ADAPTATION GUIDELINES IN SUPPORT OF CLIMATE RESILIENT PORTS[1]

- ☑ Ensure executive level understanding and commitment to adaptation;
- ☑ Build or secure appropriate technical capability—to undertake climate risk assessments, and to assist with implementing adaptation options, and ongoing monitoring;
- ☑ Work in partnership—climate impacts do not respect borders, working with relevant partners contributes to more effective outcomes; building "regional redundancy" capacity can help damaged ports bounce back from storm events more quickly by accessing resources (e.g., equipment and cargo rerouting) at nearby facilities.
- ☑ Understand risks and thresholds both for the short term and the long term—ideally identified and analyzed through some form of risk assessment process;
- ☑ Support the risk assessment by monitoring, recording and analyzing data at the port site (particularly measurement of key climate variables and of course sea levels).
- ☑ Employ adaptive management principles to cope with uncertainty—that is, iterative decision-making, incorporating feedback, and testing/updating of assumptions;
- ☑ Look for "no/low regrets" and "win–win" adaptation options—those that as well as reducing the risks of climate change impacts, help produce other benefits; in particular, encourage/promote the concept of an adaptation pathways approach for sea ports that encourages planners to consider a number of defined possible future scenarios (see, e.g., the Thames Barrier CoastAdapt, 2016; Environment Agency, 2016; Reeder & Ranger, 2011);
- ☑ Avoid "maladaptation"—or actions that limit future adaptation options;
- ☑ Ensure adaptation measures are equitable—the effects of different adaptation efforts, and the costs should be considered across different groups/sectors;
- ☑ Develop new tools for objective multiport assessment of port vulnerability that complement the self-assessments. As adaptation resources will likely be scarce, decision-makers need criteria to help evaluate priorities for resilience investments that project the public, as well as private, interest (Duncan McIntosh & Becker, 2017).

[1] Source: Becker A, Ng AKY, McEvoy D, Mullett J. Implications of climate change for shipping: Ports and supply chains. WIREs Clim Change. 2018;9:e508. https://doi.org/10.1002/wcc.508

POTENTIAL ADAPTATION MEASURES IDENTIFIED

IN THE FRAMEWORK OF THE CASE STUDY

OF SAINT LUCIA[2]

Engineering	- Enhance the structural integrity and efficiency of critical facility components including sea defenses, berths, mooring facilities, runways and parking aprons, based on design criteria that consider potential changes in wind, sea-level and wave conditions; recalculation of the return periods of major events (e.g. hurricanes and floods) should be undertaken, so that more resilient structures can be engineered - Future procurement of mechanical components for the assets (such as conveyor belts, shore cranes etc.) needs to be assessed against future operating environment requirements. That is, the expected life of the equipment should be considered against the anticipated future climate - Storage facilities need to be upgraded - Assess and develop new design standards for hydraulic structures such as drainage systems to cope with projected intense rain events - Ongoing hydrographical monitoring, to identify if dredging requirements/strategies need modification - More robust dust suppression systems may be required (such as covering coal stockpiles, rather than just dampening) - Road ways in and through ports may need to be raised to respond to flooding issues - Construction of storm retention basins for flash flooding
Technology	- Investment in more climate-resilient technologies and equipment in planned expansion and upgrade programmes, as, for example: gantry cranes that can operate at higher winds; solar photovoltaics to generate electricity more efficiently for both operations and administration - To address increased temperatures, refrigerated storage specifications should be upgraded to meet demands of temperature changes and seek less energy intensive alternatives - Onsite renewable and low emission energy for a range of functions, to avoid risks associated with power disruption, the increased cost of energy and environmental requirements - Automation of logistics procedures
Planning, design and development	- Internal capacity-building and retraining that recognizes the magnitude and implications of the threat; building of redundancy into critical operations, wherever feasible

[2] Source: UNCTAD (2017) Climate change impacts on coastal transport infrastructure in the Caribbean: enhancing the adaptive capacity of Small Island Developing States (SIDS), SAINT LUCIA: A Case study. UNDA project 1415O.

