



Future Proofing Caribbean Ports: Infrastructure, Digitalization, and Climate Resilience

October 13, 2025



SO MANY 'PROOFS'...



WATERPROOF



FIREPROOF



MESS PROOF



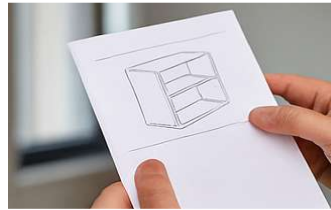
LEAK PROOF



THEFT PROOF



CHILD PROOF



FOOL PROOF



SHOCK PROOF



BULLETPROOF



TAMPER PROOF



SOUNDPROOF



CORROSION PROOF

BUT WHAT'S FUTURE PROOF?

- Designing or preparing something so that it **remains useful, effective, or relevant in the face of change.**
- To future-proof, we need to anticipate change — whether that's in technology, climate, economics, or social trends — and build in flexibility or adaptability to handle it.
- For Ports in the Caribbean—the lifelines for islands and communities—**Economic and social stakes a very high if we don't think ahead.**



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FUTURE PROOFING YOUR PORT

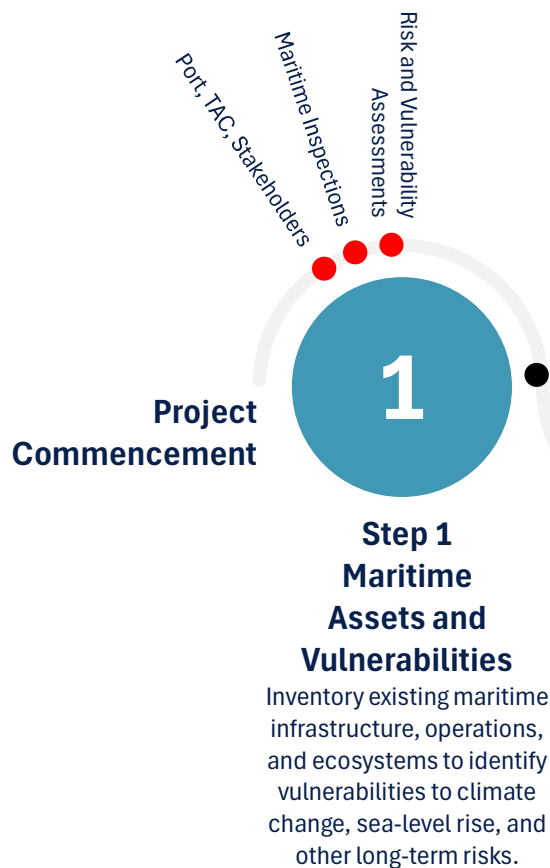
- Resilience and Adaptation
- Market Agility
- Infrastructure and Operations Flexibility
- Digitalization and Automation
- Community Integration
- Economic and Societal Well Being
- Decarbonization
- Financial and Policy Agility



