Guam Watershed Plan

GREAT SEAL OF GUAM
GUAM
TANO I MAN CHAMORRO

US Army Corps of Engineers ®
Honolulu District

July 2022

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DISCLAIMER: The information presented in this report is to provide a strategic framework of potential options to address problems within the Guam watersheds. Options identified will follow normal authorization and budgetary processes of the appropriate agencies. Any costs presented in this document are rough order magnitude estimates used for screening purposes only.

Cover images: Images from Guam; Coral reef; Tsunami; Cyclone forecast; Wildfire

Executive Summary

Study Authority
Authority for this Watershed Assessment (WA) is provided by Section 729 of the Water Resources Development Act (WRDA) of 1986 (Public Law 99-662), as amended.

Study Area
The study area encompasses the entire island of Guam, the southernmost island in the Mariana Islands Archipelago. The northern part of the island is a forested limestone plateau with sheer coastal cliffs. The southern part contains volcanic peaks covered in forest and grassland. Coral reef surrounds most of the island, except in the areas where bays exist that provide access to small rivers and streams. The Northern Guam Lens Aquifer (NGLA) is the main source of drinking water for the island.

Guam experiences two seasons: the dry season beginning in December and lasting through June, and the wet season when three-quarters of the annual rainfall occurs. On average three tropical storms and one typhoon pass within 207 miles of the island each year. The current population of Guam is approximately 154,000 persons.

Shared Vision Statement
The Territory of Guam spans 212 square miles of island bordered by 78 miles of coastline in the western Pacific Ocean. Weather related hazards, including tropical cyclones, flooding, high surf, drought, and severe wind are anticipated to intensify with climate change, with a predicted ½- to 1 ½ -foot rise in sea level by 2050. Additionally, anthropogenic stressors, including wildfires, deforestation, introduction of invasive species, erosion, sedimentation, and water quality impacts harm the social, economic, and environmental fabric of life on the island and increase vulnerability to natural hazards. Reducing the consequences of these hazards necessitates a collaborative focus on resiliency among federal and territorial agencies and stakeholders. This WA is intended to serve as a strategic roadmap to inform future decisions and actions.

Problems
The water resources problems were identified by focusing on natural hazards, past disaster events, local community needs, and local government interests. The problem statements in Tables ES-0-1 through ES-0-6 were developed collaboratively with stakeholders through both the synthesis of existing reports, and best professional judgement by subject matter experts on the project team.

Table ES-0-1. *Problems Caused by Tropical Cyclones*

Tropical Cyclones: Tropical cyclone activity at or within proximity to the Territory of Guam can result in flooding, wind damage, impacts to power supply, and other social effects, such as effects to cultural resources and native communities. In particular:
Coastal flooding can cause inundation of coastal infrastructure including harbor facilities and roadways with storm surge commonly reaching depths of 10-20 feet along the shoreline.
Loss of power supply can occur during and after tropical cyclone activity, sometimes continuing for months after the storm has passed, and can result in increased risk to life safety.
High winds can result in damages to structures and utilities throughout the territory.
The consequences of these tropical cyclone risks will be exacerbated by **sea level rise**.

Table ES-0-2. *Problems Related to Freshwater Flooding*

Freshwater Flooding: Heavy rainfall throughout the Territory of Guam can cause property damage and increase risk to life safety. In particular:
Flash flooding, which occurs frequently, can cause safety hazards, property damage, and ecologically destructive erosion, is of particular concern in southern Guam (due to streams with steep topography and presence of basaltic volcanic rocks with limited infiltration capacity), in addition to low lying areas and highly developed zones.
Riverine flooding, which generally occurs in the southern portion of Guam near the villages of Agat, Santa Rita, Hagåtña, Talofofo, Inarajan, Merizo, and Umatac, and some central locations, such as Maina and Chalan Pago, can result in life loss and property damage. Flooding may be exacerbated by rising sea levels due to increased backwater affects.
Erosion, due to the presence of erodible soils near the river systems of southern Guam, can result in impacts to utilities, property, and the environment.
Landslides/mudslides, which can occur in southern Guam due to the presence of erodible soils and steep slopes, are of particular concern where vegetation has been impacted by wildfires or other anthropogenic stressors, can result in impacts to utilities, property, and the environment.
Sedimentation, due to the presence of erodible soils and steep terrain primarily in southern Guam, can result in impacts to habitat as well as increased stream velocity and flows that can exacerbate riverine flooding.

Table ES-0-3. *Problems Related to Coastal Hazards*

Other Coastal Hazards: Coastal areas throughout the Territory of Guam are at risk of damage to infrastructure due to naturally occurring and accelerated coastal processes. In particular:
Saltwater spray damages the crops and corrodes infrastructure.
Loss of living breakwater (corals, shoreline vegetation, and near shore vegetation), which serves as natural infrastructure to minimize wave intensity, results in increased shoreline erosion.
Coastal erosion, which can occur throughout the island, with a more frequent occurrence on the western coast due to tropical cyclones and monsoon surges that produce high waves, results in increased risk to coastal infrastructure.
Sea level rise, which will exacerbate the consequences of coastal infrastructure risks.

Table ES-0-4. *Problems Related to Habitat Loss*

Habitat Loss: Anthropogenic activities, land use, and resource management practices contribute to the loss of habitat and biodiversity in coastal, upland, and riverine areas. In particular:
Loss of fish habitat due to **coral die-off** reduces fish populations, which can lead to food insecurity on the island
Sedimentation in streams and near shore coastal waters impacts aquatic habitats for both fresh water and marine species.
Coral reef degradation (e.g., coral bleaching, pollution, and sedimentation) occurs in the shallow nearshore waters surrounding Guam, which hosts approximately 42 mi^2 of coral reef habitat.
Nutrient loading, primarily from agricultural runoff and septic/cesspool discharge, causes algal blooms which can impact coral reefs and associated habitat.
Wildfires, which result from drought and anthropogenic sources, lead to deforestation, sedimentation, and loss of upland, coastal, and aquatic habitat.
Invasive species, which threaten coral reefs and other marine and inland habitats, result from anthropogenic stressors and are exacerbated by climate change.

Table ES-0-5. *Problems Related to Water Supply*

Water Supply: The water supply system throughout Guam is vulnerable to naturally occurring and anthropogenic stressors. In particular:
Nutrient loading, primarily from agricultural runoff and septic/cesspool discharge, causes algal blooms and impacts water quality
Sedimentation in streams and near shore coastal waters impacts water quality.
Drought leads to saltwater intrusion, impacts to water quality, and reduction of available water supply;
Over-use of Northern Guam Lens Aquifer leads to saltwater intrusion, impacts to water quality, and reduction of available water supply, which may be exacerbated by future elevated sea levels.
Pollution near water supply wells results from wide usage of septic tanks, illegal dumping, and siting of hazardous land use near water supply production wells, which impacts water quality.
Storm water management issues including non-conforming or non-existent storm water management infrastructure causes flooding and pollution, sending untreated runoff to near shore waters impairing water quality.

Table ES-0-6. *Problems Related to Tsunami*

Tsunami: Coastal, low-lying, and culturally significant regions of Guam are at risk from tsunami. In particular:
Tsunami waves resulting from seismic activity, volcanoes, or submarine landslides, can cause life safety risks and inundation of the coastal and low-lying areas of Guam.

Opportunities

Opportunities are future desirable conditions that could coincide with the solutions to the identified problems in the study area. For this WA, opportunities were identified to inform the implementation strategy for recommendations. As such, this WA provides opportunities throughout Guam to:

- Leverage and develop collaborative interagency partnerships to address priorities and reduce data gaps for multi-hazard risk management.
- Improve communication and foster relationships among those working to build resiliency.
- Connect government and local leaders with funding opportunities for implementation of measures to reduce risk.

Planning Goals and Objectives

The goal of this WA is to develop a framework to increase Guam's resilience to weather-related hazards and reduce the effects of anthropogenic stressors through a focus on nature-based solutions where appropriate. This WA will provide a strategic roadmap to inform future investment decisions by multiple agencies (i.e., involvement by U.S. Army Corps of Engineers, other federal agencies, or non-federal interests). Objectives identify planning outcomes that define successful resolutions of the problems and attainment of the opportunities identified. The **objectives** include:

- Improve the ability of Guam to anticipate, prepare for, and adapt to changing conditions.
- Improve the ability of Guam to withstand, respond to, and recover rapidly from disruptions.

Planning Constraints and Considerations
No planning constraints were identified for this WA.

Plan Formulation
In collaboration with the primary study partner, Guam Bureau of Statistics and Plans, and stakeholders, draft recommendations were formulated with a risk- and uncertainty-based prioritization. The study followed the U.S. Army Corps of Engineers (USACE) six-step watershed planning process: identify problems and opportunities; inventory and forecasting; identify and screen measures; formulate the initial array of strategies, refine the initial array and evaluate the focused array of strategies; and perform strategy comparison and selection.

Interagency Collaboration
Throughout the course of the study, stakeholder meetings were held to:

- Determine study scope.
- Develop a shared vision statement.
- Validate problem categories.
- Perform and review risk assessments.
- Develop the array of recommendations based on measures.

Risk and Uncertainty Assessment
To prioritize problems and stressors, several iterations of risk assessments were conducted with stakeholders and subject matter experts. The consequences and probability of each identified problem and stressor were evaluated from an economic, environmental, social, and life loss perspective. The results of this risk assessment indicated whether the problems and stressors were catastrophic, major, or minor and were used to inform the timing of recommendations (i.e., address highest risks first).

To further inform recommendations, an uncertainty assessment was completed for each of the problems and stressors. The uncertainty assessment examined how much is known about the problem and its potential solutions. The results of the uncertainty assessment were utilized to determine the most suitable types of recommendations. If a solution existed and was supported by the stakeholders with strong consensus, the recommendations were classified as *actionable*. If potential solutions were identified but did not have a strong consensus, the recommendations were classified as *evaluate options*. If no solutions were identified and more data is needed to create potential solutions, the recommendation was classified as *fill data gaps*.

