maintenance are community organization including the establishment of formal community decision-making structures; development of business plans for the sustainable use of resources from mangrove ecosystems, buy-in of local governments.

Implementation cost

\$9,000/ha (median) [Range: \$1,413-42,801/ha[35]] with maintenance cost that can range from \$7-85/ha/yr[42] (\$5,000[43]-11,000[44]/ha/yr in Florida, 10% of initial investment (\$85/ha) in Indonesia[26]. Empirical evidences suggest a benefit cost ratio of 41[26].

O&M considerations

during the first 1-2 years, the plants are vulnerable to various man-made and natural stressors. Monitoring of growth, survival, and maintenance, by removing algae or other pests, are two major activities of rehabilitation. Then, regular patrolling should be undertaken by the community or an assigned caretaker. If there is intense wave action that may affect the new trees, consider installing barriers made of rocks or bamboo. These barriers also help to trap sediment and increase the substrate level, further enhancing plant growth. The O&M will include typically: visual inspection, assessment of water quality, assessment of cover, extent and density and impact from high energy events.

Example of Haitian experience

transplantation of 85,000 mangrove seedlings in the communes of St Jean du Sud and Abacou in 2017 thanks to a 2017-2019 Global Environment Facility-funded project implemented by the UNEP, Ministry of Environment, Agriculture, and other partners.

NBS7

Coral reef conservation and restoration

NBS objective

Offer protection from wave damage to other habitats, coastal communities, and infrastructure. Coral reefs can supply and trap sediments[75] and attenuate waves. Reefs can reduce the power of storm waves reaching the shore and thereby reduce coastal flooding and erosion. Coral reef functions similarly to a submerged breakwater[76].

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right of way

Increases potential with other NBS

Living breakwaters enable establishment of corals such that they can grow as sea level rises. Also, the combined coastal protection with seagrass meadows and mangroves can also be promoted: the use of the tree habitats together has been shown to provide more protection than a single habitat or combination of two habitats.

Opportunity for hybrid solution

Increasing the area of substrate by installing artificial and natural substrates: "artificial reef creation". It can also be considered in parallel with shoreline hard interventions to reduce wave energy.

Co-benefits

Provision of essential ecosystem services and habitat for valuable fish species and other marine organisms. Ecotourism.

Implementation cost

\$165,000/ha (median)[35,36] (also \$542,500/ha[37]) with potential benefit cost ratio between 13.6 – 15. 5[77]

Risks for sustainability of NBS

Pollution, invasive species, overfishing, eutrophication, damage from shipping and tourism activities, climate change and natural hazards (increasing sea temperatures, acidification, sea level rise, more intense storms and hurricanes, variability of rainfall). Coral reefs are degraded naturally by storm events as well as coral bleaching events.

O&M considerations

It is essential to ensure that the biodiversity of coral species is maintained, to ensure that new corals increase their chances of resisting ocean degradation. Perform regular visits and inspections to address any possible adverse impact. Allow qualitative and quantitative documentation of colony survival and growth.

Example of Haitian experience[78]

Coastal Partners: Applying ecosystem-based disaster risk reduction (Eco-DRR) through a ridge-to-reef approach in Port Salut, Haiti.

NBS8
Living Breakwaters

NBS objective

Reduce wave energy by creating a barrier, most often underwater, between open water and the shoreline. While traditional breakwaters may be made from stone, concrete or other building materials, a living breakwater is intentionally designed to incorporate natural habitat components while still providing protection to the coastline . An example of natural material could be harvested oyster shells (clutch).

Living breakwaters incorporate natural habitat by providing opportunities for settlement and colonization by oysters, corals or by creating shelter and habitat for various marine and aquatic species

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right of way

Increases potential with other NBS

Such as coral reef restoration.

Opportunity for hybrid solution

Utilization of porous concrete and reef substrate designs that create structural complexity and increases the likelihood of successful colonization by desired species. Materials can involve reef balls, sinking retired boats, pieces of infrastructure, among others.

Co-benefits

Biodiversity, provision of essential ecosystem services and habitat for valuable fish species and other marine organisms, fishery production and tourism.

Risks for sustainability of NBS

Pollution, invasive species, eutrophication, damage from shipping and tourism activities, climate change (increasing sea temperatures, acidification, sea level rise, more intense storms and hurricanes, variability of rainfall). Coral reefs are degraded naturally by storm events as well as coral bleaching events.

O&M considerations

In sub-tropical waters, it may take as many as five years to establish a healthy, stable benthic community. Once they are established, they will be mostly self-sustaining. Occasional maintenance on the physical structure may be necessary. Given that living breakwaters can create a recreational attraction, care needs to be taken to make sure that oyster beds are not being harvested illegally or are being disturbed. With regards to impacts from navigation, it is recommended to perform regular monitoring to ensure there have been no impacts from boats.

NBS9

Oysterbreak systems and shoreline protection units

NBS objective

Oysterbreak systems are designed to reduce wave energy, thus reducing damage from wave action, and reduce erosion. This type of technology is designed to use the oyster's inherent nature of clustering to enhance a strategic coastal protection structure for coastal and estuary shorelines. They may be applied to any shoreline project that calls for any combination of wave attenuation, and shoreline erosion mitigation. They are designed to serve dual functions by creating a reef structure for habitat and robust structure for shoreline protection[80].

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right of way

Increases potential with other NBS

Planting of seagrasses and submerged aquatic vegetation. It can be combined with other living breakwaters

Co-benefits

stimulate oyster growth and thereby increase the biodiversity in the immediate area.

Implementation cost

$66,800/ha[6] with a benefit cost ratio of 7 .34[40]

Risks for sustainability of NBS

Risk will depend highly on design considerations such as area of frontages to be protected, current, tide and surge water levels and obstructions on seabed. With regards to materials, it is important to check characteristics such as strength and permeability.

O&M considerations

Consider monitoring the longshore transport rate that will be modified by the breakwater. Consider performing surveys of sections above the water level (visual inspection, comparative photography), profile surveys, as well as underwater visual inspections, to detect irregularities.

NBS10

Restoration of beaches, sand banks and dunes

NBS objective

Protection from storm surge and waves and sea level rise. Beaches act as a natural buffer as they efficiently dissipate wave energy. This reduces damages to hard landforms at the back of the beach, and assets in the hinterland due to overtopping, flooding, erosion, or direct wave action. Encouraging dune vegetation practices and promoting dunes as physical buffers to waves and providing barriers to wave inundation and sea level rise. Planting vegetation will not only help to prevent erosion, but also will accelerate natural recovery following storm damage.

- **In natural beach protection**, backshore stabilization measures such as picket fencing, vegetation planting or footpath management can be used to protect the existing beach alongside other measures.
- **In the case of beach nourishment/recharge**, beach material is added to an existing beach or new beaches are created artificially.
- **Beach recycling** consists of redistributing material from where it has naturally accumulated and to the updrift end of a beach frontage.
- **Beach vegetation planting** has the objective of promoting that plant roots hold sediment in place and help stabilize the area. They also reduce runoff erosion and reinforce dunes.

Please refer to Annex 4 for consulting the list of species suitable for restoration of dunes and beaches in Haiti.

Type of NBS

Ecosystem-based / hybrid: combined with groynes, offshore breakwater, artificial coral reef creation.

Intervention scale

Landscape / road's right of way

Increases potential with other NBS

Combination with beach nourishment / recharge, beach re-profiling, beach recycling. Combination with hard interventions such as offshore breakwaters that may be used to reduce sediment loss. Revetments can be quite effective if positioned behind the beach, so the toe is protected.

Implementation cost

\$3-21[36]/m^3 with benefit-cost ratio between 0.28 – 1.68[40]. Dune restoration/Revegetation from \$7,636-13,888/ha[44] with annual maintenance for dune restoration between \$333-2,526/ha/yr[81]

Co-benefits

Biodiversity. Beaches provide value for the residents and help to support the local tourism economy.

Risks for sustainability of NBS

To achieve a successful restoration, it is essential to eliminate the influx of public to the area where the action is carried out. To do this, it is necessary to carry out a series of works to protect the dune line, including fencing, adapting accesses, building walkways and information signs.