FUTURE PROOFING YOUR PORT



STEP 1: MARITIME ASSETS AND VULNERABILITIES

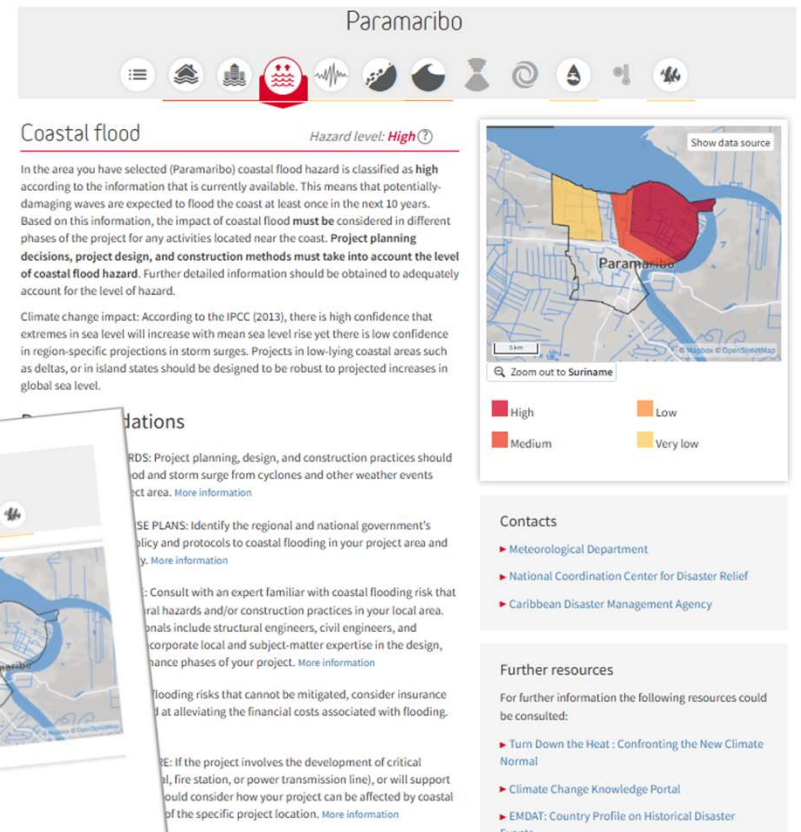
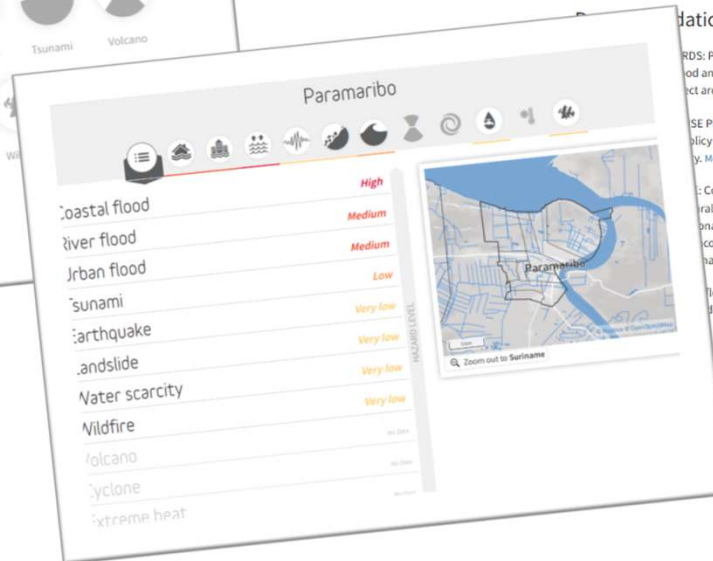
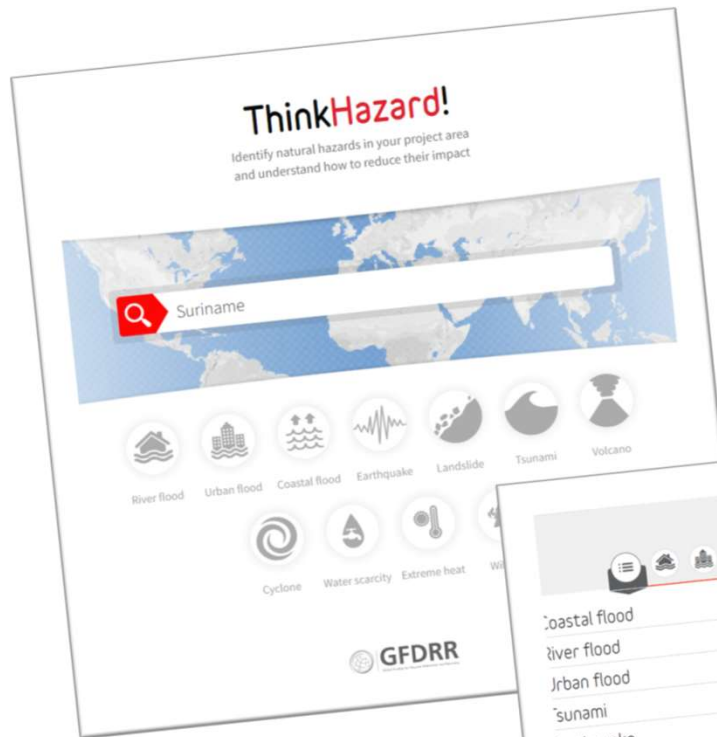


- Project Management Plan and Community Involvement Engagement Plan (CEIP)
- Assembly and evaluation of existing data and studies
- Community / stakeholder outreach
- **Maritime asset and vulnerabilities baseline**
 - Generate a maritime asset specific dashboard summarizing key features, land areas, equipment, marine throughput, surface transportation, condition, criticality (e.g. vital), and vulnerabilities. Provides an understanding of each location and the vulnerabilities to specific assets (e.g., piers, buildings, aprons).



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VULNERABILITIES BASELINE



STEP 1: MARITIME ASSETS AND VULNERABILITIES

NC DOT Ferry Vulnerability Study Ocracoke South Dock

AREA CHARACTERISTICS

Terminal: Ocracoke South Dock

County: Hyde

Area: Ocracoke South Dock, located on the unpopulated end of Ocracoke Island, connects to the Hatteras terminal through a popular tourist route used for day and overnight trips.

Routes				
Service	Distance	Travel Time	Vehicles (Annually)	Criticality
Hatteras	4.5 miles	70 minutes	203,000+	● No highway access to Ocracoke Island.

Route Vulnerabilities and Impacts

Shoaling Vulnerability	●	Dredging occurs multiple times a year.
Community Impact	●	Supports thousands of jobs and hundreds of millions in economic impact to the local economy, with 90%+ of riders who took a 2017 onboard survey for the Hatteras-Ocracoke route saying they would not or could not take their trip if the ferry was unavailable.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	●	●	●
Erosion	●	●	●
Overall Terminal	●	●	●
Roadway Access	●	●	●