The summary results of the risk assessments are in Figure ES-0-1 and Figure ES-0-2, and the detailed plots and explanations of the risk assessment can be found in Section 5.3. The highest relative risk rankings are categorized as *catastrophic* risks (highlighted by the red boxes in the figure), while problems and stressors which were not ranked among the highest relative risks were categorized as *major* risks. No problems were categorized as minor, as each problem was ranked as major or catastrophic for at least one risk metric.

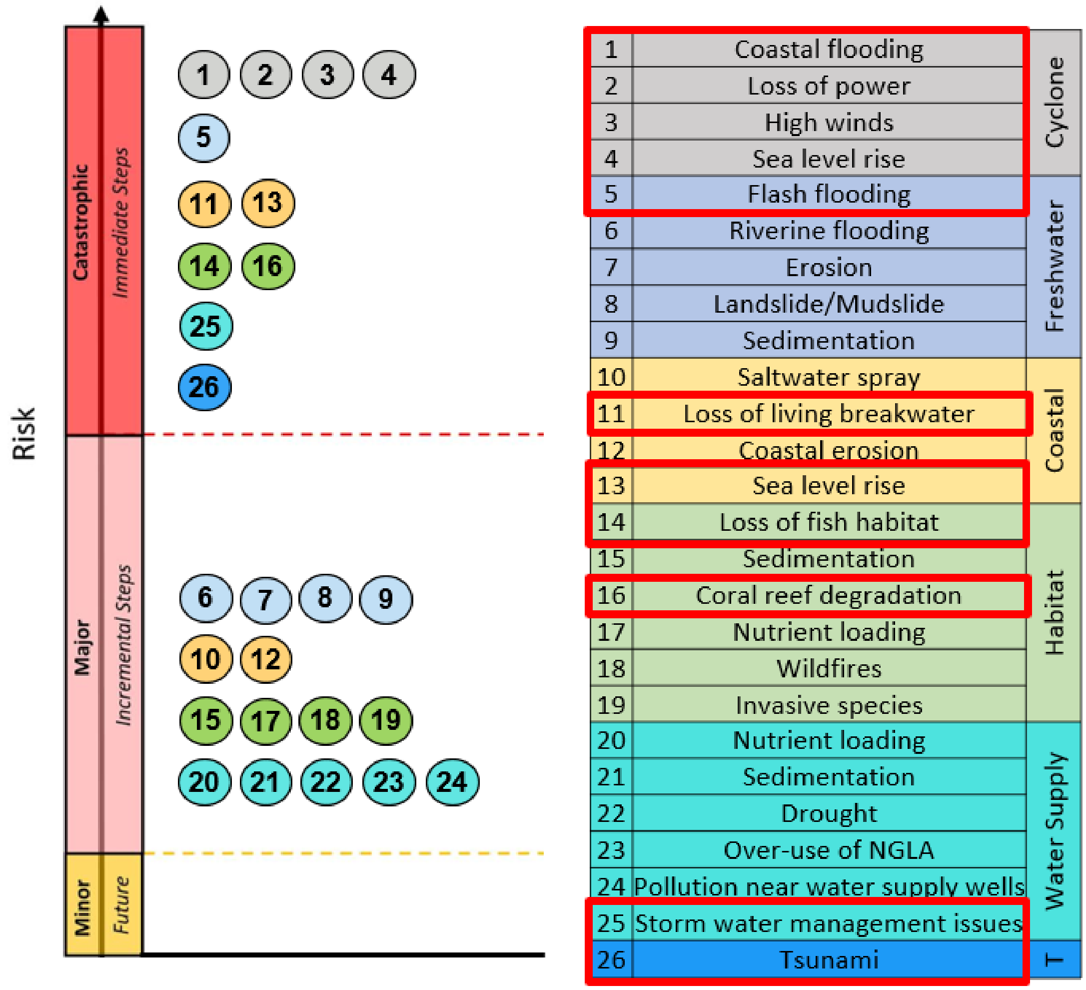

Figure ES-0-1. *Risk Assessment Summary*

Uncertainty Assessment

In addition to risk, a qualitative assessment of uncertainty was also performed for each problem and stressor to help identify the appropriate type of recommendations (Figure ES-0-2). This qualitative uncertainty assessment was conducted through a review of existing information and with input from the study partner and stakeholders through a series of collaborative workshop

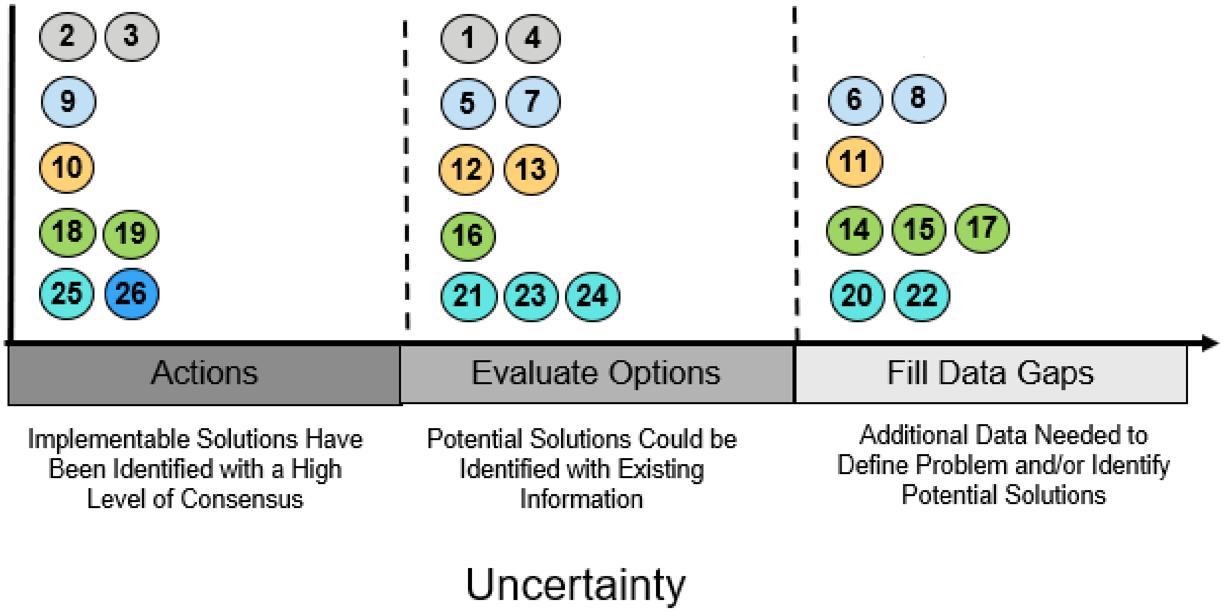

***Figure ES-0-2**. Uncertainty Assessment Summary*

Prioritization of Strategies

The following recommended strategies are prioritized into near-term strategies (Table ES-0-7) for catastrophic risks and incremental strategies (Table ES-0-8) for major or minor risks. Near-term strategies reduce potentially catastrophic risks while incremental strategies reduce major risks. Each table is further divided into implement, evaluate options, and data gaps based on the uncertainty assessment results. A suggested timeline of implementation follows each recommendation.

***Table ES-0-7.** Near-term Strategies*

Priority	Stressor	Recommendation	0-5 yrs.	5-10 yrs.	10+ yrs.
Near-term actions	High Winds and Power Outages	*Wind Resistant Solar Panels*	Implement	-	-
		Emergency Generators for Critical Facilities	Implement	-	-
		Underground Power Distribution	Evaluate	Implement	-
		Long-term Recovery Planning	Evaluate	Implement	-
		Comprehensive Structure Inventory	Implement	-	-
		Building Policies	Implement	-	-
	Stormwater Management	*Improve Urban Drainage Network*	Implement	-	-
		Scheduled Maintenance & Drain Cleaning	Implement	-	-
		Stormwater Management Planning	Implement	-	-

Priority	Stressor	Recommendation	0-5 yrs.	5-10 yrs.	10+ yrs.
		Wetland/Vetiver Grass Restoration	Evaluate	Implement	-
	Tsunami	*Development Management in High-Risk Areas*	Evaluate	Implement	-
	Tsunami	*Continue Education, Outreach, & Risk Communication*	Implement	-	-
	Tsunami	*Continue Annual Tsunami Drills*	Implement	-	-
	Tsunami	*Establish/Continue Tabletop Exercises for First Responders*	Implement	-	-
	Tsunami	*Maintain/Improve Tsunami Warning System*	Implement	-	-
	Tsunami	*Maintain/Improve Tsunami Zone Mapping w/ Sea Level Rise*	Implement	-	-
Near-term evaluate options	Coastal Hazards	*Pilot Multi-Purpose Ecosystem Restoration/Coastal Storm Risk Management Study*	Evaluate	Implement	-
Near-term evaluate options	Coastal Hazards	*Build Interagency Partnerships and Identify Additional Future Options to Evaluate Coastal Risk Reduction*	Evaluate	Implement	-
Near-term evaluate options	Flash Flood and Inland Erosion	*Build Interagency Partnerships*	Evaluate	Implement	-
Near-term evaluate options	Flash Flood and Inland Erosion	*Warning Systems*	Evaluate	Implement	-
Near-term evaluate options	Flash Flood and Inland Erosion	*Pilot Multi-Purpose Ecosystem Restoration/Flood Risk Management Study*	Evaluate	Implement	-
Near-term data gaps	Loss of Living Breakwater and Fish Habitat	*Focus on Areas and Opportunities Identified in the Guam Coastal Atlas*	Evaluate	Implement	-
Near-term data gaps	Loss of Living Breakwater and Fish Habitat	*Build Interagency Partnerships and Identify Additional Future Opportunities*	Implement	-	-

Table ES-0-8. *Incremental Strategies*

Priority	Stressor	0-10 yrs.	10-15 yrs.	15+ yrs.
Incremental Actions	Riverine Sedimentation	Evaluate	Implement	-
Incremental Actions	Saltwater Spray	Implement	-	-

	Wildfires	Implement	-	-
	Invasive Species	Implement	-	-
Incremental evaluate options	Sedimentation of Water Supply	Evaluate	Evaluate	Implement
	Overuse of NGLA	Evaluate	Implement	-
	Pollution Near Water Supply Wells	Fill data gaps	Evaluate	Implement
Incremental data gaps	Riverine Flooding	Fill data gaps	Evaluate	Implement
	Landslide	Fill data gaps	Evaluate	Implement
	Sedimentation of Streams and Nearshore Coastal Waters	Fill data gaps	Evaluate	Implement
	Nutrient Loading	Fill data gaps	Evaluate	Implement
	Drought	Fill data gaps	Evaluate	Implement