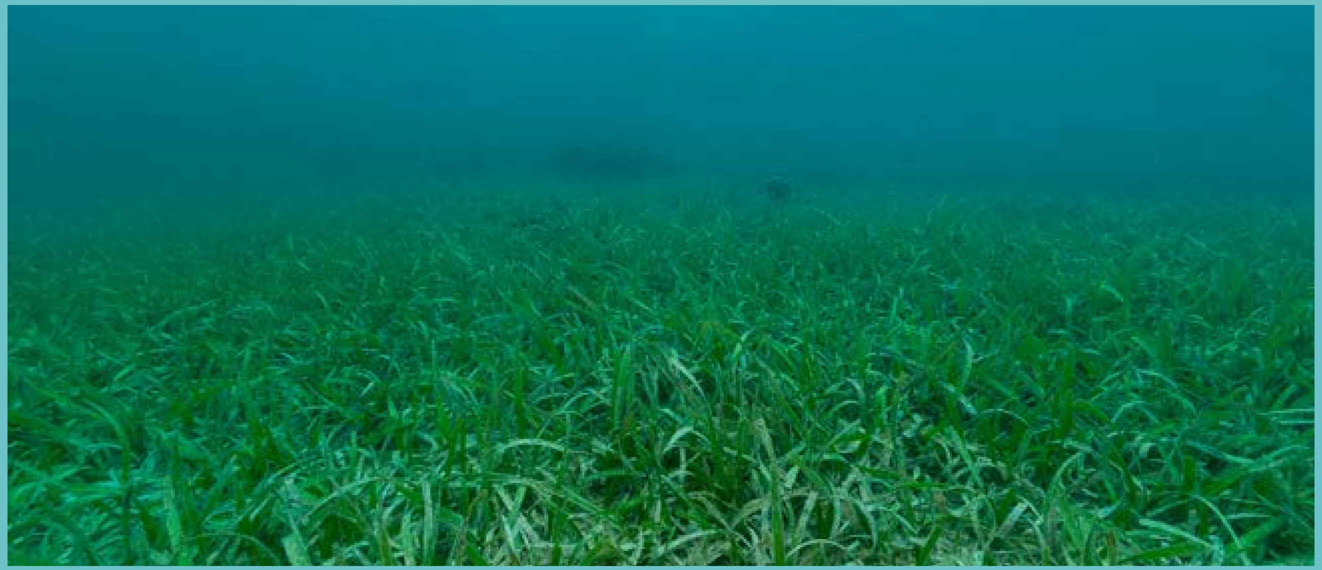
O&M considerations

When selecting beach nourishment, the design should consider offshore and land-based sources available locally. In general, maintenance will be further required if combined with hard structure. With regards to dune vegetation, it is key to select the appropriate locations and time of planting, provide protection mechanisms for letting the root systems to establish, and select the suitable species depending on site-specific conditions.

The maintenance work consists of controlling and promoting the appropriate evolution and development of the plantings and checking that they acquire the desirable coverage and size over time, maintaining adequate conditions of conservation and dynamics.

It will also be necessary to carry out a continuous monitoring of the state of the sand and of the general state of conservation of the facilities such as walkways, enclosure, signs, etc., repairing the damages as they may arise.

O&M will include visual inspections, beach profile surveys, fixed aspect photos and aerial photographs.



NBS11

Seagrass restoration and conservation

NBS objective

Attenuate waves and stabilize sediments (most reliably in shallow waters and low wave energy environments) Reduce current velocity. Reducing the height of waves reaching the shore can decrease floods.

Seagrasses are flowering plants that grow in marine, fully saline environments. Seagrass beds start close to the shore and extend below the water surface to maximum depths of 30 m, depending on the clarity of the water.

The most common shallow habitats (up to a depth of 15 m) consist of sandy seabeds with or without sea turtle grass (Thalassia testudinum) or expanses of sea turtle grass mixed with manatee grass (Syringodium filiforme) and various types of seaweed. This vegetation is an important source of primary productivity, releasing oxygen and nutrients to marine species and serving to stabilize soft substrates. Seagrass meadows provide food for many species of herbivores, including fish and the West Indian manatee (Trichechus manatus) (Haiti's CBD Fifth

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right of way

Increases potential with other NBS

Functional interactions with mangroves and coral ecosystems. The use of the three habitats together have been shown to provide more protection than a single habitat or combinations of two habitats.

Co-benefits

Biodiversity, refuge for calcifying organisms, key habitat (spawning, nursery and feeding grounds), seagrasses play an important role as carbon sinks: as biomass increases with ocean acidification, carbon sequestration is increased. Fishing.

Risks for sustainability of NBS

Pollution brought by rains, sedimentary erosion created by cyclonic swells affects certain species of seagrasses, exposition due to low barometric tides. Impact from anthropogenic pressures: the feet of marine phanerogams can be mechanically damaged by the use of fishing gear such as towed gear, traps and tools used when fishing on foot; impact of anchorages and boat propellers on seagrass beds; removal of meadows from bathing areas for the "well-being" of tourists; impact from the extraction of coral or sand construction materials; development of infrastructure such as defense walls, indirect pollution from domestic, agriculture and industrial activities.

O&M considerations

Once transplantation is complete, sites should be monitored to determine survival rates, sprout density, and graft coverage. Sufficient information and signposting must be maintained, as well as surveillance systems to prevent entry into protected areas and areas under restoration, and to avoid fishing gear that could cause damage. It is recommended to organize and maintain a good organization of the mooring of the boats,

Solutions catalogue

NBS12

Natural wetland management

NBS objective

Act as "buffers" and thus perform important functions with regards to the protection of communities, ecosystems, and assets. These functions are sediment and erosion control, storm water runoff reduction through infiltration. Protecting wetlands adjacent to and upstream of the road might be a vital component of an ecosystem services-based strategy for flood regulation. Conversely, if the wetlands were degraded or paved over, this could severely compromise the flood regulation service.

Wetland management addresses morass, swamps, and wetlands. Two major aspects of managing wetlands for protection include buffering wetlands from direct human pressures and maintaining natural processes in surrounding lands.

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right of way

Increases potential with other NBS

Gabions and other erosion control systems.

Implementation cost

For coastal wetland can range from $85,000-230,000/ha ($67,000/ha[35]) with annual maintenance around $25/m/yr[49] and a benefit-cost ratio between 6 – 8.72[40]

Co-benefits

Recreation, water quality, nutrient transformation, and removal; reduction of human impacts by limiting easy access; biodiversity, and a barrier to invasion of exotic species. Reduction of water temperature, pollution reduction, enhanced access to water for local communities. Restoration or construction of vegetation that improves water quality can be a cost-effective way of mitigating road impacts and ensuring road project compliance with regulatory requirements[83].

Risks for sustainability of NBS

Pollution. Impacts from direct human activity on the ecosystem.

O&M considerations

Core activities usually consist of removal of alien vegetation, re-vegetation of cleared areas with native wetland vegetation, and conservation legal framework.

NBS13

Coastal slope stabilization with hybrid materials

NBS objective

Protect infrastructure from coastal erosion by waves, currents, and wind.

Revetments: placed on sloping structures or against a vertical wall to protect against erosion on the coast by environmental loads such as waves, currents and wind and geotechnical loads and to reduce wave overtopping and consequential damage/flooding of land behind. They are typically permeable surfaces such as rock, steel wire mesh, open stone/sand asphalt. They are flexible and allow for some degree of movement or deformation due to settlement. Drainage from overtopping should be considered case by case.

Groynes: narrow structures of varying height and length (generally long) typically constructed perpendicular to the shoreline. Used to control and manage the natural movement of beach material. A groyne system can detain or slow down the longshore drift of material by building up the material in bays. Groynes also deflect tidal currents away from the shoreline. Adjustable timber groynes can be considered. They consist of removable planks between piles. Gabions are not durable, and therefore considered a short-term solution.

NBS objective

Gabions: mesh baskets that are compactly filled with crushed rocks, cobbles or stones. They are commonly used to prevent erosion and to stabilize banks, cliffs and dune slopes. Gabions are suited to low energy beaches and are usually best placed above the tidal zone as they are not durable enough to withstand regular, direct wave action .

Sandbag structures: temporarily stops or slows the effects of coastal erosion. Generally placed in front of and parallel to development to prevent the destructive forces of the sea reaching coastal structures. They should be used only as short term or temporary interventions.

Sediment-filled geotextile material tubes: placed parallel to shore to dissipate high-energy waves. The tubes create new avenues for dredge material disposal and produce a hard surface on which reefs can be constructed.

Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right of way

Increases potential with other NBS

Beach protection, beach vegetation planting

Co-benefits

Biodiversity, fishery habitat

Risks for sustainability of NBS

Revetments can disrupt natural shoreline processes by cutting-off inshore supply of materials and can also destroy shoreline habitats and reduce the width of inter-tidal beaches. Climate events can affect short-term structures such as gabions and sandbags

O&M considerations

Although a design life can be predicted, structures can be damaged earlier or later. Extreme events such as hurricanes can cause damage as well as ongoing developments and activities in the area. A visual inspection should be carried out on a yearly basis and after any extreme events or large storms

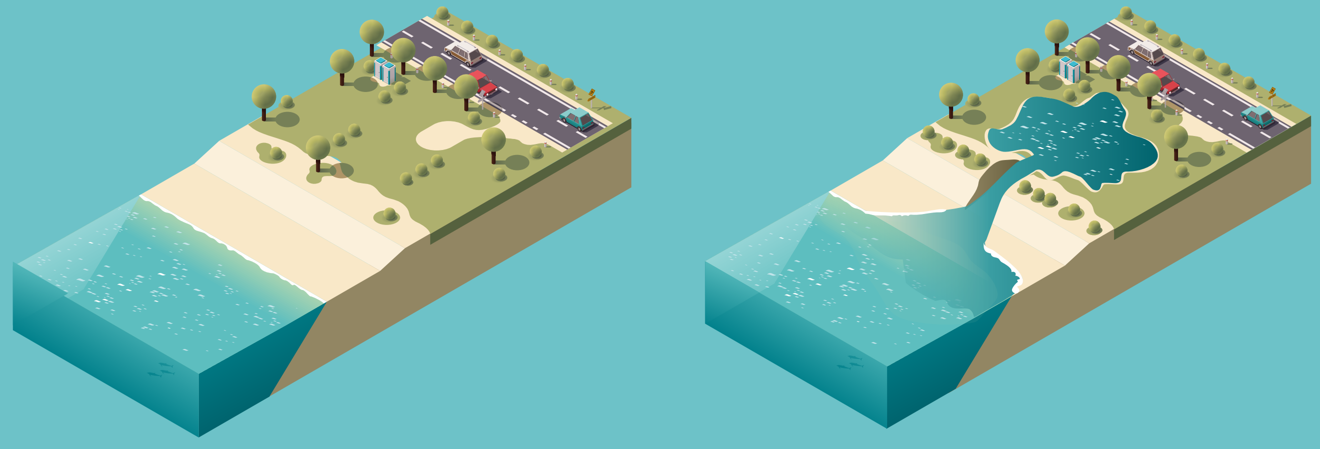
NBS14

Managed coastal realignment

NBS objective

Flood risk management, face sea level rise, storm surge. This management strategy aims to "create space for coastal ecosystems to persist in the face of rising sea levels by removing coastal defense structures to allow the rising waters to intrude. The benefits of this approach are that it allows coastal zones to retain their natural ecosystems and associated ecosystem services as well as providing certainty to local human settlements. It also allows redirection of resources from costly hard defenses". Once salt marshes develop, large scale erosion is unlikely to occur, since salt marsh vegetation will enhance sedimentation and creation of the area that will reduce waves and improve safety.

Diagram: The pocess of managed realignment. **Source:** CoastAdapt. Adapted from ComCoast 2006.



Type of NBS

Ecosystem-based / hybrid

Intervention scale

Landscape / road's right of way

Increases potential with other NBS

Natural infrastructure can be used to protect built infrastructure in order to help the built infrastructure have a longer lifetime and to provide more storm protection and benefits. Wider beach profiles gained through retreating will absorb a greater proportion of the incident way energy. Watershed management and habitat rehabilitation can be adopted in conjunction with an embankment re-design.

Co-benefits

Biodiversity, fishery habitat, mitigation of loss of intertidal habitat, carbon sequestration and storage, recreational use.

Risks for sustainability of NBS

Option that is often of high political and social controversy. The schemes frequently suffer from a lack of public acceptance. Managed realignment is also likely to be highly disruptive and expensive if relocation of coastal infrastructure is required. Care should be taken to ensure that if infrastructure is abandoned rather than relocated, that nearby areas do not become isolated, thus leading to increased poverty

O&M considerations

Periodic inspections should attend the evolution of accretion / erosion on site and off site, physico-chemical parameters of sediments, vegetation, fauna, water quality, among others.

Regional experience

To date, the managed realignment approach has only been applied in North-West Europe and North America, where saltmarshes are the dominant intertidal habitat. There appears to be no reason creation of other wetland habitats, such as mangroves, should not be possible through realignment, although such an approach has not been undertaken to date[85].

NBS15

Rockfill and vegetation for protecting bridges' piles and abutments

NBS objective

Protection against local scour of piles and abutments due to water and sediment erosion.

It should be noted that the erosion processes suffered by the bridge piles and abutments are part of an intrinsic system that involves both the river course and the vegetation in and around it. There are various solutions to reduce the speed of deterioration of the structures. The use of rockfill and vegetation is one the most economically and technically viable.

Consists of placing rocks around the piles and abutments, and the planting of aquatic plants. As an emergency measure, installation of sandbags can be considered around the piles or abutments for further protection.

Revetments can also be placed in the slopes next to the abutments, to protect them from landslides.

Type of NBS

Ecosystem-based / hybrid

Co-benefits

Biodiversity

Intervention scale

Landscape / road's right of way

Risks for sustainability of NBS

Extreme events can damage the implemented solution.

Increases potential with other NBS

For a real protection of bridges, all applicable NBS such as riverbank slope protection and ecosystem restoration need to be put in place upstream. It is necessary to think about protection on a larger scale, to ensure that upstream there is a porous soil that infiltrates water and carries it to the aquifers and not to the surface courses.

O&M considerations

It is important to carry out technical inspections on the bridge structures that pay special attention to signs of incipient pathologies that indicate damage or defects. The state of the enrockment and vegetation should be monitored to replace damaged parts or correct any flaws it may have suffered.

NBS16

Riverbank works for bridge protection

NBS objective

Protection against local scour of piles and abutments due to water and sediment erosion.

Riverbank works can be effective for the area to protect, but they can also change the natural flow regime and have undesirable effects on downstream areas. It is essential to know the behavior of the flow, the erosion processes and the forces that can act on the structures. Inadequate knowledge of these can lead to the failure of the proposed protection system.

Although these measures are usually partially,destroyed or washed away, it is more economical and easier to repair them than to repair the bridge.

- **Channeling dikes:** structures that are built from the abutments of a bridge and extend upstream. They must be located parallel to the abutments and the distance between them must be equal to the distance between the abutment walls. They are built with a soil or sand embankment that should preferably be protected with rock and at least with grass or vegetation. Filters may be required or the granulometry may need to be varied to avoid the loss of fine material.
- **Spurs:** Their purpose is to gently deflect the current and hold objects that may drag the course. They require monitoring and possible partial cleaning or reconstruction. The spurs or breakwaters can be built with rocks, gabions, wood, or bamboo.

Type of NBS

Ecosystem-based / hybrid

Co-benefits

Biodiversity, in the case of revegetation.

Intervention scale

Landscape / road's right of way

Risks for sustainability of NBS

Extreme events can damage the implemented solution

Increases potential with other NBS

For a real protection of bridges, all applicable NBS such as riverbank slope protection and ecosystem restoration need to be put in place upstream. It is necessary to think about protection on a larger scale, to ensure that upstream there is a porous soil that infiltrates water and carries it to the aquifers and not to the surface courses.

O&M considerations

It is important to carry out technical inspections on the bridge structures that pay special attention to signs of incipient pathologies that indicate damage or defects. The state of the riverbank structures should be monitored to replace damaged parts, correct any flaws it may have suffered, or detect potential negative effects on downstream areas, due to changes in flow regime.

ANNEXES

ANNEX 1

Useful resources

The existing literature for the application of NBS to strengthen the resilience of transportation infrastructure is scarce, and related to the use of NBS for the protection of transport infrastructure in coastal areas.

Table 30 provides a list of some of the recent guidelines and other documents for the use of NBS, including some of the existing literature on the application of these approaches for the protection of transport infrastructure.

Table 30: List of existing guidelines and reports for application of NBS in the transport sector for the general use of NBS

Resource	Year of publication	Description - Objectives	Application
NBS & TRANSPORT INFRASTRUCTURE			
Guidelines			
Nature-based solutions for Coastal Highway Resilience: An Implementation Guide (US Department of Transportation. Federal Highway Administration, August 2019)	2019	The guide aims to provide transportation professionals transportation professionals with relevant, timely, and science-based information regarding the complete project implementation process for nature-based solutions that will enable them to consider nature-based solutions for protecting coastal highways[86] as part of a broader portfolio, or system, of resilience measures, under conditions ranging from typical to extreme weather events and sea level rise. The guide addresses various examples of nature-based solutions applicable for coastal areas (i.e. tidal marshes, mangroves, maritime forests, reefs, beaches, and dunes), to mitigate storm surge flooding, wave-related damage, erosion, shoreline retreat, and the potential impacts of sea level rise, which pose threats to coastal infrastructure.	Overall process for the implementation of NBS for the protection of transportation infrastructure in coastal areas
Green Infrastructure Design for Transport Projects. A Road Map to Protecting Asia's Wildlife Biodiversity (ADB, December, 2019)	2019	The report aims to provide an overview of considerations for the proactive integration of ecological protection measures. These measures include management, planning, and design activities in road and railway projects to balance construction with the conservation of Asia's remaining biodiversity. The considerations are applicable to both new and existing transport projects, and even standalone "retrofit" applications to address existing impacts on biodiversity.	Enhancing biodiversity through green infrastructure designs for Transport Infrastructure
Green Rural Infrastructure Guide (Ministry of Rural Development, Cambodia, March 2019)	2019	The MRD Green Rural Infrastructure Guide (an adaptation guide for the rural infrastructure sector) was developed to support effective, on-the-ground implementation of Cambodia's Climate Change Adaptation Plan (CCAP 2014-2018). The Guide provides guiding principles and insights for policy makers, planners and practitioners on how to apply climate resilience to their planning and project implementation. The guide is divided into three parts and comprises of 30 adaption technologies/measures and 12 case studies. It presents a matrix table of adaptation technologies/measures for rural infrastructure development, describes some appropriate adaptation technologies/measures for sustainable development of road, canal, reservoir, embankments slopes and stream banks, and sustainable rural water supply and management systems, and capacity building and showcases case studies of where the respective adaptation technologies have been applied in Cambodia and other countries.	Adaptation technologies/measures for rural infrastructure development (incl. road, canal, reservoir, embankments slope etc.)