Terminal Criticality and Vulnerabilities

Terminal Criticality	●	Limited access to island, there is only one ferry terminal (Hatteras) providing access to this terminal. The critical roadway between OSD and Ocracoke Village is frequently overwashed by ocean water causing a disconnection.
Community Impact	●	Terminal serves emergency evacuation route and ferry service serves as the only vehicle ferry to Ocracoke from Hatteras Island. Moderate Average Transportation Disadvantage Index of Riders: 8.4 (3-19 scale)
Terminal Flood Hazards	●	The most critical terminal assets have high flooding vulnerability making the terminal more vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	●	Visible damage to seawall/bulkhead adjacent to inlet. Ongoing erosion at inlet shoreline.
Critical Roadways Vulnerability to Erosion	●	21% of critical roadway within 230 ft of ocean shoreline, less than 5% within 50 ft of stabilized estuarine shoreline. 21% of critical roadway vulnerable to sound-side breaching.
Critical Roadways Vulnerability to Flooding	●	Critical Roadways vulnerable to flooding from many sources, including multiple high risk segments

KEY: ● Low ● Medium ● High



Ocracoke South Dock

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

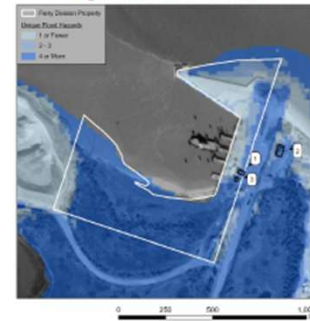
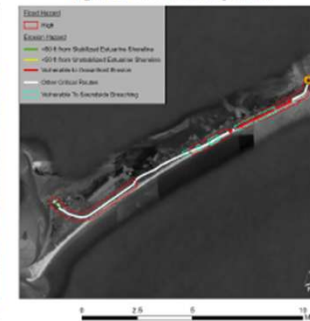


Figure 2: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	048-014-003	Ferry Office	●	●
2	048-014-005	Visitors Restroom Building	●	●
3	OSD-AST	Storage Building with Above-ground Storage Tank	●	●

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion / Breaching Vulnerability	Roadway Flood Vulnerability
NC 12 on Ocracoke Island	●	●	●

KEY: ● Low ● Medium ● High



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STEP 2: MARKET DRIVERS AND COMMUNITY NEEDS

Step 2 Market Drivers and Community Needs

Analyze market drivers and community needs by assessing economic trends, stakeholder priorities, and social, environmental, and operational factors.

2

Ongoing Planning
Cargo, Cruise, and Ferry
Market Drivers
Port, TAC, Community

- Macroeconomic and social trends
- Community growth trends
- Maritime markets assessment and trends
 - Preparation of forecasts of cargo (e.g. containers, bulk / breakbulk, and auto trade), cruise, ferry, and other trade and transportation flows to maritime assets specifically.
- Community / stakeholder outreach



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STEP 2: MARKET DRIVERS AND COMMUNITY NEEDS

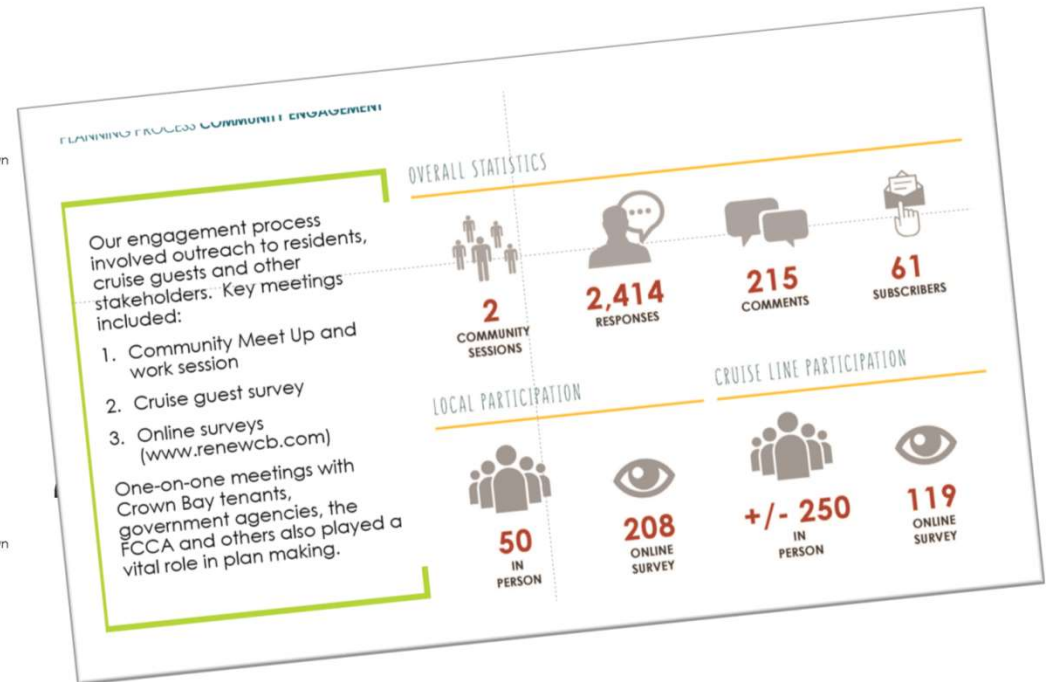


Residents KEY FEATURES

- 33% Increase shade and softscape features throughout Crown Bay to create cooler, more pleasant walking areas.
- 27% Invest in the adaptive reuse of historically significant buildings to better convey the area's Sub Base roots and past.
- 17% Integrate sustainable infrastructure design features throughout the area, inclusive of new construction and site reuse.
- 11% Retain and expand the number of available community recreational assets.
- 7% Preserve and restore landscape and habitat areas around Regis Point.
- 4% None of the above.