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List of Acronyms

AEP	Annual Exceedance Probability
BMP	Best Management Practices
BRIC	Building Resilient Infrastructure and Communities
BSP	Bureau of Statistics and Plans
CAP	Continuing Authorities Program
CCRC	Climate Change Resilience Commission
CLTC	CHamoru Land Trust Commission
COTS	Crown of Thorn Starfish
CWSRF	Clean Water State Revolving Fund
DAWR	Division of Aquatic and Wildlife Resources
DLM	Department of Land Management
DPHSS	Department of Health and Social Services
DPW	Department of Public Works
DOE	Department of Energy
DOI	Department of Interior
EC	Engineering Circular
EMPG	Emergency Management Performance Grant
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
ER	Engineering Regulation
EWN	Engineering with Nature
FEMA	Federal Emergency Management Agency
FMAG	Fire Management Assistance Grant
FPMS	Floodplain Management Services
GDOA	Guam Department of Agriculture
GDOA-FSRD	Guam Department of Agriculture – Forestry & Soils Resource Division
GDOE	Guam Department of Education
GEPA	Guam Environmental Protection Agency
GFD	Guam Fire Department
GHS	Guam Homeland Security
GHS-OCD	Guam Homeland Security – Office of Civil Defense
GIS	Geographic Information System
GMHA	Guam Memorial Hospital Authority
GNA	Guam Nature Alliance
GPD	Guam Police Department
GPR	Guam Department of Parks and Recreation
GWA	Guam Waterworks Authority
HMGP	Hazard Mitigation Grant Program
HMP	Hazard Mitigation Plan
IBC	International Building Code
IPCC	Intergovernmental Panel on Climate Change
MEC	Munitions and Explosives of Concern
MEOW	Maximum Envelope of Water
MOM	Maximum of the MEOWs
MOU	Memorandum of Understanding
NEPA	National Environmental Policy Act
NCEI	National Centers for Environmental Information
NGLA	Northern Guam Lens Aquifer
NMFS	National Marine Fisheries Service

NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	The Natural Resources Conservation Service
NRHP	National Register of Historic Places
NWS	The National Weather Service
PAG	Port Authority of Guam
PAR	Population at Risk
PAS	Planning Assistance to States
PB	Planning Bulletin
RSLC	Regional Sea Level Change
RSM	Regional Sediment Management Program
SLC	Sea Level Change
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SLR	Sea Level Rise
SWCD	Soil and Water Conservation Districts
TC	Tropical Cyclone
TCP	Traditional Historic Properties
TNC	The Nature Conservancy
UoG	University of Guam
UoG-ML	University of Guam Marine Laboratory
UoGSG	University of Guam Sea Grant
U.S.	United States
USACE	U.S. Army Corps of Engineers
USD	U.S. Dollar
USDA	U.S. Department of Agriculture
USDA-FS	U.S. Department of Agriculture – Forestry Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UXO	Unexploded Ordinances
WA	Watershed Assessment
WERI	Water and Environmental Research Institute of the Western Pacific
WMO	World Meteorological Organization
WQS	Water Quality Standards
WRDA	Water Resources Development Act

1 Study Information

1.1 Study Authority

Authority for this Watershed Assessment (WA) is provided by Section 729 of the Water Resources Development Act (WRDA) of 1986 (Public Law. 99-662, title VII, Section 729), as amended, which authorizes the U.S. Army Corps of Engineers (USACE) to:

> *"Assess the water resources needs of river basins and watersheds of the United States including needs related to –*
> *(1) ecosystem protection and restoration;*
> *(2) flood damage reduction;*
> *(3) navigation and ports;*
> *(4) watershed protection;*
> *(5) water supply; and*
> *(6) drought preparedness."*

This study is funded by the Additional Supplemental Appropriations Disaster Relief Act, 2019 (P.L. 116-20), which fully federally funded the WA, therefore a cost share agreement was not required.

1.2 Federal Interest

There is federal interest in conducting a WA to investigate strategies to increase community resilience from post-disaster effects in the Territory of Guam. For the purposes of this WA, resilience is defined as to the ability of Guam's communities to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. By focusing on the social, economic, and environmental aspects that contribute to resilience, this WA provides recommendations to increase community resilience that could be implemented by various federal, territorial, local and non-governmental organizations.

1.3 Purpose and Scope

This WA was initiated in response to the Category 2 Typhoon Mangkhut, which struck Guam in September 2018 and caused widespread damage throughout the territory. Strong winds, flash floods, coastal flooding, and landslides resulted in power outages and significant damage to public and private properties. The intent of this WA is to provide recommendations both within and outside of USACE authorities that will help to rehabilitate and improve the resiliency of damaged infrastructure and natural resources, reducing risks to human life and property from future natural disasters in Guam. The WA incorporates available information related to recent storm damages from Typhoon Mangkhut, as well as other past storms and hazardous events that had a major impact on Guam. The WA assessed the drivers of economic, social, life loss, and environmental risks through engagement with federal and territorial agencies.

1.4 Watershed Planning Process

The Guam WA is following the Watershed Studies Guidance outlined in Engineering Regulation (ER) 1105-2-102 (Watershed Plans). This study process combines USACE traditional water resources planning, structured partner and stakeholder participation, and collaborative systems modelling to work towards comprehensive and strategic evaluations and analyses.

The goal of this process is to improve the economic, environmental, life safety, and social outcomes of water management decisions through facilitation of a common understanding of natural resources systems, allowing stakeholders to identify tradeoffs and management options.

Conceptual models of significant resources and issues in the watershed were developed throughout the study to provide a comprehensive view of the watersheds of Guam. The models were used in the evaluation of plans to ensure that all effects on the uses of significant regional resources were considered according to the shared vision statement and objectives. Figure 1 is the conceptual ecological model developed with partners to communicate the complex interplay between drivers, stressors, and effects.

Because a watershed study will not generate a specific proposal for a major federal action that could adversely affect the human environment as defined by the National Environmental Policy Act (NEPA), the preparation of a NEPA document is not required as part of a watershed study.

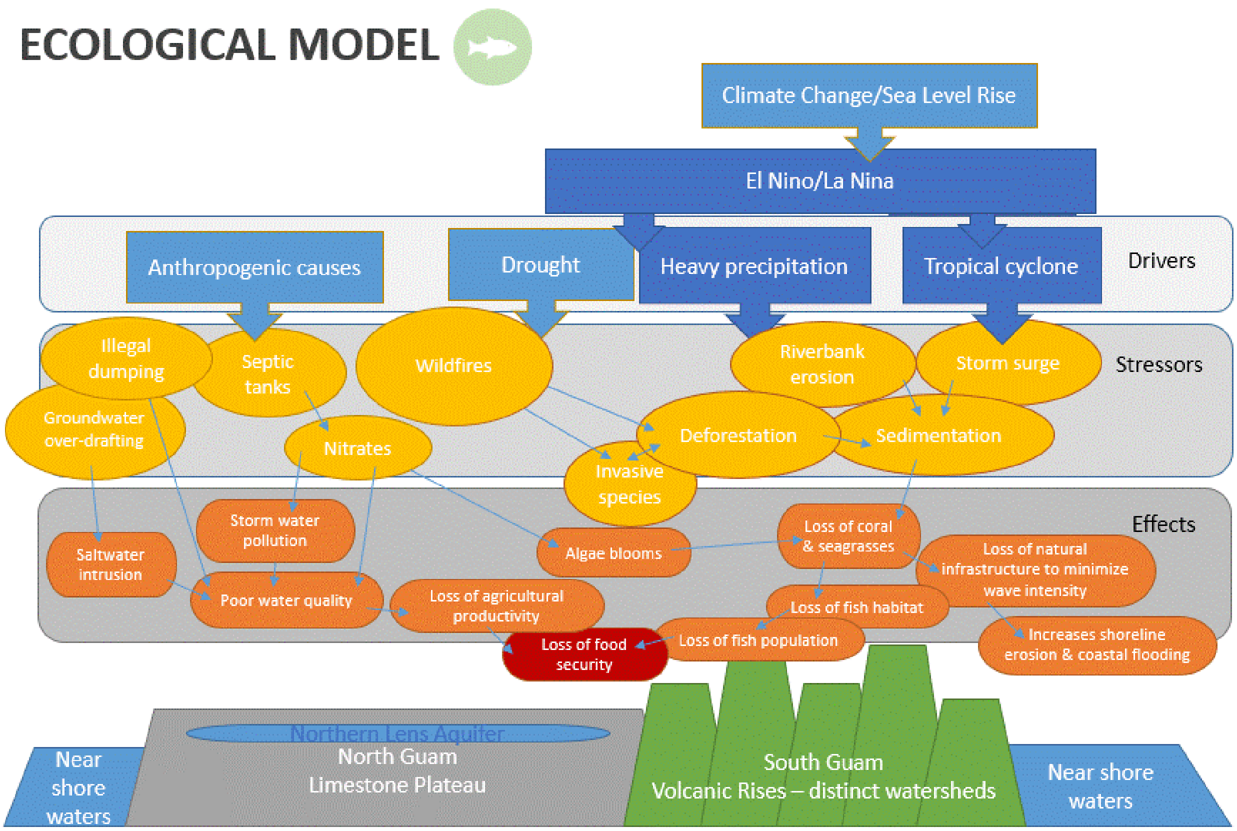


Figure 1-1. *Conceptual Ecological Model*

1.5 Study Location and Background

Guam is in the western Pacific Ocean and is the largest and southern-most island of the Mariana Archipelago (Figure 1-2). The island is approximately 30 miles long with a landmass of 212 square miles. A majority of the approximately 154,000 people of Guam live along the western shore and northern portion of the island, with smaller villages spread over the southern and eastern areas of the island.