Resource	Year of publication	Description - Objectives	Application
Community-based Bui-Engineering for Eco-safe Roadsides in Nepal (Devkota et al., 2014)		The manual provides guidance to communities and local government agencies on the occurrence, assessment and mitigation of road construction-induced landslides and erosion. It is an important contribution to explaining low cost bio-engineering practices for communities, roads committees and citizen groups which was used to support Nepal's road extension work to improve the safety and quality of rural earthen roads in the country.	Using low-cost bio-engineering practices for rural earthen roads
Reports, Articles & Papers			
White Paper: Nature - Based Solutions for Coastal Highway Resilience (US Department of Transportation. Federal Highway Administration, February 2018)	2018	While nature- based solutions have been used extensively across a diverse array of coastal settings, they are not commonly deployed within the transportation sector. In some cases, understanding of the engineering tools and methods for designing nature- based solutions to achieve a specific outcome is lacking. This white paper addresses these issues by providing examples of nature- based solutions and highlighting the best available science that describes their performance as solutions for coastal highways' resilience. This white paper serves as input to an upcoming round of regional peer exchanges on nature-based solutions, and constitutes an incremental step toward developing an implementation guide for using nature- based solutions to improve the resilience of coastal highways to extreme events and sea level rise.	Examples of NBS applied for coastal highway's resilience.
GENERAL RESOURCES ON NBS			
Guidelines			
Engineering with Nature: an Atlas, Volume 2 (Bridges et al. 2018)	2021	Engineering With Nature: An Atlas, Volume 2 showcases EWN principles and practices "in action" through 62 projects from around the world. These exemplary projects demonstrate what it means to partner with nature to deliver engineering solutions with triple-win benefits. The collection of projects included were developed and constructed by many governments, private sector, non-governmental organizations, and other organizations. By photographs and narrative descriptions, the EWN Atlas was developed to inspire interested readers and practitioners with the potential to engineer with nature.	Diverse portfolio of case studies where the EWN approach has been applied
Practical Guide to Implementing Green-Gray Infrastructure (Green-Gray Community of Practice, 2020).	2020	The guide outlines a set of tools, experiences (case studies), and techniques that may be applied to leverage near-term investments to fundamentally shift the practice of civil engineering and construction towards designing and building with nature, using a hybrid green-gray infrastructure approach, that provides benefits of biodiversity and community climate adaptation.	Overall process to be followed in the implementation of Hybrid interventions
Integrating Green and Grey. Creating Next Generation Infrastructure (Browder et al. 2019)	2019	This joint report by the World Bank and the World Resources Institute seeks to guide developing country service providers and their partners on how to integrate natural systems into their infrastructure programs in ways that better protect their populations and achieve service delivery goals. It provides insights, solutions, and examples that will guide the World Bank's thinking on how "putting nature to work" can help meet its core mandates related to reducing extreme poverty, promoting shared prosperity, and meeting the challenges of climate adaptation and resiliency. The report is intended for a broad audience of stakeholders that are key to advancing the integration of green and gray infrastructure solutions on the ground.	Approach to integrating green and grey infrastructure solutions

Resource	Year of publication	Description - Objectives	Application
Thinknature Nature-based Solutions Handbook (EU, 2019)	2019	Developed in the framework of the ThinkNature project, this Handbook aims to gather and promote state-of-the-art knowledge regarding Nature-Based Solutions (NBS), comprising a comprehensive guide to all relevant actors. To this end, each aspect of NBS is investigated, from project development to financing and policy making, and is presented in a concise and comprehensive way. This Handbook contributes to expanding the knowledge base about the effectiveness of NBS, supporting the implementation of NBS through enhancing their replicability and upscaling, utilising the knowledge and experience of stakeholders, and proposing a comprehensive methodological approach for innovation.	Overall process for the implementation of NBS
Engineering with Nature: an Atlas (Bridges et al. 2018)	2018	This atlas aims to highlight and share examples of the Engineering with Nature® practice—and efforts to simultaneously achieve engineering, environmental, and social benefits—from around the world. These projects are presented and considered in this atlas using an Engineering with Nature® lens as a means of revealing the use of nature-based approaches and the range of benefits that can be achieved. This atlas is a collection of 56 projects that illustrate a diverse portfolio of contexts, motivations, and successful outcomes. The projects were developed collaboratively to integrate natural processes into engineering strategies that support navigation, flood risk management, ecosystem restoration, or other purposes.	Diverse portfolio of case studies where the EWN approach has been applied
Implementing nature-based flood protection: Principles and implementation guidance (World Bank 2017)	2017	The document aims to present five principles (describing key considerations to consider when planning NBS), and implementation guidance (describing the timeline and activities needed for the planning, assessment, design, implementation, monitoring, management, and evaluation of NBS) for flood risk management, as an alternative to or complementary to conventional engineering measures. It is intended for professionals in risk management and climate adaptation, NGOs, donors, and international organizations.	Overall process for implementation NBS for flood risk management
Nature-based Solutions to address global societal challenges (International Union for Conservation of Nature.2)	2016	This report aims to provide conservation and development practitioners, policy makers and researchers, as well as civil society organizations, with a useful basis for understanding what Nature-based Solutions involve and what they offer in terms of benefits for human and nature, by contributing to resolving societal challenges. The report proposes a definitional framework for NbS, including a set of general principles for any NbS intervention. The report also defines the scope of NbS as an umbrella concept embracing a number of different ecosystem-based approaches. The report considers several potential parameters that can be used to build an operational framework, on the basis of which the efficiency, effectiveness, and sustainability of NbS interventions can be systematically assessed. The report outlines how the Ecosystem Approach offers a solid foundation for the NbS concept. Finally, the report presents ten case studies of NbS applications from around the world, which represent the range of ecosystem services and societal challenges that can be addressed by NbS interventions, looks at some of the lessons learned from these cases and discusses the importance of building an evidence base for NbS to support future replication and upscaling.	NBS framework and case studies

Annexes

Resource	Year of publication	Description - Objectives	Application
Reports, Articles & Papers			
Economics of Nature-based Solutions: Current Status and Future Priorities (UNEP, 2020)	2020	The document is devoted to the economic analysis of NBS based on the benefits that they provide, looking to three categories of objectives: mitigation of climate change, adaptation to the effects of climate change and provision of other ecosystem services, as a result of maintaining or restoring natural systems. It provides a review of a number of applications of such analyses as well as examples to illustrate common topics of application and important conceptual points.	
Understanding the value and limits of nature-based solutions to climate change and other global challenges (Seddon et al., 2020)	2020	This article highlights the rise of NbS in climate policy—focusing on their potential for climate change adaptation as well as mitigation—and discusses barriers to their evidence-based implementation. It outlines the major financial and governance challenges to implementing NbS at scale, highlighting avenues for further research, and stresses the urgent need for natural and social scientists to engage with policy makers to ensure that NbS can achieve their potential to tackle both the climate and biodiversity crisis while also contributing to sustainable development. This article is part of the theme issue 'Climate change and ecosystems: threats, opportunities and solutions'.	
Nature-based Solutions for Disaster Risk Management (World Bank, 2019)	2019	This booklet aims to support the understanding of how NBS can enhance DRM, and how to begin integrating these approaches into projects. It is intended for staff at governments, development finance institutions (DFIs), and other development institutions. The booklet illustrates NBS through 14 real-world examples, covering the World Bank's Nature-based Solutions Program and World Bank projects already investing in NBS components, examples of NBS for three types of hazards (coastal flooding and erosion, urban stormwater flooding, and river flooding), and guidance to support implementation of NBS in DRM, including a high-level review of emerging policies and financing approaches that encourage the use of NBS	
Comparing the cost effectiveness of nature-based and coastal adaptation: A case study from the Gulf Coast of the United States (Reguero et al. April 2018)40	2018	This articles applies a quantitative risk assessment framework to assess coastal flood risk (from climate change and economic exposure growth) across the United States Gulf of Mexico coast to compare the cost effectiveness of different adaptation measures, including nature-based (e.g. oyster reef restoration), structural or grey (e.g., seawalls) and policy measures (e.g. home elevation). The study demonstrates that the cost effectiveness of nature-based, grey and policy measures can be compared quantitatively with one another, and that the cost effectiveness of adaptation becomes more attractive as climate change and coastal development intensifies in the future. It also shows that investments in nature-based adaptation could meet multiple objectives for environmental restoration, adaptation, and flood risk reduction.	

ANNEX 2
Glossary

Biodiversity: Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (article 2, Convention on Biological Diversity).