	- Ensure ports have a proactive infrastructure and management plan that considers asset lifecycle elements, including altered materials deterioration regimes - Working in partnership with governments and supply chain logistics infrastructure providers to appropriately plan and design connected logistics hubs, resilient to the impacts of CC relevant for the area - Re-examine land use planning in flood prone areas, in order to alleviate flash floods affecting the major transport assets
Management	Various operational systems need to mainstream climate-change considerations into their procedures, for example, shut-down and start-up operations, emergency protocols and evacuation, environmental management systems, occupational safety and health protocols
Insurance	Some risks cannot be avoided; therefore, they must be insured by third parties; collaboration with port management, climate scientists and insurance providers might provide a basis for more reliable quantification of exposure and risks that must be covered
Technical and operational adaptation options for road network	- New heat thresholds for road surfaces and bridge expansion joints, edge strengthening of road embankments, incorporation of steel grids in the road structure - Elevation of roads, bridges and tunnels above the flood fields and development of 'submergible' road pavements, tolerant to frequent flooding - Addition of drainage canals near coastal roads, relocation of sections of roads, strengthening and heightening of existing levees, seawalls and dikes, additional pumping capacity for tunnels - Integration of emergency evacuation procedures into operations and protection of critical evacuation routes - Expansion of systems for monitoring scouring of bridge piers/abutments - Addition of slope retention structures and retaining facilities for landslides - Changes in drainage capacity standards for new infrastructure and rehabilitation (e.g., assuming the current 1 in 500-year rather than 1 in a 100-year storm).

ADAPTATION OPTIONS[3]

Ports

1. Process enhancements

Adaptation Option	Relevant Climate Hazards
Improve transition planning to ensure staff with more experience transfer their institutional knowledge to new staff	Sea Level Rise, Tropical Storms/Hurricanes/ Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Review all planned capital investments with lifetimes > 20 years to ensure they are designed with future climate in mind	Sea Level Rise, Tropical Storms/Hurricanes/ Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Account for sea level rise when doing inventories for replacement and refurbishment of equipment and infrastructure	Sea Level Rise
Review flood early warning systems	Heavy Precipitation/Flooding
Implement traffic management measures to minimize bottlenecks during extreme events	Storm Surge, Extreme Heat, Heavy Precipitation/Flooding
Enhance emergency evacuation plans	Storm Surge, Heavy Precipitation/Flooding
Take strategic actions to help spread the risk and manage future uncertainty, including diversification of trading partner countries and growing a broader range of business lines	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Support improved waste management activities in the nearby community to reduce debris.	Storm Surge, Wind, Heavy Precipitation/Flooding
Provide warnings of extreme temperatures to minimize heat stress risks for workers	Extreme Heat
Review and update plans for business continuity during extreme events	Storm Surge, Extreme Heat, Heavy Precipitation/Flooding
Engage with stakeholders to plan landscape-level flood management options	Heavy Precipitation/Flooding
Incorporate rising temperatures into energy audits	Extreme Heat
Engage with the government on the importance of developing a climate resilient transport system	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Adjust maintenance programs to ensure that the maximum capacity of the existing drainage system inside the port is being achieved	Heavy Precipitation/flooding
Update dredging programs and schedules to reduce loss of draft clearance	Heavy Precipitation/flooding
Undertake review and adjust maintenance programs to ensure that maximum capacity of existing drainage system is being achieved (e.g., frequency of drain clearance)	Heavy Precipitation/Flooding
Close port and stop handling operations before operating thresholds for equipment are reached	Wind
Increase standards of port construction to deal with higher winds	Wind

[3] Source: UNCTAD (2017) Climate change impacts on coastal transport infrastructure in the Caribbean: enhancing the adaptive capacity of Small Island Developing States (SIDS), Climate Risk and Vulnerability Assessment Framework for Caribbean Coastal Transport Infrastructure. UNDA project 1415O.
Note: Low regrets strategies are shaded in green.