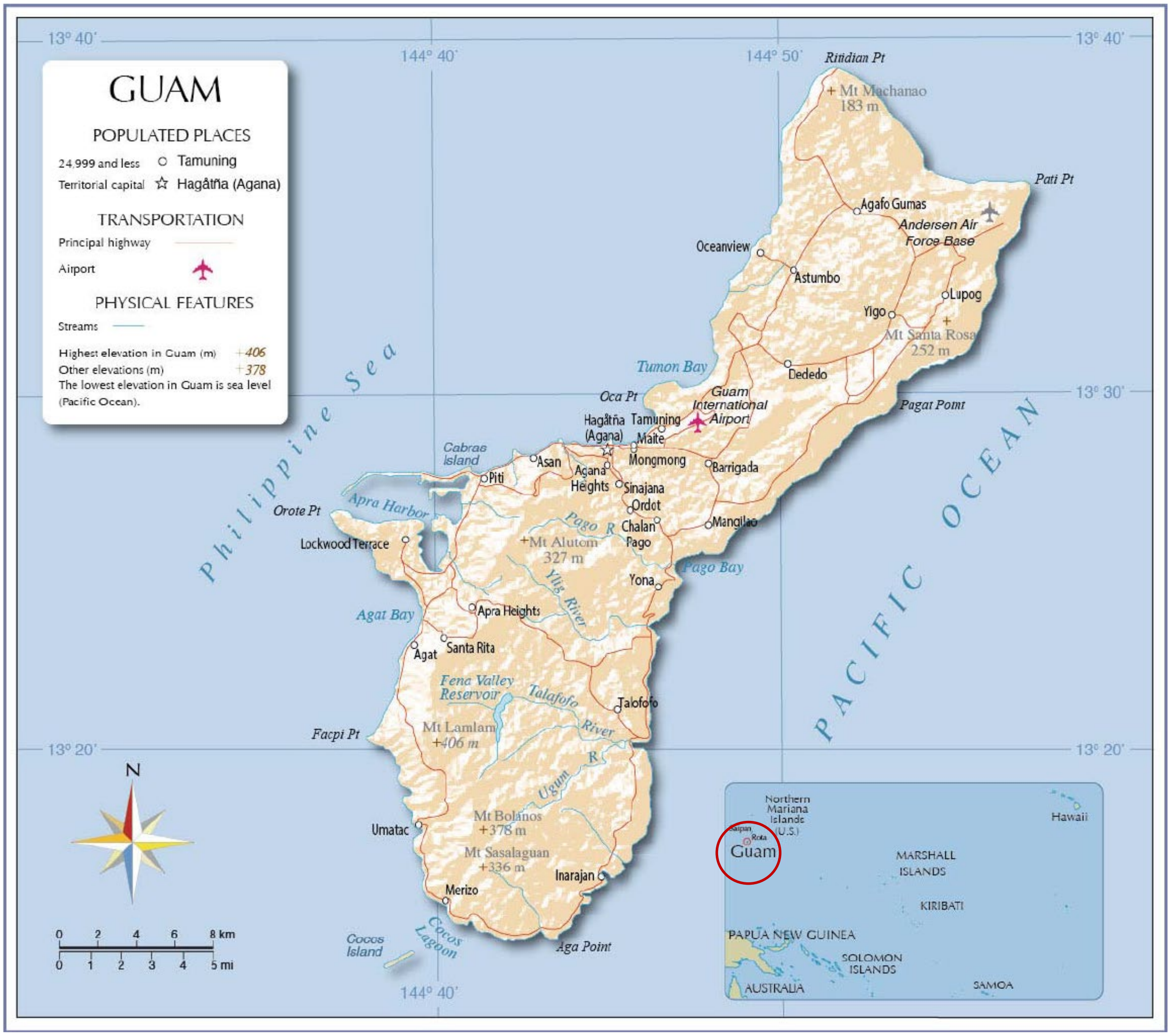


Figure 1-2. *Island of Guam (Image Courtesy of Government of Guam and University of Guam)*

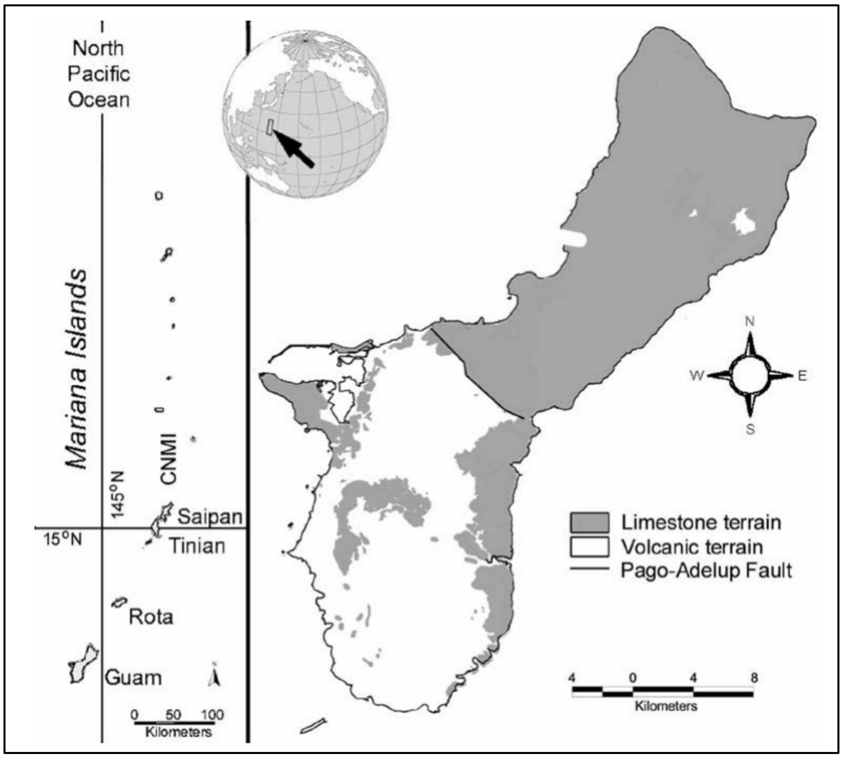


Figure 1-3. *Underlaying Geology of the Island of Guam*
(Image Courtesy of University of Guam)

Guam can be categorized into two distinct regions, northern and southern, due to its unique geology (Figure 1-2). A flat limestone plateau in the northern region provides a permeable surface for rainfall to infiltrate and recharge the Northern Guam Lens Aquifer (NGLA), the main source of drinking water for the population. The southern portion of Guam contains a mountain range on the west coast and more than 45 rivers that discharge into the ocean. Much of the south is covered by grassland. Guam is enclosed by a fringing reef interrupted only at a few of the bays.

The tropical monsoon climate brings an average rainfall of 98 inches during the wet season (July – November). Guam lies within the western Pacific Ocean, which accounts for one-third of all tropical cyclones globally. As such, the island is affected by the winds, storm surges, and rains of near-passing typhoons and has suffered direct contact with typhoons in the past. On average, Guam is impacted by one to three tropical storms per year (NWS, 2020).

Guam's climate, to include typhoon activity, is affected by the El Niño Southern Oscillation (ENSO), a climate phenomenon with three phases: El Niño, La Niña, and ENSO-neutral. El Niño and La Niña are opposite phases that involve changes in both the ocean and atmosphere. The ENSO-neutral phase is in the middle of the continuum between El Niño and La Niña. The El Niño phase brings about lower sea levels and reduced rainfall near Guam. The La Niña phase brings about higher sea levels and more typical rainfall patterns near Guam. During the ENSO-neutral phase, conditions are generally closer to average for the area.

The U.S. military currently occupies approximately 32% of the land on Guam for military use. While U.S. military lands were included in the island-wide analysis of existing and future conditions, specific recommendations for military lands are not included in this WA, as described in Section 3.4, Planning Constraints and Considerations.

2 Interagency Alignment and Stakeholder Engagement

USACE worked in collaboration with the study partner and other stakeholders to develop the WA (Table 2-1. The Guam Bureau of Statistics and Plans served as the primary study partner and was instrumental in ensuring collaboration with appropriate agencies and other stakeholders. For the purposes of this WA, a stakeholder is defined as any interested party, to include federal, territorial, and local agencies.

Two months after this study initiated, the COVID-19 pandemic struck the world and redefined collaboration. As a result, the study team relied almost entirely on virtual interactions across five time zones. Unable to go on a site visit early in the study, the study team communicated often with local partners to better understand the study area. As the study progressed, interagency alignment and concurrence was obtained throughout the study process, from scoping the study to prioritizing actions.

2.1 Stakeholder Engagement

In accordance with the study authorization provided by Section 729 of WRDA 1986, as amended, cooperation letters were sent to the United States (U.S.) Environmental Protection Agency (EPA), United States Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Natural Resources Conservation Service (NRCS), State Historic Preservation Officer, and National Park Service (NPS). USACE received email responses expressing continued interest and cooperation from all required federal agencies. The cooperation letters can be found in Appendix A-2 – Guam Cooperation Letters.

The U.S. military land, infrastructure, and personnel residing within the bases in Guam are susceptible to problems and stressors identified in this study; however, for the purposes of this watershed study, the U.S. military was not considered a stakeholder. This is because the U.S. military is not solely reliant on the government of Guam for its resilience to chronic and acute changing conditions.

Table 2-1 *Study Partner, Federal and Territorial Agencies, and Other Stakeholders*

Organization	Purview		
	Flooding	Water Quality	Environmental
Study Partner, Federal and Territorial Agencies, and Other Stakeholders			
Guam Bureau of Statistics and Plans	-	X	X
Guam Environmental Protection Agency	-	X	X
Guam Legislature	X	X	X
Guam Homeland Security	X	-	-
Guam Department of Agriculture	X	X	X
Guam Department of Public Works	X	X	-
Guam Division of Aquatic and Wildlife Resources	-	X	X
Guam State Historic Preservation Office	-	-	X
Guam Department of Land Management	X	X	X
University of Guam	X	X	X
Guam Department of Education	X	X	X
Federal Agencies			
USACE**	X	X	X
U.S. EPA*	-	X	X
Department of Interior* (USFWS/NPS/Office of Insular Affairs/U.S. Geological Survey)	X	-	-
Department of Agriculture* (NRCS)	-	X	-

Organization	Purview		
	Flooding	Water Quality	Environmental
Department of Commerce* (NMFS/National Oceanic and Atmospheric Administration/Economic Development Administration/National Hurricane Center)	X	X	X
Federal Emergency Management Agency (Region IX/Pacific Area Office)	X	X	-
National Weather Service (NWS)	X	X	X

* Required by Section 729 of WRDA 1986, as amended.
** USACE may investigate each of these three focus areas under various programs (see section 6.2); however, the ability to implement projects will vary depending on alignment with USACE primary mission areas of flood risk management, coastal storm risk management, ecosystem restoration, and navigation.