Capacity building: In the context of climate change, the process of developing the technical skills and institutional capability in developing countries and economies in transition to enable them to effectively address the causes and results of climate change.

Climate change resilience: Climate resilience is the capacity of a system to "anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions[88].

Co-benefits: The positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare. Co-benefits are often subject to uncertainty and depend on local circumstances and implementation practices, among other factors. Co-benefits are also referred to as ancillary benefits.

Ecosystem approach: Strategy for the integrated management of land, water and living resources that provides sustainable delivery of ecosystem services in an equitable way (CBD Secretariat 2000).

Ecosystem-based adaptation (EbA): The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. Ecosystem-based adaptation uses the range of opportunities for the sustainable management, conservation, and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change. It aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change. Ecosystem-based adaptation is most appropriately integrated into broader adaptation and development strategies[89].

Ecosystem services: The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth. Some of the ecosystem services can enhance people's adaptive capacity towards climate change (MEA 2005).

Extreme weather event: An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).

Exposure: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected

Hard intervention: Typically used historically as coastal defenses, hard interventions refer to engineered designed and built structures.

Hybrid intervention: Combination of nature-based, hard, and non-structural interventions that may be used to protect infrastructure by providing protection, while also providing other ecosystem service benefits.

Indigenous knowledge or local knowledge: Knowledge that is unique to a given culture or society. It is the basis for local-level decision making in agriculture, healthcare, food preparation, education, natural resource management, and a host of other activities in rural communities. It contrasts with the international knowledge system generated by universities, research institutions and private firms.

Nature-based intervention: Intervention projects that are inspired and supported by nature. They provide habitat for plants and animals through careful consideration of the site and strategic placement of components along the entire ridge to reef profile. They are cost-effective and simultaneously provide environmental, social, and economic benefits and help build resilience.

Ocean acidification: Ocean acidification refers to a reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere but can also be caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity[90].

Participatory approaches: A range of approaches involving communities in project planning and implementation, from passive participation (where people are informed or provide information) to consultation (where the information provided is used for decision making by others), to collaborative or active participation (where decisions are made with or by local people).

Risk: The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard. In this report, the term risk is used primarily to refer to the risks of climate-change impacts.

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

ANNEX 3

Methodology for producing vulnerability maps for Haiti and results

This annex describes the process followed for the development of vulnerability maps in Haiti.

Information source

To obtain the vulnerability maps, it is necessary to obtain and process geospatial information from various sources and at different scales.

The information used was provided by the National Geo-spatial Information Center (Centre National de l'Information Géo-Spatiale, CNIGS), and included vector information (hydrography, roads, and administrative limits) and raster information (Digital Elevation Model acquired through high resolution LiDAR). This information was compiled and processed in a Geographic Information System (ArcGIS, ESRI).

In relation to the vector-type layers, the following information was obtained:

- Principal and Secondary rivers and water bodies
- Classification of the main roads (communal, departmental and national)
- 200 m buffer as area of influence of roads
- 150 m buffer as area of influence of hydrology
- Crossings and bridges

Regarding the raster data, 3,515 LiDAR images were processed, with which the following information was obtained:

- Digital Elevation Model at country and departmental level
- Analysis of the degree of slope
- Contour lines at 50 m
- Coastline and areas susceptible to flooding

Figure: Vector data processing

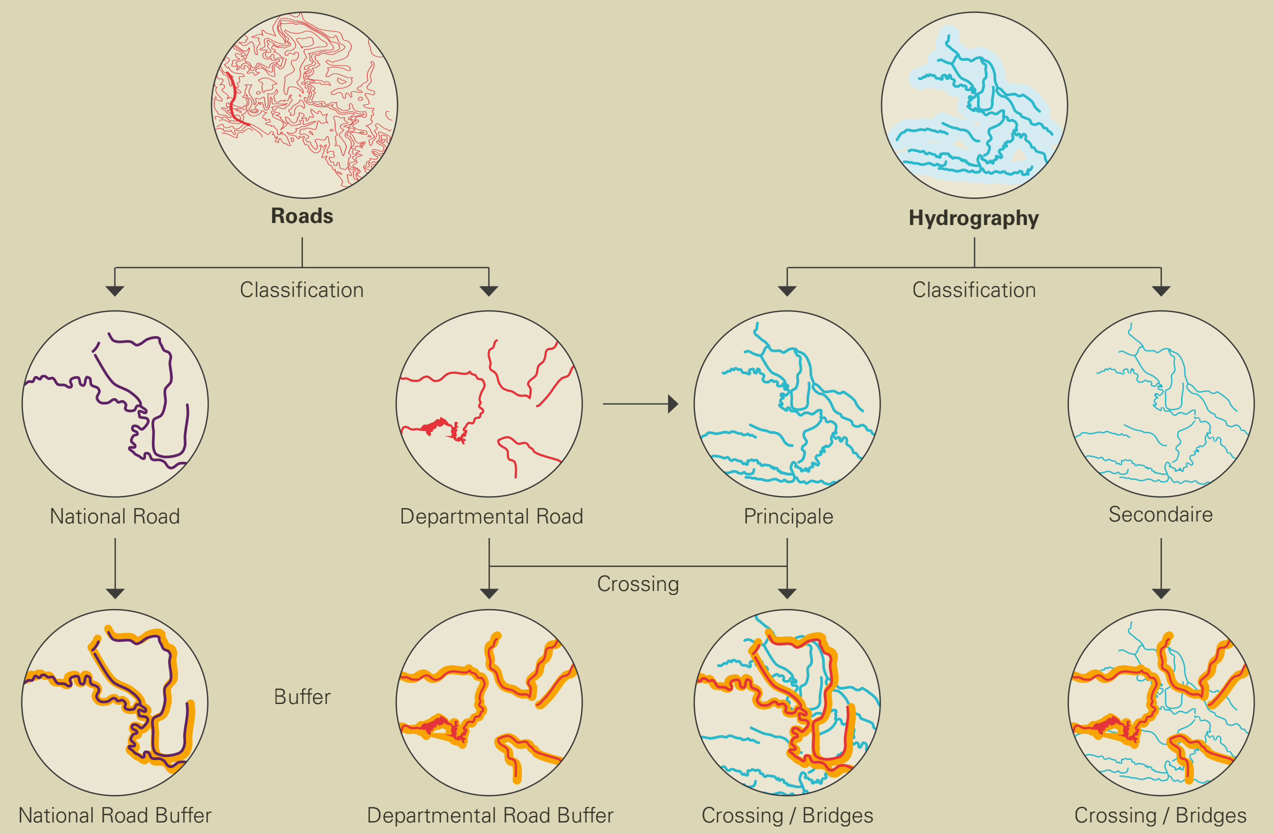
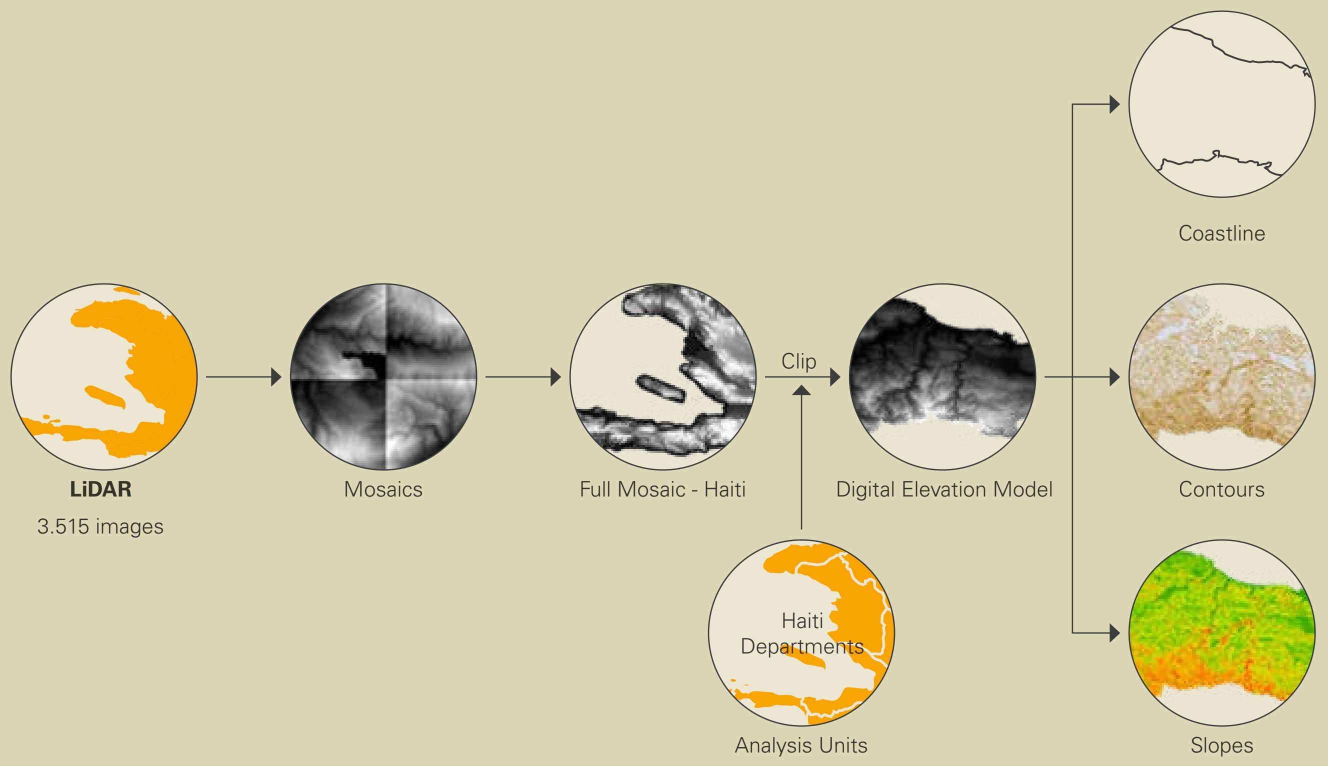