Island Guests KEY FEATURES

- 41% Increase shade and softscape features throughout Crown Bay to create cooler, more pleasant walking areas.
- 23% Invest in the adaptive reuse of historically significant buildings to better convey the area's Sub Base roots and past.
- 22% Integrate sustainable infrastructure design features throughout the area, inclusive of new construction and site reuse.
- 7% Retain and expand the number of available community recreational assets.
- 4% Preserve and restore landscape and habitat areas.
- 3% None of the above.



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STEP 3: 2050+ MARITIME FUTURE STATE



- Program development
- Facility planning, optimization, and criticality update
 - Plans and criticality updates formatted to align with the draft maritime asset and vulnerabilities baseline dashboard. Together, these define the anticipated 2050+ maritime future state for each location. In cases where future development paths may vary due to market conditions or other influencing factors, multiple distinct future state scenarios to reflect alternative outcomes.
- Community / stakeholder outreach

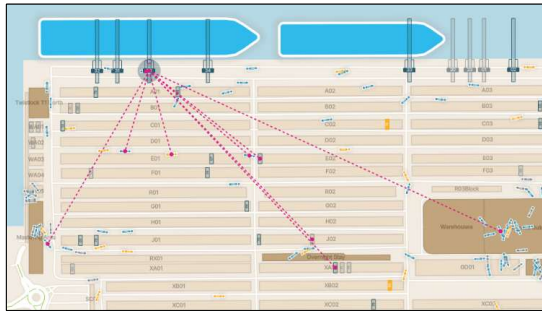
NEXTPORT

- **Technology & Innovation** arm of M&N
- **Software solutions** for Ports & Terminals
- **+240 years** of collective industry experience
- **Early adopter** portfolio



OPTIMIZING PORT OPERATIONS WITH DIGITAL TWINS

NextPort.ai, created by Moffatt & Nichol, is a technology platform that integrates artificial intelligence and digital twin technology to optimize port and terminal operations. It offers real-time visibility, predictive analytics, and data-driven decision-making tools to enhance efficiency, reduce emissions, and improve resource allocation across maritime logistics. By consolidating data from various systems, NextPort.ai enables ports to streamline workflows, anticipate challenges, and drive continuous improvement.



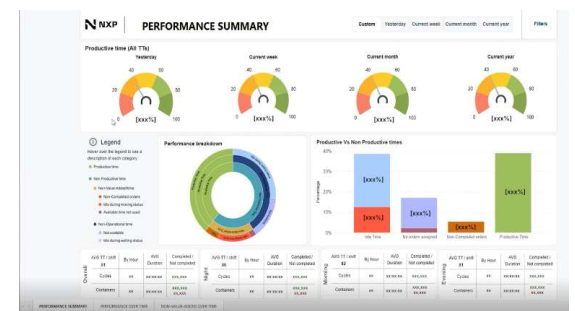
Top View

Top View offers a comprehensive set of visual tools to enhance port planning and operational efficiency. Designed for Port and Terminal Operations Managers and Ship Agents, it unifies master, event, and predictive data into a single interface.

Date	Type	Trigger time	Delayed time	Container ID	Status	Operator ID	ROW	OIE
18 Jan 11:44:58	TT Container cycle excessive time	18 Jan 11:44:58	18 Jan 11:44:58	10000000000000000000	OK	83003	0005	100000
18 Jan 11:44:58	TT Container cycle excessive time	18 Jan 11:44:58	18 Jan 11:44:58	10000000000000000000	OK	83003	0006	100000
18 Jan 11:44:58	VLS free anomaly	18 Jan 11:44:58	18 Jan 11:44:58	10000000000000000000	OK	10000	00000000	100000
18 Jan 11:44:58	TT Container cycle excessive time	18 Jan 11:44:58	18 Jan 11:44:58	10000000000000000000	OK	83003	0007	100000
18 Jan 11:44:58	VLS with order assigned	18 Jan 11:44:58	18 Jan 11:44:58	10000000000000000000	OK	83003	0008	100000
18 Jan 11:44:58	VLS free anomaly	18 Jan 11:44:58	18 Jan 11:44:58	10000000000000000000	OK	10000	00000000	100000
18 Jan 11:44:58	VLS with order assigned	18 Jan 11:44:58	18 Jan 11:44:58	10000000000000000000	OK	83003	0009	100000
18 Jan 11:44:58	Order assignment delay	18 Jan 11:44:58	18 Jan 11:44:58	10000000000000000000	OK	83003	0010	100000
18 Jan 11:44:58	TT Container cycle excessive time	18 Jan 11:44:58	18 Jan 11:44:58	10000000000000000000	OK	83003	0011	100000
18 Jan 11:44:58	VLS with order assigned	18 Jan 11:44:58	18 Jan 11:44:58	10000000000000000000	OK	83003	0012	100000

FlowOps

FlowOps empowers Marine Operations Controllers and Ship Agents to stay ahead of potential issues by transforming alarm management into a seamless, proactive process.



LeanIQ

LeanIQ empowers Marine Operations Managers to harness data for optimized operations and continuous improvement.