Partner and stakeholder involvement was a cornerstone for the development of the Guam WA. The study partner and stakeholders were invited and encouraged to participate throughout all stages of the planning process and report development. They were involved in the scoping and drafting of the shared vision statement below, which encompassed the perspectives of the stakeholders and was used as the basis for developing problems and measures. Partner concurrence with the shared vision statement was formalized and documented through the Shared Vision Milestone.

Shared Vision Statement
The Territory of Guam spans 212 square miles of island bordered by 78 miles of coastline in the western Pacific Ocean. Weather related hazards, including tropical cyclones[1], flooding, high surf, drought, and severe wind, are anticipated to intensify with climate change, with a predicted ½- to 1 ½ -foot rise in sea level by 2050[2]. Additionally, anthropogenic stressors, including wildfires, deforestation, introduction of invasive species, erosion, sedimentation, and water quality impacts harm the social, economic, and environmental fabric of life on the island and increase vulnerability to natural hazards. Reducing the consequences of these hazards necessitates a collaborative focus on resiliency among federal and territorial agencies and stakeholders. This Watershed Assessment is intended to serve as a strategic roadmap to inform future decisions and actions.

After receiving endorsement of the shared vision statement during the Shared Vision Milestone, the USACE team held a series of meetings targeted at agencies with interest and involvement in specific problem areas to assess the current and changing risks. Within these meetings, several questions were asked focusing on assessing the probability and consequences of problem categories and stressors. Stakeholders were also asked if potential solutions have been identified and what roadblocks may exist to solution implementation.

Appendix A – Interagency Engagement, contains the meeting agendas, take home points, and records of stakeholder inputs.

[1] Tropical cyclone is a generic term for a low-pressure system that forms over tropical waters. The terms tropical disturbance, tropical depression, tropical storm, and hurricane/typhoon describe the intensity of the tropical cyclone. Tropical cyclones with winds over 74 mph are designated as a typhoon in the western Pacific Ocean.

[2] The broad sea level rise range covers the low, intermediate, and high USACE scenarios.

2.2 Current Initiatives

The initiatives and goals described in Table 2-2 are the currently known reported planned actions and defined goals of both local and federal agencies throughout Guam that are taking place relative to the problems identified in this WA. The discussion provides a summary of the goals and actions taking place or planned. The agencies column shows which local agencies are involved with the decision making and implementation of the initiatives.

Table 2-2 *Current Initiatives and Goals*

Problem	Description	Discussion	Agencies
Tropical Storm, Coastal	Relocation of Infrastructure	Using 2019 Climate Vulnerability Assessment with help from utilities, government agencies, and private sector relocate 30% of critical infrastructure away from flood and low laying areas by 2025.	Continuing Care Retirement Communities (CCRC), Bureau of Statistic and Plans Guam (BSP), Port Authority of Guam (PAG), Guam Waterworks Authority (GWA), Guam Department of Public Works (DPW), Guam Memorial Hospital Authority (GMHA), Guam Department of Public health and Social Services (DPHSS), Guam Police Department (GPD), Guam Fire Department (GFD), Guam Department of Education (GDOE)
Tropical Cyclone, Coastal Hazards	Replace Building Materials	Update maps by 2024 to identify at-risk infrastructure to be replaced. Replace 30% of substandard buildings with concrete structures by 2030.	Guam Homeland Security (GHS), BSP
Water Supply	Stormwater Management Plan (SWMP)	Develop rules and regulations for SWMP to account for climate change effects; sea level rise, storm surge, and rainfall.	Guam Environmental Protection Agency (GEPA), DPW, Department of Land Management – Guam (DLM), Chamoru Land Trust Commission (CLTC), Mayors
Tropical Cyclone, Coastal Hazards	Building Code Update	Adopt the International Building Code (IBC) to strengthen structural requirements for resiliency against storms and earthquakes.	CCRC, DPW

Problem	Description	Discussion	Agencies
Coastal Hazards	Coastal Research	Coastal Atlas for Guam - identifying vulnerable infrastructure and establishing vulnerability index for priority planning.	GWA
Water Supply	Reduce Cesspools over NGLA	Pipeline construction and connection of properties within 200 feet of new lines, 5000 feet/year. Enforcement of existing statute requiring residents to connect to existing septic/cesspool properties that are within 200 feet of existing sewer lines.	GWA
Water Supply	Maintain EPA Drinking Standards	Periodic testing and monitoring of supply wells.	GWA, GEPA
Water Supply	Wastewater Discharge	Upgrade Northern and Hagåtña Wastewater Treatment Plants to meet secondary treatment standard for discharge of effluence into the ocean.	GWA
Water Supply	Aquifer Capability Prediction	Continue to support models that predict the capacity of the NGLA. Work with Water and Environmental Research Institute of the Western Pacific (WERI) and GWA develop a drought plan.	GWA and NGLA working groups
Water Supply	Watershed Master Plan Completion	By 2025, complete at least 3 Southern Guam watershed Master Plans. By 2030, complete the Southern Guam Master Plan. Steps to complete: 1) Review potential government of Guam properties that can be restored and conserved to build resilience 2) Review current policies and practices related to water management; 3) Develop integrated water management; 4) Organize focus groups to develop watershed masterplans; 5) have stakeholder meetings to identify the priority watersheds.	WERI, GEPA, USDA-FS, DAWR, Guam Fire; Mayors, SWCD, CLTC, DLM, DPW
Water Supply	Surface and Groundwater Management	Support best management practices (BMPs) that reduce contaminants that enter the aquifer and surface water sources; implement BMPs for wellhead protection; reduce illegal dumping especially around wells and sink holes.	WERI, GEPA, GWA, SWCD, CLTC, DLM, Mayor's
Water Supply	NGLA Protection	Develop an Island Wide Drought Response Plan in partnership with the Department of Defense, One Guam Water, and Wastewater Working Group.	GWA

Problem	Description	Discussion	Agencies
Water Supply	Aquifer Research	Pilot Climate Geographic Information System (GIS) Project - visual demonstration of existing conditions and different climate scenarios, within a predefined area, to understand the geography of climate and predict change. OTECH will use this pilot as a template for a Government of Guam GIS system, which would allow the Government of Guam to better understand climate change's effects on the surrounding geography, such as temperature changes, rainfall, stream flow, etc.	BSP
Water Supply	NGLA Protection	Water resource management programs to increase production capabilities, improve and identify additional sources of surface water to improve resiliency, reduce water loss in the distribution system, and provide for active management of well pumping rates for effective management of the aquifer.	GWA
Water Quality	Maintain GEPA water quality standards	To maintain GEPA water quality standards (WQS-designated uses, water quality criteria, and antidegradation requirements) for water bodies on Guam continued education, enforcement, and remediation must continue.	GEPA, GWA, U.S. Geological Survey (USGS), WERI
Habitat loss	Coral Reef Conservation Grant Program	An ongoing project that involves the long-term monitoring of a suite of coral reef ecosystem health parameters at high priority sites.	UoG-ML; BSP
Habitat Loss	Conservation Outreach	Decrease the number of fires per year and increase the number of watershed concepts in teachers lesson plans. Integrate USDA-FS's fire curriculum into education	Mayors, NPS, GNA, Schools, USFWS
Habitat Loss	Reforest 30% of Watersheds	By 2025, increase area of managed forests by 25% across local, federal, and privately held lands.	USDA, BSP, UoG, GEPA, TNC, GNA, GWA,
Habitat Loss	Coral Reef Resilience Strategy	Tool for adaptive, strategic and effective management of coral reefs; and a guide for funding projects designed to reach a common goal out to 2025.	USFWS, National Oceanic and Atmospheric Administration (NOAA), GEPA

Problem	Description	Discussion	Agencies
Habitat Loss	Place Valued Forest and Marine Areas Under Protection	Complete the Vulnerability Assessment on Natural Resources from the Impacts of Climate Change (VANRCC). Identify nature-based solutions, funding sources, and timelines. Identify additional areas for environmental protection, management, and conservation. Create metrics and ranking of vulnerability. Gain public support and begin legislation.	UoG, BSP
Habitat Loss	Decrease Wildfires 3% Annually	Update laws and regulations related to arson. Increase the number of conservation officers and enforcement officers. Increase personnel capacity for Forestry for reforestation/urban/rural forestry management, wildland firefighters, and investigators. Elevate Forestry personnel to 'public safety'. Improve community understanding of fires and support community wildfire protection plans. Provide funding to agencies that fight fires. Provide alternative methods for hunting.	USDA-FS, Guam Fire, Mayors
Reforestation	Approve State Forest System Plan	By 2022, establish Memorandums of Understanding (MOUs) with CHamoru Land Trust Commission (CLTC) for their properties; By 2024, create legislation to set aside undeveloped CLT properties under some level of conservation for forest health.	USDA, BSP, CLTC, DLM
Wildfire, Erosion	Watershed Restoration	Reforestation throughout southern watersheds for erosion control. Additional fire break maintenance, and debris clean up.	UoG, BSP, NOAA, Dept of Ag Forestry and Soil Resources

3 Resilience Planning Process

The USACE watershed planning process aims to provide a comprehensive and strategic evaluation and analysis that includes diverse political, geographic, physical, institutional, technical, and stakeholder considerations. To increase resilience to future tropical cyclone activity, a full range of water resources needs must be considered. Ecological impairments such as habitat loss can increase consequences of a typhoon. For example, loss of coral reef habitat may directly correlate to a reduction in the natural barrier to reduce storm surge. Likewise, upland deforestation can contribute to stream erosion and result in sedimentation in estuaries, increasing coastal storm risks to infrastructure. Unique water supply challenges and vulnerabilities may exist within a remote island environment, which, when further challenged by a tropical cyclone, could leave people without potable water for extensive periods of time.