Figure: LiDAR processing



Results from the vulnerability analysis

Grand'anse department

The Grand'Anse department has approximately 225 km of main roads of which 43 km are Community/Tertiary Roads, 121 km are Departement/Secondary Roads, and 59 km are National Roads.

The following figures provide an overview of the distribution of slope grade, coastal proximity and crossings of the different types of roads (community, department and national roads).

Grand'Anse

Figure: Slope grade

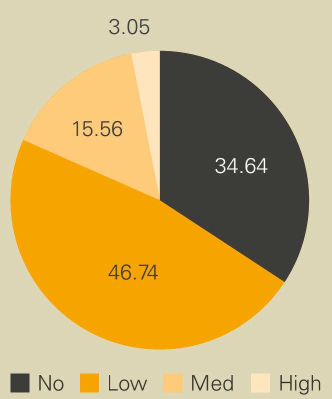


Figure: Coastal proximity

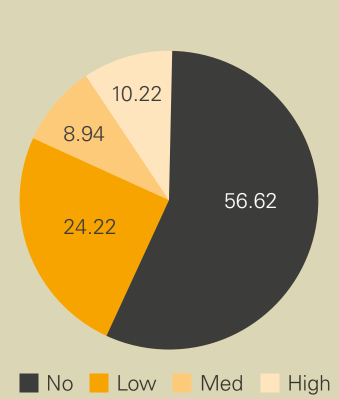
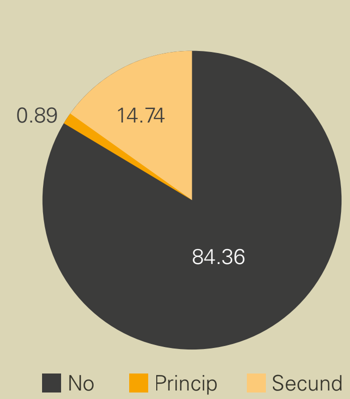


Figure: Crossings



Communal Routes

Figure: Slope grade

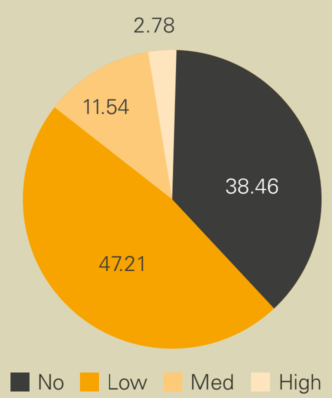


Figure: Coastal proximity

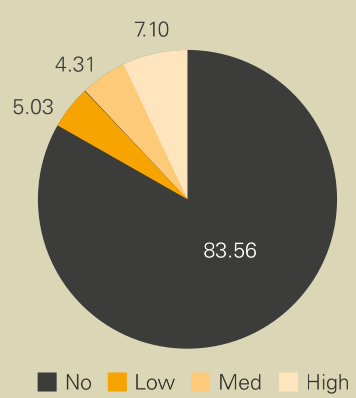
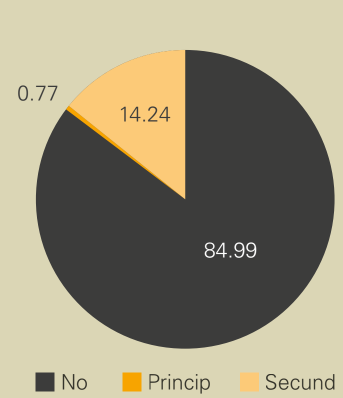


Figure: Crossings



Departemental Routes

Figure: Slope grade

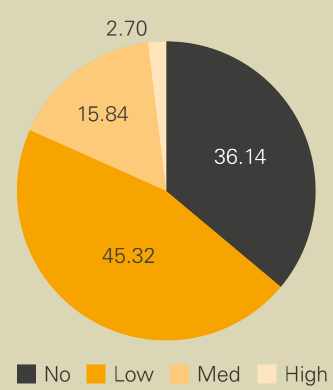


Figure: Coastal proximity

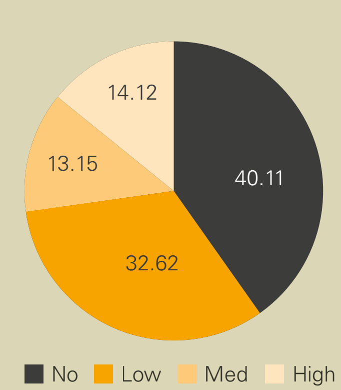
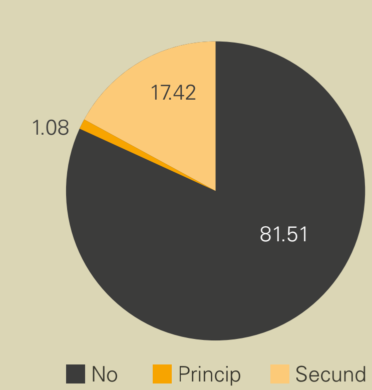


Figure: Crossings



National Routes

Figure: Slope grade

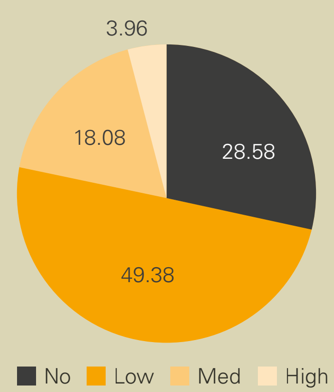


Figure: Coastal proximity

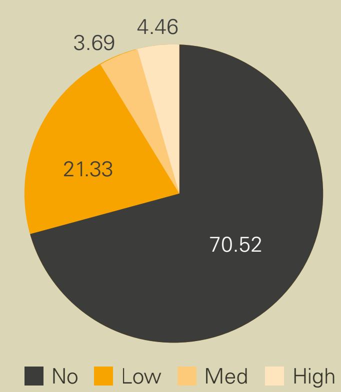
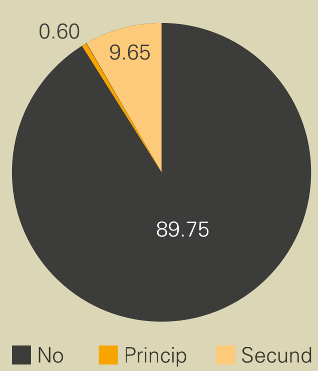


Figure: Crossings



ANNEX 4

List of species suitable for NBS in Haiti

As described in Section 2.1, Haiti has a diversity of ecosystems, each with its own characteristic flora and fauna. When considering which species is appropriate in any given location it will be important to receive guidance from experienced ecologists with knowledge of the impacted habitats.

NBS approaches might include a two-phased objective, the first, to protect exposed soil on hillsides from the impact of heavy rainfall to reduce erosion and the second, to re-establish native habitat (dry forest, humid forest, wetland, dune etc.). To achieve the first objective a rapidly growing, native, 'weedy' herbaceous ground cover would be more effective than planting slow growing trees. For restoring habitat, a diversity of native herbaceous plants, shrubs and trees appropriate for the particular habitat impacted will be required.

In all cases, it will be necessary to assure that plants are procured from sustainable sources and not, for example, taken from the wild. To achieve this, in anticipation of the need for revegetating or restoring impacted areas, a project might include funds for the establishment early in the project life-cycle of one or more native plant nurseries to produce the required volume of the appropriate species. These might also potentially create new income generating opportunities for local people.