Existing Client IT Ecosystem
PCS, PMS, AIS / TOS, ECS, PLC

COMPLY



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STEP 3: 2050+ MARITIME FUTURE STATE

European port models offer valuable insights for the Caribbean on how to optimize limited berthing and terminal resources for both cargo and cruise operations. Many European ports successfully integrate shared-use infrastructure, seasonal scheduling, and flexible terminal design to accommodate dual maritime demands. We need to find new ways Caribbean ports can adopt smarter, more efficient strategies to balance trade and tourism while maximizing economic and spatial value and construction costs.



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STEP 4: ADAPTATION CONCEPTS AND ASSESSMENT

Step 4
Adaptation
Concepts
Development and
Assessment
Formulate concepts,
shortlist preferred
approaches, and identify
triggers for
implementation.

4

Port, TAC, Community

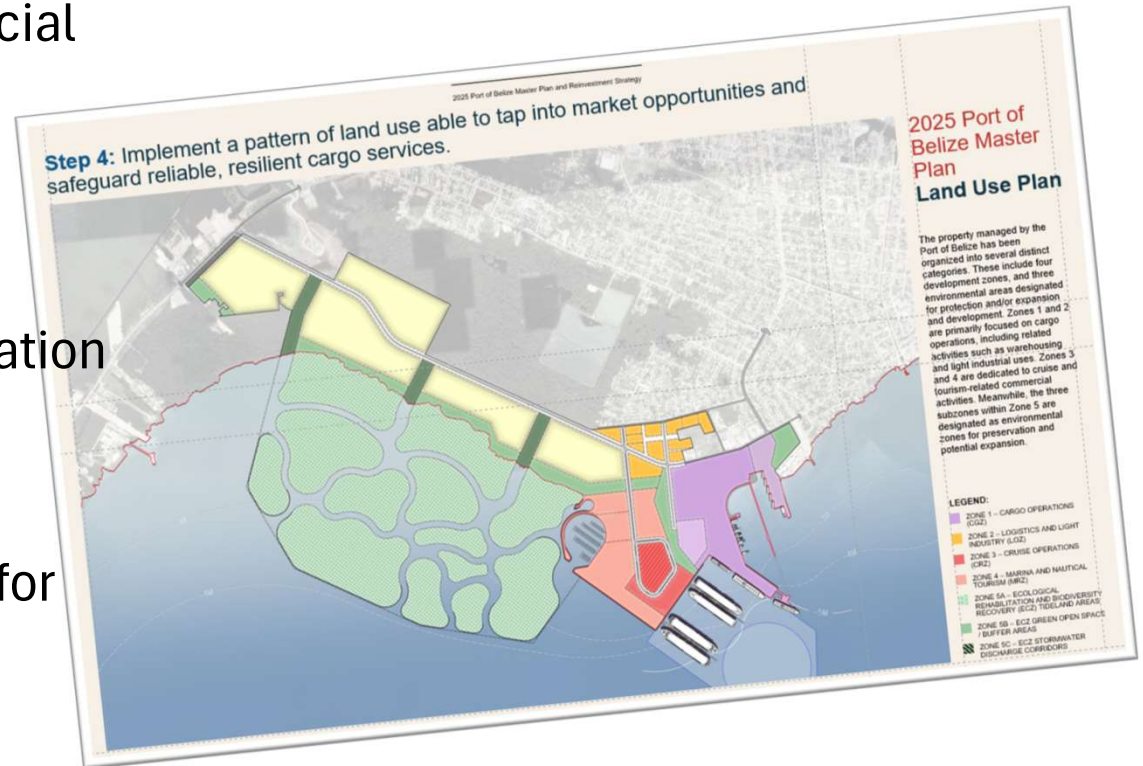
- **Develop adaptation concepts**
 - Concepts may include hard and soft protection measures, natural “living” shoreline strategies, hazard accommodation through elevation or floodproofing, or managed retreat and re-alignment of transportation infrastructure.
- **Develop and evaluate adaptation alternatives**
 - Develop adaptation alternatives that address vulnerabilities and leverage opportunities for growth. Prepare a generalized cost/benefit analysis of the alternatives to compare and weigh each alternative from the level of calculated benefits relative to the estimated life cycle costing of the project concept.
- **Monitoring plan and triggers for adaptation**