To identify the full range of drivers and stressors that may contribute to increased risks associated with tropical cyclone activity, this watershed assessment considers all water resources needs, regardless of agency responsibilities, and develops a strategic roadmap to inform future investment decisions by multiple agencies, in coordination with local, territorial, and federal agencies.

USACE follows a six-step structured and iterative planning process as outlined in Engineering Regulation (ER) 1105-2-100, the “USACE Planning Guidance Notebook” and ER 1105-2-102 “Watershed Studies”.

The six-step USACE watershed planning process includes:

1. **Identify Problems and Opportunities** – Determine problems, needs and opportunities in the watershed by involving study partners, stakeholders, resource agencies, and the public.
2. **Inventory and Forecasting** – Prepare an inventory of relevant water and land resources, existing models, maps, and data. Examining anticipated future actions, assumptions and uncertainties, describe the most likely future scenarios.
3. **Identify and Screen Measures** – Develop management measures based on a feature or activity which addresses one or more of the planning objectives. Measures are then screened using any identified constraints, expert judgment, and specific screening criteria to focus on those that will meet the planning objective.
4. **Formulate Initial Array of Strategies** – Using the measures, provide a description of alternative approaches to address identified problems and needs, emphasizing alignment of actions of federal and local entities.
5. **Refine Initial Array and Evaluate Focused Array of Strategies** – Evaluate the alternative strategies, in consultation with study partners, to assess how effectively the strategies address the identified problems.
6. **Strategy Comparison and Selection** – Compare the strategies against one another, noting trade-offs between strategies, and select the best suited strategy for meeting the study goals and objectives.

The Guam WA is following the Watershed Studies Guidance outlined in ER 1105-2-102 “Watershed Studies””. This study process combined USACE traditional water resources planning, structured public participation, and collaborative systems modelling to work towards comprehensive and strategic evaluations and analyses. Figure 31 illustrates the planning process for this WA and how the six-step planning process was used to formulate recommendations and is carried forward through the report to illustrate steps followed throughout the planning process.

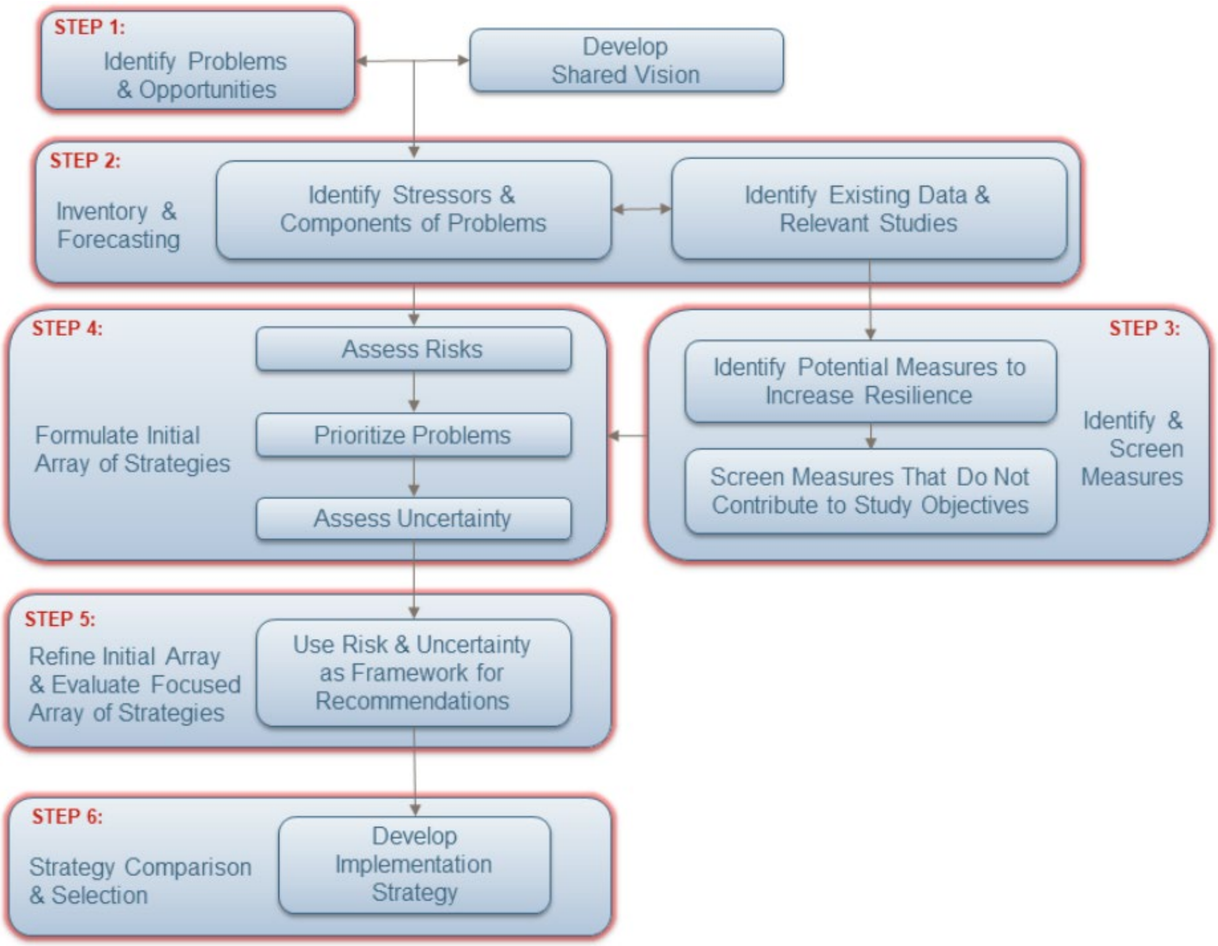
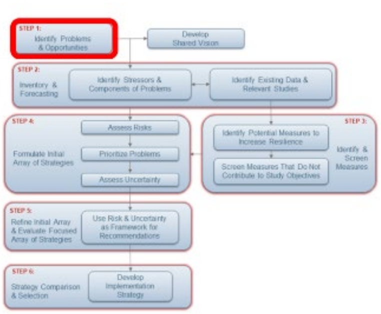


***Figure 3-1**. Guam WA Planning Process*

3.1 Problems



A wide range of problems stemming from both anthropogenic and weather-related drivers were identified within the study area. Anthropogenic drivers are those that derive from human activities, as opposed to those occurring in natural environments without human influences. While some hazards have impacts throughout Guam, many hazards affect northern and southern Guam differently due to the two distinct geological features of the two regions. Identified categories of problems include tropical cyclones, freshwater flooding, other coastal hazards, habitat loss, water supply, and tsunami.

Problems are listed in Table 3-1 through Table 3-6. Problems are in the first row; subsequent rows describe stressors. For the purposes of this WA, stressors are conditions or events that occur because of the primary hazard.

Table 3-1 *Problems Caused by Tropical Cyclones*

Tropical Cyclones: Tropical cyclone activity at or within proximity to the Territory of Guam can result in flooding, wind damage, impacts to power supply, and other social effects, such as effects to cultural resources and native communities. In particular:
Coastal flooding can cause inundation of coastal infrastructure including harbor facilities and roadways with storm surge commonly reaching 10-20 feet depths along the shoreline.
Loss of power supply can occur during and after tropical cyclone activity, sometimes continuing for months after the storm has passed, and can result in increased risk to life safety.
High winds can result in damages to structures and utilities throughout the territory.
The consequences of these tropical cyclone risks will be exacerbated by **sea level rise**.

Table 3-2 *Problems Related to Freshwater Flooding*

Freshwater Flooding: Heavy rainfall throughout the Territory of Guam can cause property damage and increase risk to life safety. In particular:
Flash flooding, which occurs frequently and can cause safety hazards, property damage, and ecologically destructive erosion, is of particular concern in southern Guam (due to streams with steep topography and presence of basaltic volcanic rocks with limited infiltration capacity), in addition to low lying areas and highly developed zones.
Riverine flooding, which generally occurs in the southern portion of Guam near the villages of Agat, Santa Rita, Hagåtña, Talofofo, Inarajan, Merizo, and Umatac; and some central locations, such as Maina and Chalan Pago, can result in life loss and property damage. Flooding may be exacerbated by rising sea levels causing increased backwater affects.
Erosion, due to the presence of erodible soils near the river systems of southern Guam, can result in impacts to utilities, property, and the environment.
Landslides/mudslides, which can occur in southern Guam due to the presence of erodible soils and steep slopes and are of particular concern where vegetation has been impacted by wildfires or other anthropogenic stressors, can result in impacts to utilities, property, and the environment.
Sedimentation, due to the presence of erodible soils and steep terrain primarily in southern Guam, can result in impacts to habitat as well as increased stream velocity and flows, which can exacerbate riverine flooding.

Table 3-3 *Problems Related to Coastal Hazards*

Other Coastal Hazards: Coastal areas throughout the Territory of Guam are at risk of damage to infrastructure due to naturally occurring and accelerated coastal processes. In particular:
Saltwater spray damages the crops and corrodes infrastructure.
Loss of living breakwater (corals, shoreline vegetation, and near shore vegetation), which serves as natural infrastructure to minimize wave intensity, results in increased shoreline erosion.
Coastal erosion, which can occur throughout the island, with a more frequent occurrence on the western coast due to tropical cyclones and monsoon surges that produce high waves, results in increased risk to coastal infrastructure.

Sea level rise, which will exacerbate the consequences of coastal infrastructure risks.

Table 3-4 *Problems Related to Habitat Loss*

Habitat Loss: Anthropogenic activities, land use, and resource management practices contribute to the loss of habitat and biodiversity in coastal, upland, and riverine areas. In particular:
Loss of fish habitat due to **coral die-off** reduces fish populations, which can lead to food insecurity on the island.
Sedimentation in streams and near shore coastal waters impacts habitat.
Coral reef degradation (e.g., coral bleaching, pollution, and sedimentation) occurs in the shallow nearshore waters surrounding Guam, which hosts approximately 42 mi^2 of coral reef habitat.
Nutrient loading, primarily from agricultural runoff and septic/cesspool discharge, causes algal blooms which can impact coral reefs and associated habitat.
Wildfires, which result from drought and anthropogenic sources, lead to deforestation, sedimentation, and loss of habitat.
Invasive species, which threaten coral reefs and other marine and inland habitats, result from anthropogenic stressors and are exacerbated by climate change.