Below is a provisional list of a selection of plant species that might be considered (assuming a sustainable source is available) for habitat restoration and ground cover. More information can be found in here[92]. Additionally, *The Jardin Botanique de Cayes and The National Botanical Garden of Haiti (JBNH) at Source Zabeth (Ganthier, West Dept.) might be able to provide the needed expertise*

Mountain Habitats

Pilosocereu polygonus
Cactus / Cactus

Melocactus intortus / Melon de costa, siège de belle-mère / Cactus

Opuntia tayllorii
Nopal, Cactus / Cactus

Melocactus Lemairei
Cactus / Cactus

Opuntia tuna
Nopal, Cactus / Cactus

Selenicereus boeckmannii
Pitayita Nocturna Organillo / Cactus

Melochia manducata -/ Herbaceous
Melochia a rapidly growing “weedy” native plant - good for ground cover

Salvia Shrub

Samuelssonia verrucosa
is a species of concern

Chrysopogon zizanioides /Vetiver /herbaceous - Vertiver exotic (though not invasive) commonly used for slope stabilization, but potentially problematic for soil erosion if pulled up for its deeps roots used in lucrative perfume trade.

Calyptronoma plumeriana
Manaca, / Palm Tree

Calyptronoma rivalis
Palm tree / Palm tree

Coccothrinax boschiva
Guano de Barreras / Palm tree

Coccothrinaz boschiana
Guano de Barreras / Palm tree

Cascabela thevetia
Cabalonga / Shrub

Cascabela thevetia / Cabalonga / Shrub - Non native and very invasive

Croton eluteria
Cascarilla, cascarilla / Shrub

Phyllanthus acuminatus / Grosella de Jamaica / Jamaican gooseberry tree / shrub

Senna domingensis / Senna / Shrub - Vulnerable native (a good choice if it can be sourced)

Adelia ricinella
Jia blanca (white Jia) / Tree

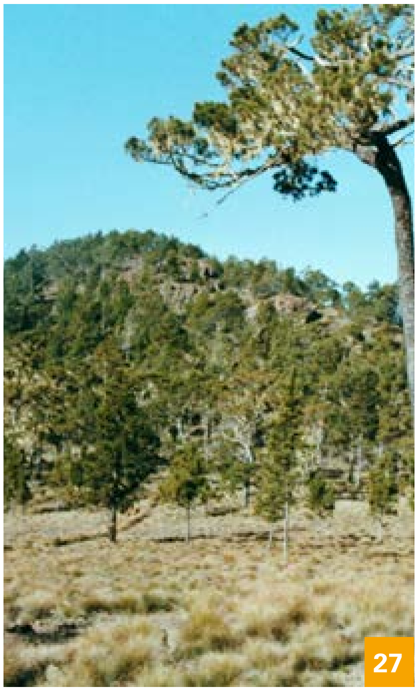
Albizia berteriana / Coreano blanco, Abey blanco, moruno de costa / tree

Coccoloba diversifolia
Uvero / Tree Dry and Coastal habitats

Erythrina corallodendron
Coral tree / Tree

Guaiacum santum
American guayacan / Tree - Endangered

Juniperus gracilior
Sabina, cedre / Tree - Critically endangered



Pinus occidentalis
Créole fine, pin créole / Tree

Posocarpus aristulatus /Palo de Cruz (wood of the cross) / tree - vulnerable

Productive land

The selection of these species was made taking into consideration their market value, their relatively fast growth, their potential use as timber, and their current presence in different parts of the country. However, some of them are exotic invasive which have a high risk of escape into and negative impacts in natural habitats and therefore should be excluded even though all are likely already established in Haiti. It is recommended to not use the invasive species.

Frut Species	Fodder and medicinal plants	Forest Species
Mango Tree (*Mangifera indica*); Avocado Tree (*Persea americana*); Sweet Orange Tree (*Citrus sinensis*) ; Chadèque Citrus maxima (aussi *Citrus grandis* ou *Citrus decumana*) ; Lemon Tree (*Citrus limonum*) ; Carambolier (*Averrhoa carambola*).	Elephant grass (*Pennisetum purpureum*) - Invasive Guinea grass (*Panicum maximum Jacq.*) - Invasive Citronella (*Cymbopogon citratus Stapf.*) - Invasive	Cedar (*Juniperus gracilior, Cedrela odorata*, L.) *; Frene (*Simaruba glauca*); Acacia (*Racosperma mangium, Acacia scleroxyla, L.*)) - Invasive; Cassia (*Cassia siamea L.* & *Cassia spectabilis, L.*) Mahogany (*Khaya senegalensis*); Oak (*Quercus Pedonculata, Catalpa longissima Jacq.*); Eucalyptus (*Eucalyptus globulus*) - Invasive; Casuarina (*Casuarina equisetifolia, L.*) - Invasive; Capable (*Colubrina ferruginosa, L.*) Cashew (*Anacardium occidentale*).

* Note : These are two species of cedar, Juniperus gracilior is a species endemic to the island of Hispaniola; however in Haiti, Cedrela odorata is used for reforestation activities.

Dune, beach, coastal restoration

Coastal species are almost all by definition, pan-tropical, due to their natural marine distribution and therefore widespread. The main species that may be suitable for the implementation of Nature-based Solutions in Haiti's coastal areas are:

Dunes

Sesuvium portulacastrum

Ipomoea pes-caprae

Canavalia rosea

Galium arenarium: gaillet des sables

5

Pourpier de mer: *Honckenya peploides*

6

Rizophorae mangle / Red mangrove, Palétuvier rouge / Tree

7

Avicennia germinan / Black mangrove, ManglierJaune / Tree

8

Conocarpues Erectus / Button mangrove, Button Wood / Tree*
Note: The use of this species is not common due to lack of knowledge and research on its development. It is recommended that an evaluation be carried out prior to its selection for restoration. The White mangle (Palétuvier blanc, Lagunularia racemes) is not included in this list because it does not resist to salinity and pollution conditions which are common at present.

ANNEX 5

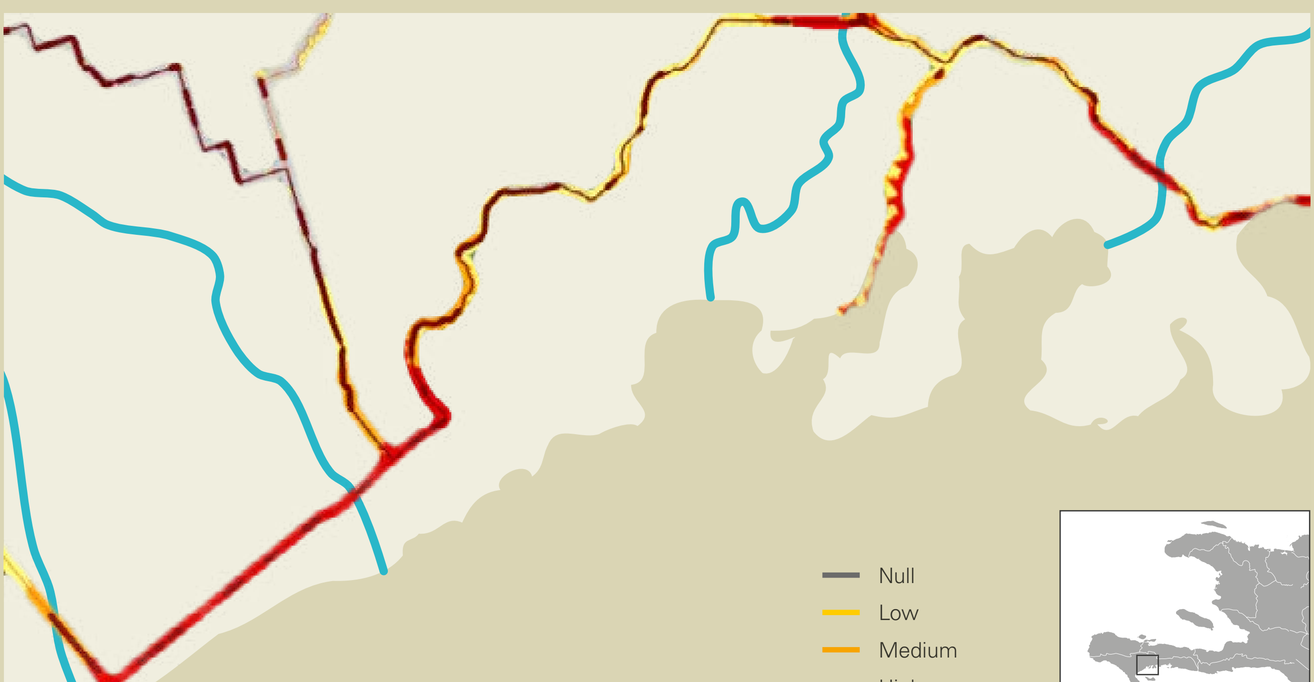
Step 1 to 4: Identifying nature-based solutions for road infrastructure resilience in Haiti

This annex presents an example of a possible exercise that could be carried out with stakeholders for the identification of NBS to strengthen the resilience of road infrastructure in Haiti. It follows Steps 1 to 4 as presented previously in Section 5.

Objective of the exercise: This exercise is based on the phased approach to planning and implementing the NBS for road resilience that was carried out in Haiti. The objective of this exercise is to provide participants with an opportunity to explore the practical steps needed to plan and implement solutions based on nature.