Increase funding for dredging and beach nourishment programs	Sea Level Rise, Storm Surge
Develop plans to ensure port *services* are functional over time (and make contingency plans if those services cannot be provided by this port in the future)	Sea Level Rise, Storm Surge

2. Ecosystem enhancements

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

3. Engineering enhancements

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

Airports

1. Process enhancements

Adaptation Option	Relevant Climate Hazard
Improve transition planning to ensure staff with more experience transfer their institutional knowledge to new staff	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Review all planned capital investments with lifetimes > 20 years to ensure they are designed with future climate in mind	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Account for sea level rise when doing inventories for replacement and refurbishment of equipment and infrastructure	Sea Level Rise
Review flood early warning systems	Heavy Precipitation/Flooding
Take strategic actions to help spread the risk and manage future uncertainty, including diversification of trading partner countries and growing a broader range of business lines	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Support improved waste management activities in the nearby community to reduce debris.	Storm Surge, Wind, Heavy Precipitation/Flooding
Provide warnings of extreme temperatures to minimize heat stress risks for workers	Extreme Heat
Add climate change resilience as a factor in the Airport Master Plan	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Review and update plans for business continuity during extreme events	Storm Surge, Extreme Heat, Heavy Precipitation/Flooding
Establish a policy so that climate resilience enhancements are encouraged when infrastructure is due for replacement or renovation	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Diversify infrastructure related to fuel supply to ensure continued operations during disruptions	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Modify design criteria based on an understanding of potential climate change effects	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Engage with the government on the importance of developing a climate resilient transport system	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Establish a climate change contingency fund	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Establish methods to track the costs of weather events over time (e.g., charge codes or incident reports)	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Relocate critical operational centers or records (e.g., Met Service) from ground floor to higher floors	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Develop irregular operations protocols	Sea Level Rise, Storm Surge, Wind, Extreme Heat, Heavy Precipitation/Flooding
Plan for increased debris removal operations	Sea Level Rise, Storm Surge, Wind, Heavy Precipitation/Flooding
Enhance building codes to increase setback distances	Sea Level Rise, Storm Surge
Engage with stakeholders to plan landscape-level flood management options	Heavy Precipitation/Flooding

Adjust maintenance programme to ensure that the maximum capacity of the existing drainage system inside the port is being achieved	Heavy Precipitation/flooding
Update dredging programmes and schedules to reduce loss of draft clearance	Heavy Precipitation/flooding
Undertake review and adjust maintenance programmes to ensure that maximum capacity of existing drainage system is being achieved (e.g., frequency of drain clearance)	Heavy Precipitation/Flooding
Increase monitoring, maintenance and cleaning of stormwater systems	Heavy Precipitation/Flooding
Schedule more frequent pavement inspections on very hot days	Extreme Heat
Procure land to allow for future runway extensions, if possible	Extreme Heat
Educate employees about heat injuries	Extreme Heat
Incorporate rising temperatures into energy audits	Extreme Heat
Schedule cooling breaks for employees on very hot days	Extreme Heat
Improve temperature control and monitoring strategies	Extreme Heat
Close airport and stop handling operations before operating thresholds for equipment are reached	Wind
Require tie-downs for larger aircraft to prevent wind damage	Wind

2. Ecosystem enhancements

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

3. Engineering enhancements

Adaptation Option	Relevant Climate Hazards
Retrofit infrastructure or assets that are vulnerable to flooding	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Install flood barriers to protect flood-prone areas	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Install on-site, raised and protected backup power supplies	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding
Install pavement sensors to monitor runway degradation from the sun or from standing water	Sea Level Rise, Storm Surge, Extreme Heat, Heavy Precipitation/Flooding
Relocate high-value, high vulnerability infrastructure to reduce risk	Sea Level Rise, Storm Surge, Heavy Precipitation/Flooding

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