Table 3-5 *Problems Relating to Water Supply*

Water Supply: The water supply system throughout Guam is vulnerable to naturally occurring and anthropogenic stressors. In particular:
Nutrient loading, primarily from agricultural runoff and septic/cesspool discharge, causes algal blooms and impacts water quality.
Sedimentation in streams and near shore coastal waters impacts water quality.
Drought leads to saltwater intrusion and reduction of water quality and supply.
Over-use of Northern Guam Lens Aquifer leads to saltwater intrusion and reduction of water quality and supply, which may be exacerbated by future elevated sea levels.
Pollution near water supply wells results from wide usage of septic tanks, illegal dumping, and siting of hazardous land use near water supply production wells, which reduces water quality.
Storm water management issues including non-conforming or non-existent storm water management infrastructure causes flooding and pollution, sending untreated runoff to near shore waters.

Table 3-6 *Problems Related to Tsunamis*

Tsunami: Coastal, low-lying, and culturally significant regions of Guam are at risk from tsunami. In particular:
Tsunami waves, resulting from seismic activity, volcanoes, or submarine landslides, can cause life safety risks and inundation of the coastal and low-lying areas of Guam.

3.2 Opportunities

Opportunities are future desirable conditions that could coincide with the solutions to the identified problems in the study area. For this WA, opportunities were identified to inform the implementation strategy for recommendations. As such, this WA provides opportunities throughout Guam to:

- Leverage and develop collaborative interagency partnerships to address priorities and reduce data gaps for multi-hazard risk management.
- Improve communication and foster relationships among those working to build resiliency.
- Connect government and local leaders with funding opportunities for implementation of measures to reduce risk.

3.3 Planning Objectives

The goal of this WA is *to increase Guam's resilience to weather related hazards and reduce the effects of anthropogenic stressors through a focus on nature-based solutions where appropriate*. To achieve that goal, the following objectives are identified, consistent with Presidential EO 13653, Preparing the U.S. for Impacts of Climate Change (Figure 3-2):

- Improve the ability of Guam to anticipate, prepare for, and adapt to changing conditions.
- Improve the ability of Guam to withstand, respond to, and recover rapidly from disruptions.

These objectives are applied and evaluated over a 50-year planning horizon, also referred to as the period of analysis, which spans from 2022 to 2072 for this WA.

RESILIENCE means "the ability to **anticipate, prepare for,** and **adapt** to **changing conditions** and **withstand**, respond to, and **recover** from **disruptions**."
Presidential Executive Order 13653, Preparing the U.S. for Impacts of Climate Change (NOV 2013)

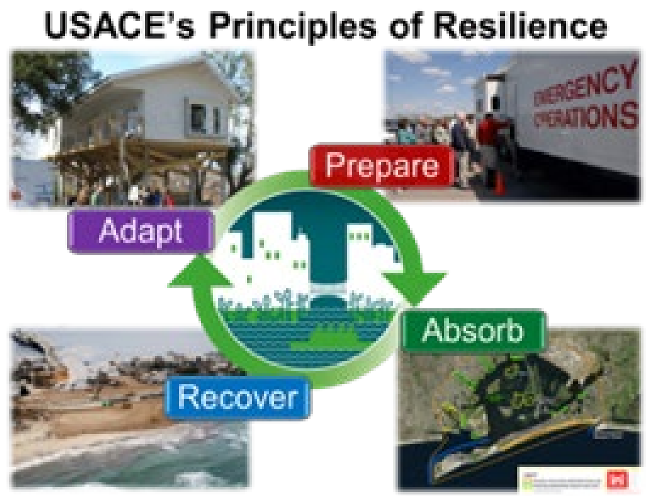
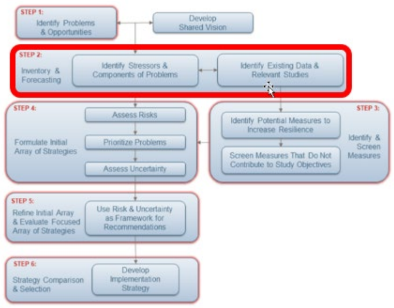


Figure 3-2. *USACE's Principles of Resilience*

3.4 Planning Constraints and Considerations

No planning constraints were identified for this Watershed Assessment; however, one planning consideration was identified regarding military land use. All major military installations are required to have a Master Plan. Unified Facilities Criteria 2-100-01 (Installation Master Planning) describes minimum requirements for master planning processes and products to ensure effective long-term development and management of resources. Energy and climate resilience, military installation resilience, and climate change effects are key components of the installation planning process. Since the military planning process is already comprehensive, this Watershed Assessment focuses on the Territory of Guam outside of the military land.

4 Inventory and Forecasting



The existing conditions describe the current conditions of the study area, and the future condition describes the most likely condition expected to exist in the future if no additional actions are taken. Conditions are projected 50-years in the future and will provide a baseline for evaluating and comparing potential plans or management options. The future without-project condition described below is the most likely condition expected to exist in the future if no additional actions are taken.

4.1 Land Use

The island of Guam is mostly rural. Most of the population lives on the coralline limestone plateaus of the north, with political and economic activity centered in the central and northern regions. The rugged geography of the south largely limits settlement to rural coastal areas. About 2% of all land in Guam is used for agriculture. Watermelons and vegetables account for 48% of total sales. Most of the island's agricultural land is in the south, although small pockets of agriculture are scattered across the north and central plains, as well as large areas of designated recreational/open space. Farming consists of poultry, hogs, cattle, goats, beans, cucumbers, eggplant, tomatoes, bananas, melon, mango, kangkong, peppers, guava, sweet potato, yams, cassava, and taro. The remainder of the island is either in use for low-density residential development, designated open space, or undeveloped.

The federal government owns approximately 32% of the land on Guam, primarily for military uses. The largest concentrations of federal land ownership are at the northern tip of the island (Anderson Air Force Base) and on the southwest coast (U.S. Naval Base Guam and Ordinance Annex). It is estimated that the Government of Guam owns an additional 20%, though data on the exact location and extent of Government of Guam land are incomplete. Less than half of the island is currently available for private development. Munitions and explosives of concern (MEC) including unexploded ordinances (UXOs) are present in Guam. Land use maps and planning publications may be found in Appendix D – Environmental Analysis.

Most commercial and industrial uses, including tourist-oriented development are concentrated in the area surrounding districts of Hagåtña and Tamuning. Hagåtña is the capital city and serves as a base for industry, commerce, and government. Many of the island's public sector jobs are located here, and land use consists of a commercial core surrounded by residential development, as well as some federally owned land. Tumon Bay, located within the municipality of Tamuning, is the center of Guam's tourist industry. Tumon has many hotels, condominiums, and tourist-oriented businesses including restaurants and entertainment. This area is the most densely developed and urban portion of the island.

The northern municipalities of Barrigada, Dededo, Mangilao, Tamuning, and Yigo comprise 66% of Guam's population. These areas have seen the greatest residential growth in recent years and are predicted to absorb much of Guam's projected future population growth. The United Nations anticipates a 10% increase by 2070 to 191,000 persons.

4.2 Environmental

4.2.1 Climate Conditions, Variability, and Change

Guam's climate is strongly tied to ENSO fluctuations. During El Niño years, for example, easterly trade winds are weakened which allows warmer western Pacific waters and higher sea levels to migrate eastward. This reduces sea levels in the western Pacific, reduces the warm oceanic pool, and is typically followed by drought. El Niño has a wet and dry phase in Guam which starts with higher rainfall and tropical storm/typhoon activity, then migrates into drought later in the cycle. During El Niño events, strong typhoons can develop southwest of Hawaii and travel to Guam, allowing the storm to develop strength (Guam Homeland Security, 2019). El Niño events are projected to intensify in the Pacific due to climate change (NOAA, 2018), (Grecni, et al. 2020). Figure 4-1 illustrates the three phases of ENSO: neutral, El Niño (warm ocean temperatures), and La Niña (cooler ocean temperatures) climate conditions.

ENSO cycles as well as tropical storm activity can vary in both duration and frequency, which disrupts normal rainfall patterns. As a result, annual precipitation under ENSO cycles compared to normal conditions are difficult to quantify. However, climate change, including increased oceanic and atmospheric temperatures and concentrations of carbon dioxide, is expected to increase rainfall intensity, droughts, and storms (IPCC, 2019). The average maximum temperatures from 1991 to 2020 (known as NOAA Normals) reflect a 4.8° F increase. Table 4-1 summarizes base climate conditions and variation for Guam using data from 1991 to 2021.

Table 4-1 *Guam Climate Conditions*

Average annual rainfall	98.1 inches Min: 80 inches (lowland); Max: 100 inches (mountain)
Climate type	Tropical maritime
Wet season	July - December
Average temperature	81.7°F; min 76.3°F; max 87.2°F; variation: 5°F
Data source: NOAA NOWDATA	

Climate preparedness and resilience activities are considered and recognized in all USACE studies to ensure reliable project performance due to changing future climatic conditions. Changing climatic conditions could result in changes to storm intensity, frequency, and duration which may potentially have wide ranging effects to USACE projects. Coastal effects include increased shoreline erosion and the associated increased coastal storm risk, and increased frequency of overtopping for coastal levees. Increased rainfall intensity/duration could lead to inland hydraulic effects such as altered channel sedimentation that can increase flood elevations, increased reservoir sedimentation that reduces storage for flood control and water supply, further leading to an inability to provide necessary water pumping capacity.

The engineering analyses, consistent with ER 1100-2-8162 (Incorporating Sea level Changes in Civil Works Programs) and Engineering and Construction Bulletin 2018-14 (Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil W8162orks Studies, Designs, And Projects), describe existing climatic conditions, and describe and reference some expected future change to specific coastal and hydraulic baselines. These changes in baseline conditions are based on published information and are not determined in this study and are included for reference only. However, since no specific projects are recommended in this report due to the intent and focus of watershed assessments, specific and direct effects due to climate change are not quantified. More information about the existing and future climate conditions can be found in Appendix C – Engineering Analysis.