Guidelines: The exercise consists of 4 consecutive steps that include guiding questions to advice participants on what information is needed to complete each step. These steps are interdependent, which means that the information from each step is needed to inform the next step. Please use the tables provided as a format and provide summary information. Attached is a map showing the vulnerability of a section of the South Department. This map will be used throughout the exercise. Before the exercise, please explore the map and in particular the highlighted area to better understand the context.

Case study: Road infrastructure in the South Department



Step 1: Situation analysis to define the scope and the problem

1.1 Ecosystem definition

Identify the type of ecosystems that exist where the road infrastructure is built in the highlighted portion of the map. Please answer the following questions:

- Identify the ecosystem (mountain, coast, etc.) where the road infrastructure is located.
- What is the state of the ecosystem? (For example, degraded / fragile / healthy)?
- What are the factors that have affected / are affecting the ecosystem and degrading it?

Table: Example of answers:

Ecosystem type	Description	State of the ecosystem
Mountain	It is a fragile ecosystem with very little vegetation. The risk of accelerated erosion due to deforestation coupled with steep slopes is very high. Indeed, their level of vulnerability is very high compared to the hazards to which the southern department is exposed.	Degraded
Coast	For coastal ecosystems, levels of vulnerability range from high to mostly medium. In addition to being degraded, these ecosystems are also very fragile because of their exposure to several anthropogenic and climatic hazards. These include coastal erosion by tides, which is often accelerated by the uncontrolled extraction of sand, weed farming, deforestation, flooding and sedimentation from rivers. Anarchic coastal construction, blocking the natural outlets for run-off water, is also a significant fragility factor.	Degraded and fragile

Step 2: Climate Risk and Vulnerability Assessment

2.1 Risk analysis

Identify the threats posed by natural hazards and climate change (heavy rains, droughts, rising temperatures, sea level rise, landslides). Please use the map and answer the following questions:

- What hazards have you observed in the road structure in the past? ,
- Which of these hazards had the greatest impact on the road structure?

Table: Example of answers:

Danger	Description
Heavy rains, landslides, droughts, rising temperatures	• In Haiti we generally have thunderstorms/heavy rains which increase runoff from adjacent lands, contributing to flooding from surface water and overloading of drainage systems. • Compared to the topographical situation, the risks of increased slope instability and landslides are remarkably high. • Therefore, on mountain ecosystems and based on the map, these risks are very high.
Sea level rise, landslide	• In the coastal zone, there may be an increased probability of infrastructure failure due to sea level rise and coastal erosion. • These risks are identified for road infrastructure at the level of coastal ecosystems.

2.2 Hazard impact and Exposure analysis

Describe the main impacts of the hazards identified in 1A and identify the level of exposure of the road infrastructure. Please use the map and answer the following questions:

- What are the impacts of the identified hazards on road infrastructure and ecosystems?
- What is the area of potential impact?

Table: Example of answers:

Threats	Impacts on road infrastructure	Impacts on ecosystems
Heavy rains, landslides, droughts, rising temperatures	• Increased water and sludge runoff that can cause pavement destruction and overloading of drainage works. • Traffic obstruction is a major safety concern. • Increased frequency of fog episodes, which reduce visibility and road access.	• Erosion. • Destruction of landscape structure. • Loss of vegetation.
Sea level rise	• This could cause coastal erosion and an increase in groundwater levels that could cause enormous damage to the base of the road.	• Destruction of mangroves and wetlands
Sea level rise	• Destruction of the route	• Coastal and soil erosion
Heavy rains	• Running surface degradation (destruction, sedimentation, and others)	• Soil Erosion and Habitat Degradation in Fragile Ecosystems
Landslides	• Destruction or obstruction of the road	• Soil and habitat loss

2.3 Vulnerability analysis

Identify the level of vulnerability in the area presented in the case study map. Please use the map and answer the following question:

- What is the level of vulnerability of the road in the area highlighted on the map? (Low, medium, high)

Table: Example of answers:

The level of vulnerability of the road in the area highlighted on the map is medium with a few sections where the level of vulnerability is high.

Step 3: Identification and prioritization of nature-based solution options

3.1 Identification of nature-based measures

Identify a maximum of 2 solutions based on nature from the Solutions Catalogue (Section 7 of the Guide) to avoid/mitigate the impacts identified in 2.2 and reduce the vulnerability of the road infrastructure. Please answer the questions:

- What nature-based measures (from the Solutions Catalogue) can reduce the identified impacts on the road infrastructure and the surrounding ecosystem?
- How exactly does the measure proposed reduce the identified impacts?
- Which actors should be involved in the planning and implementation of the measure?

Table: Example of answers:

NBS	Impacts treated	Key actors
Measure 1: NBS1 - Stabilization of mountain slopes: general principle	Landslide and erosion protection	MTPTC, MDE, territorial community
Measure 2: NBS6 – Mangroves conservation and restauration	Coastal erosion	MTPTC, MDE, MARNDR, Town Hall, CASEC, NGOs, community, and riverside organizations
Measure 3: NBS15 – Embankment and vegetation to protect bridge piers and abutments	Local scouring of piles and abutments due to water and sediment erosion.	MTPTC, City Hall, CASEC, community and riverside organizations

NBS	Impacts treated	Key actors
Measure 4: NBS13 - Stabilization of coastal slopes with hybrid materials	Protection of infrastructure from coastal erosion by waves, currents, and wind.	MTPTC, MDE, MARNDR, territorial communities
Measure 5: NBS11 – Stabilization of coastal slopes with hybrid materials	Destruction or obstruction of the road	MTPTC, MDE, Town Hall, CASEC, fishermen's and residents' organizations
Measure 6: NBS3 - Stabilization of mountain slopes with hybrid materials	Soil and habitat loss	Town Hall, CASEC, farmers' and residents' organizations

Step 4: Protection of infrastructure from coastal erosion by waves, currents and wind.

3.1 Identification of nature-based measures

- In the design of nature-based solutions it is important to consider the specific characteristics of the project site and surrounding ecosystems. Therefore, consideration should be given to the specific location where the chosen solution must be implemented to be most effective, the materials required, tree species, among others. Identify the key considerations for the design of the solutions selected in step 3.1:

- What specific biophysical information (e.g. slope, soil erosion, vegetation condition, etc.) is needed to design the identified measures?
- What materials are needed?
- What additional expertise/analysis is required?
- What are the appropriate tree species?

Table: Example of answers:

NBS	NBS6 – Mangroves conservation and restauration	NBS11 – Stabilization of coastal slopes with hybrid materials
Biophysical considerations	• Coastal occupation • Shoreline depth and tidal strength • State of existing vegetation • Anthropogenic activities at the coastal level • Pollution level of runoff outlets	• Slope of the land overlooking the coast and the road. • Depth of coastline and tidal force • Existing vegetation • Anthropogenic activities at the coastal level • Level of coastal erosion • Level of sedimentation by alluvium from the slopes • Runoff strength and frequency
Material	• Plant species adapted to local ecosystems • Native and/or favorably endemic plants	• Plant species adapted to local ecosystems • Native and/or favorably endemic plants • Mechanical materials (stone, sand, gravel, and others)
Expertise	• Specialist in phytotechnics • Native Plant Botanist • Environmentalist	• Civil Engineer • Native Plant Botanist • Planner or environmentalist
Tree species	• Adapted mangroves	• See the list of plants that have been the subject of previous discussions (Annexes 4). • Avoid invasive alien plants as much as possible. • Use native plants such as *Panicum maximum, Leucaena leucocephala.*

4.2 Describe the main activities required to implement the chosen option

Once we have information on the design of the solution based on the option selected in step 3.1, it is important to list the activities and enabling conditions necessary for implementation. Enabling conditions refer to the need to see if there are relevant regulations for the implementation of the solutions, land ownership. Please answer the questions:

- What are the key activities for the implementation of the solution based on the nature chosen?
- What are the enabling conditions (laws, regulations, land tenure) relevant for the implementation of the solutions?
- What are the key activities that will be necessary for the maintenance of the NBS?

Table: Example of answers:

NBS	Main activities	Enabling conditions (laws, regulations)
NBS6 – Mangroves conservation and restauration	A.1.1 - Survey and field visits A.1.2 - Stakeholder Engagement A.1.3 - Preparation of restoration and management plans A.1.4 - Implementation and monitoring	Verify the standards and procedures of the financing partner. E.g. National Legal Framework and World Bank Procedures for Environmental Assessment and Habitat Management
NBS11 – Stabilization of coastal slopes with hybrid materials	A.1.1 - Mobilization of stakeholders (Contractor, Engineer, Authorities concerned, community organizations, local residents and workers) A.1.2 - Prepare the appropriate plans (technical, environmental, and social plan) / Technical and socio-environmental study A.1.2 - Preparation and validation of backup tools[92] including the complaint management mechanism A.1.2 - Mobilization of biological and mechanical materials A.1.3 - Execution and supervision of work	• Land status of the intervention area and areas of influence of the work. • National regulations and World Bank requirements for expropriation and resettlement; and • Haitian Coastal Management Laws • Others

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