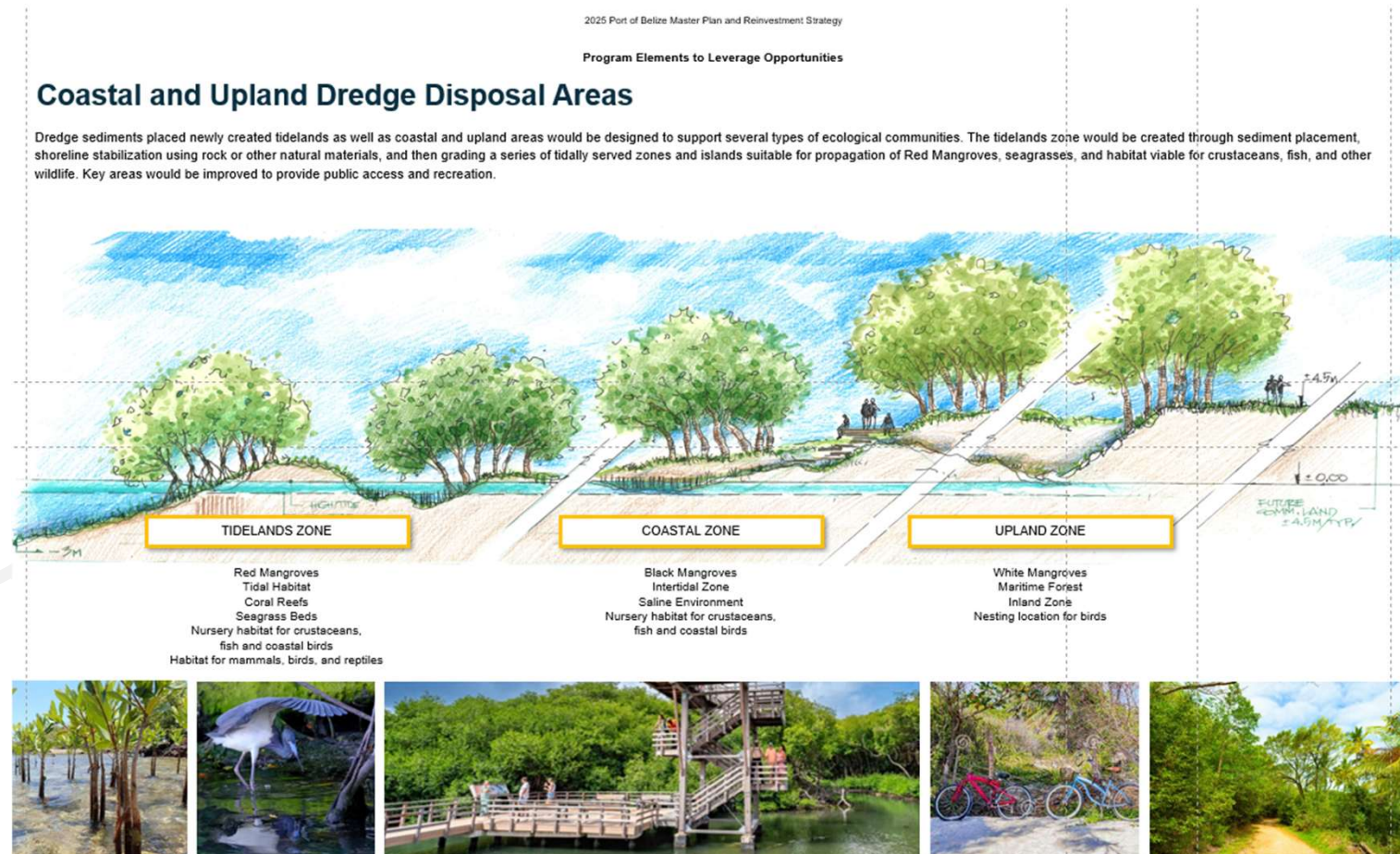
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NATURE-BASED + HYBRID SOLUTIONS FOR PORT RESILIENCE

- Living shorelines & beneficial sediment reuse
- Mangrove and salt-pond restoration to buffer surge
- Coral and seagrass restoration as natural breakwaters
- Align with World Bank's "Nature-Based Solutions for Ports" guidance



NATURE-BASED + HYBRID SOLUTIONS FOR PORT RESILIENCE



ENGINEERING AND OPERATIONAL PORT RESILIENCE

- Elevate critical systems (control rooms, substations)
- Reinforce quays, fenders, and mooring dolphins
- Flood-proof electrical & IT infrastructure
- Drainage redesign for cloudburst and surge events
- Standard Operating Procedures (SOPs) for hurricane season
- Pre-storm tie-downs, lay-up protocols, emergency energy supply
- Rapid post-storm damage assessment framework

STEP 4: ADAPTATION CONCEPTS AND ASSESSMENT

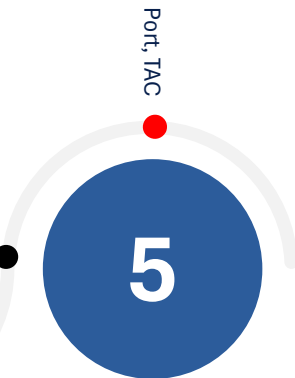
ADAPTATION

Adaptation							
Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	●	●	Culverts & Drainage	Near Term	\$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	\$\$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	\$\$\$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	\$\$\$\$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Visitors Center & Office	●	○	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Long Term	\$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	\$\$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	\$\$\$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	\$\$\$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Marine Maintenance Building	●	○	Elevate Contents/Floodproof Building	Long Term	\$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Above-ground Storage Tank	●	○	Elevate Contents/Floodproof Building	Long Term	\$ (Low)	◆ (Low)	Elevate storage tanks and/or ensure contents can withstand being flooded
Pump House	●	●	Elevate Contents/Floodproof Building	Near Term	\$ (Low)	◆ (Low)	Elevate pump controls and ensure contents can withstand being flooded
Erosion							
Roadways	●	●	Maintain Existing Shoreline Stabilization	Near Term	\$ (Low)	◆◆ (Med-Low)	Maintain existing revetment/bulkheads
			Install Revetment Along Unstabilized Shoreline	Long Term	\$\$ (Med-Low)	◆◆ (Med-Low)	General permit available, relatively straightforward design
			Install Living Shoreline Along Unstabilized Shoreline	Long Term	\$\$ (Med-Low)	◆◆ (Med-Low)	Enhanced ecological function, nature-based solution, may require more design considerations
Property Shoreline	○	○	Maintain Existing Seawall/Bulkhead	Near Term	\$ (Low)	◆ (Low)	Ensure seawall/bulkhead remains in good condition
			Raise Seawall/Bulkhead	Long Term	\$\$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements

KEY: ○ Low ● Medium ● High



STEP 5: CRAFTING THE PLAN



Step 5
Crafting the Plan
Draft and Finalize the plan,
taking into account the
prioritization of
improvements and
funding sources.

- Synthesize technical findings, stakeholder input, and strategic guidance around the five main planning priorities
 1. Risk-Informed Resilience Framework.
 2. Asset-Specific Adaptation Strategies.
 3. 2050+ Future-State Vision.
 4. Governance, Implementation, and Monitoring Tools.
 5. Stakeholder Engagement and Co-Benefits.
- Community / stakeholder outreach – presentation of the draft plan
- Final plan making and roll out

FINANCING RESILIENCE AND ADAPTATION

- Blend funding sources
 - Cruise, cargo, operator, and other industry co-investment
 - Port environment and sustainability recovery fees
 - Linkages to national initiatives
 - World Bank and IDB adaptation grants
 - CDB resilience financing
 - Blue bonds and ESG-linked loans
- Essential to know improvement triggers, integrate resilience into port, coastal, and infrastructure CAPEX outlays
- Ready projects early for funding and implementation

ADAPTATION ACTIONS IN PORTS⁹

7 DESIGN ACTIVITIES, OPERATIONS AND MAINTENANCE RELATED TO INCREASED SALINITY, ACIDIFICATION, SEA TEMPERATURE CHANGES, SEA SPRAY AND OTHER HAZARDS

PURPOSE: to adapt existing or planned infrastructure, operations and maintenance to future conditions that result from changes in salinity, acidification, sea temperature changes and sea spray, among others, with co-benefits that include reducing the number or severity of damages to port infrastructure.

POTENTIAL ACTIONS: select construction materials tolerant to salinity and acidification; review, revise and prioritize maintenance for assets that are vulnerable to these conditions; develop contingency plans covering future loss of protective role of coral reef (wave attenuation).

USEFUL TIPS: establish appropriate indicators to monitor and evaluate reductions in annual cost of damages related to increased salinity, acidification, sea temperature changes, sea spray and other such hazards (\$/year) and reductions in lost days of operation due to these hazards (%).

8 PROTECT COASTLINE AND RIVER OR ESTUARY BANKS THROUGH BOTH HARD AND SOFT ADAPTATION MEASURES

PURPOSE: to protect the shoreline or riverbanks from wave energy to avoid adverse impacts in the project area, with co-benefits that include reducing or avoiding exposure to coastal flooding or fluvial flooding, mitigating social and environmental impacts, and adding recreational and aesthetic value.

POTENTIAL ACTIONS: analyze and adopt both soft and hard engineering measures to improve adaptation. Soft engineering measures are actions that do not radically change the environment or counteract natural processes. Examples include adding sediment to beach areas with shoreline erosion; restoring natural and artificial dunes; restoring ecosystems (i.e., saltmarshes or mangroves and seagrasses) or planting riparian vegetation; and protecting coral reefs. Hard engineering measures involve human-built, rigid and complex infrastructures that intervene in coastal processes by altering wave energy. Examples include shore-parallel detached or offshore structures (breakwaters) to reduce incoming wave energy at the shoreline; dikes to protect adjacent low-lying areas from inundation under extreme conditions; and jetties at the banks of tidal inlets and river mouths to trap a portion of the longshore sediment to stabilize the inlet and prevent silting of the channel.

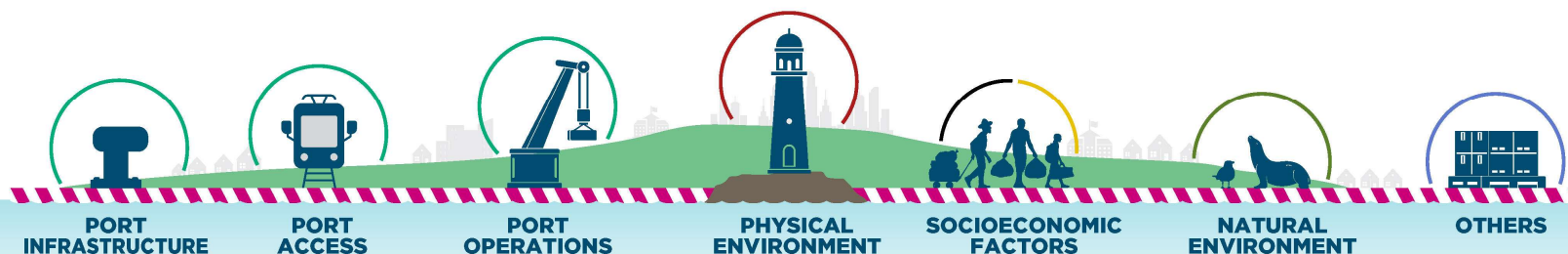
USEFUL TIPS: establish appropriate indicators to monitor and evaluate reductions in annual cost of damages related to modification of coastline and river or estuary banks (\$/year) and reductions in lost days of operation related to this indicator (%).

9 LOCAL COMMUNITY INVOLVEMENT

PURPOSE: to involve local communities to ensure that the project meets local requirements and enhances opportunities for employment, benefiting the local economy and improving quality of life.

POTENTIAL ACTIONS: devise plans for stakeholder and community engagement, outreach activities, regular focus group meetings and capacity-building.

USEFUL TIPS: establish appropriate indicators to monitor and evaluate increases in local household income (%), available jobs in the port area (%), diversity of businesses (%) and growth of port-related local companies (%).



10 WORK IN PARTNERSHIP WITH OTHER RELEVANT STAKEHOLDERS

PURPOSE: to build partnerships and networks with relevant stakeholders (e.g., local governments, civil society, academia, supply chain logistic stakeholders) and collaborate in developing strategies to adapt to climate change.

POTENTIAL ACTIONS: design connected logistics hubs; create local knowledge related to climate change; develop innovation tools and practices for vulnerability and risk management. Co-benefits include resource efficiency and more effective outcomes.

USEFUL TIPS: establish appropriate indicators to monitor and evaluate such factors as the number of collaborative strategies developed with key stakeholders and resource efficiency (in economic terms) in implementing climate change adaptation actions.

11 CREATE DIVERSIFIED PORTS THROUGH THE DEVELOPMENT OF SUSTAINABLE BUSINESS OPPORTUNITIES THAT HELP TO PROTECT THE NATURAL ENVIRONMENT AND BENEFIT THE LOCAL ECONOMY

PURPOSE: to create sustainable businesses in the port areas in order to protect the natural environment, increase awareness and provide socioeconomic benefits through new development opportunities.

POTENTIAL ACTIONS: promote the development of tourism businesses such as whale watching, scuba diving centers and boat excursions. Co-benefits include promoting environmental conservation and improving the local economy.

USEFUL TIPS: establish appropriate indicators to monitor and evaluate the number of sustainable business created; the growth of local companies related to the port (%); the number of ecosystems and species recovered; and the increase in tourism.

12 INSURANCE MANAGEMENT

PURPOSE: to analyze financial exposure in light of the probability of climate change impacts and identify maximum loss value of assets or revenue, in order to manage insurance costs and coverage, reduce exposure and optimize costs.

POTENTIAL ACTIONS: conduct a risk assessment to analyze the potential exposure of each asset to the main potential hazards; determine acceptable levels of risk (risk tolerance) for each hazard; verify and strengthen insurance coverage, including replacement and business interruption coverage; document the port's assets via video or photo in the case of claims; establish or improve crisis management plans to take into account priority hazards.

USEFUL TIPS: establish appropriate indicators to monitor and evaluate the number of operations with insurance for extreme weather events and the percentage of uncovered risks (%).

⁹ Adapted from The World Association for Waterborne Transport Infrastructure (PIANC). (2020). Climate Change Adaptation Planning for Ports and Inland Waterways.

LEADERSHIP



www.cruising.org

CHAPTER 6 FOREWORD CLIA SUSTAINABILITY PAPER 2023

“This past year has been one of significant milestones for CLIA member cruise lines as they pursue net zero carbon cruising by 2050. Our member lines are investing in building a more sustainable future for cruise travel, both at sea and on shore.”



KELLY CRAIGHEAD
President and CEO,
Cruise Lines International Association (CLIA)

CRUISE LINES



Royal
Caribbean
Group



MSC
CRUISES



NORWEGIAN
CRUISE LINE®

CRUISE PORT OPERATORS



GLOBAL PORTS
HOLDING PLC



SSAMarine
A Carrix Enterprise



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FUTURE PROOF RECAP

- **To future-proof, we need to anticipate change** — whether that's in technology, climate, economics, or social trends — **and build in flexibility or adaptability to handle it.**
- We build flexibility and adaptability by approaching port planning with eye towards resilience and adaptation, market agility, infrastructure and operations flexibility, digitalization and automation, community integration, economic and societal well being, and financial and policy agility.
- In implementation, we prioritize what matters most – **focus the triggers and asset criticality to ensure continuity**



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October 13, 2025



ABOUT MOFFATT & NICHOL

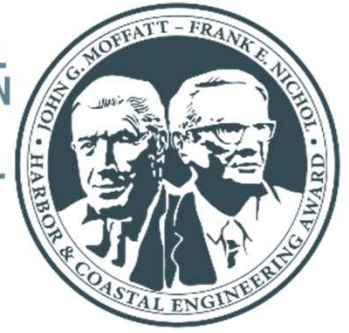
11,000+
PROJECTS COMPLETED



ENR
Engineering News-Record

TOP 100
DESIGN FIRM

AMERICAN
SOCIETY OF CIVIL
ENGINEERS JOHN
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COASTAL
ENGINEERING
AWARD



FOUNDED IN

1945

64+
OFFICES



80%
REPEAT BUSINESS



1350
EMPLOYEES



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