Future projections of climate change impacts to coral reef environments indicate that a shallow depth range, in combination with its other biological, demographic, and spatial characteristics, contributes to a risk of extinction within the foreseeable future for coral species. The Environmental Analysis, Appendix D contains more information on the effects of climate change on ocean chemistry and species.

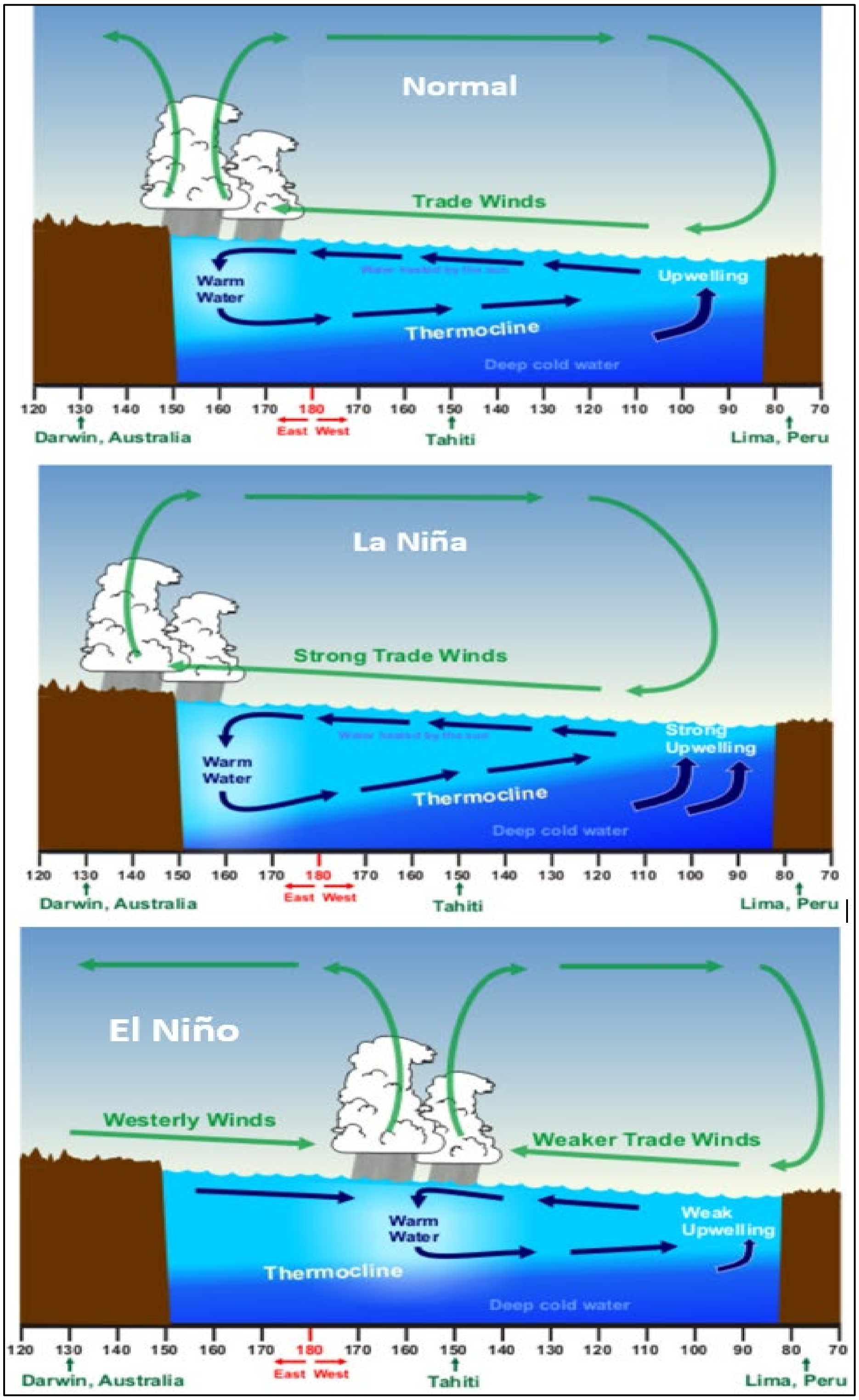


***Figure 4-1**. ENSO Fluctuations in the Pacific Viewed from the Equator: Neutral, El Niño, and La Niña*

4.2.2 Sea Level Change

Subsidence adjusted relative sea level change (RSLC) was calculated for Guam and is shown in Figure 4-2. NOAA recommends use of the intermediate or high curves in planning, and this study relies on the high curve (shown in red), which is more in line with territory and other agency projections for SLR. The USACE Sea Level Change (SLC) Calculator provides a way to visualize the USACE and other authoritative sea level riSse (SLR) scenarios for any tide gauge that is part of the NOAA National Water Level Observation Network. A 3-foot rise in sea level is projected by the year 2070, and a 5.3-foot rise by the end of the century, based on the USACE high curve. The USACE high curve roughly corresponds to the NOAA intermediate-high curve. Engineering analysis utilized 100-year forecast period with an estimated high RSLC of 7.2ft (Appendix C, Fig. 31) to accommodate future high tide, storm surge, wave, and wave run up conditions.

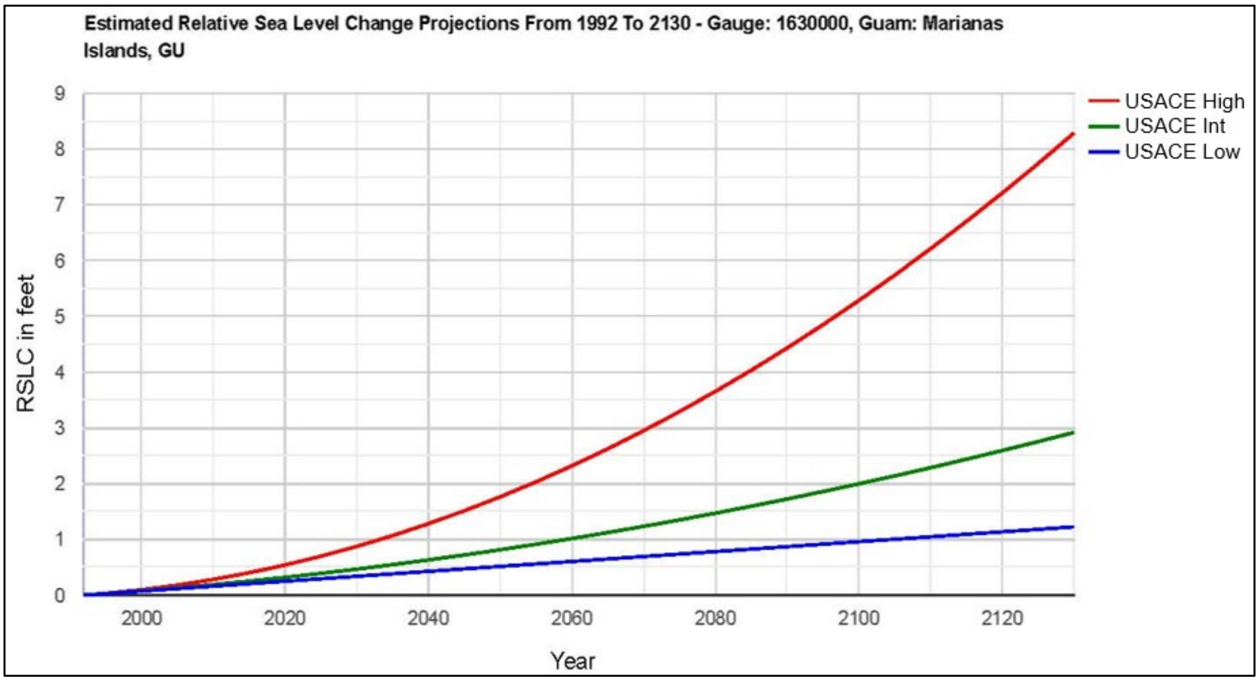


Figure 4-2. *Projected RSLC for Guam*

The future of climate variability and greenhouse gas emission projections are based on human activity. The Intergovernmental Panel on Climate change (IPCC) has high confidence that global mean sea level will continue to rise for centuries. SLR creates higher water surface elevation profiles affecting costal infrastructure, ports, estuaries, and adversely affects water supply by increasing saltwater intrusion in the NGLA.

4.2.3 Ecology

A major factor that determines the current condition of terrestrial environments of Guam is natural and anthropogenic disturbance. Uprooting and breaking of trees by wind and defoliation by typhoons periodically damage forests and keep vegetation patterns in a state of flux due to changing light, moisture, and nutrient levels. Erosion and associated sedimentation are the primary threats to Guam's terrestrial and aquatic environments, and to human land uses. Human activities that reduce vegetation cover increase erosion. Natural processes and geography can also contribute to erosion through intense rain, steep terrain, narrow river cross sections, changes in river direction, areas of existing bank erosion, and mass wasting. Climate change and associated weather patterns may exacerbate the environmental risks associated with erosion and sedimentation. Anthropogenic disturbance has more permanent effects. Terrestrial environments are extremely vulnerable to clearing for construction and expansion of residential, commercial, and military facilities. Guam's natural land cover is losing native forests and being replaced by disturbed vegetation, managed landscapes, and urban areas.

Guam has very few freshwater resources. The freshwater environments of Guam can be classified as wetlands, lentic environments (ponds and artificial impoundments), lotic environments (streams and rivers), and groundwater. The distribution of freshwater in Guam is controlled by local geology and topography. Surface freshwaters are common in the south, where the land is dominated by volcanic bedrock and clays. Surface water is rare in the north, where the terrain is made of highly porous limestone. Therefore, southern Guam has numerous rivers but limited groundwater areas, whereas northern Guam has no rivers, but is underlain by groundwater.

Wetlands are limited to freshwater marshes on clayey limestone and limited swamp vegetation around Pago River. In the subsurface, the aquifer represents a complex freshwater ecosystem in which different habitats can be recognized: freshwater zone, brackish water zone, salty groundwater beneath the aquifer, large water-saturated cavities, small water-saturated interstices, open-surface freshwater pools and streams inside caves, and coastal springs (Digital Atlas of Guam).

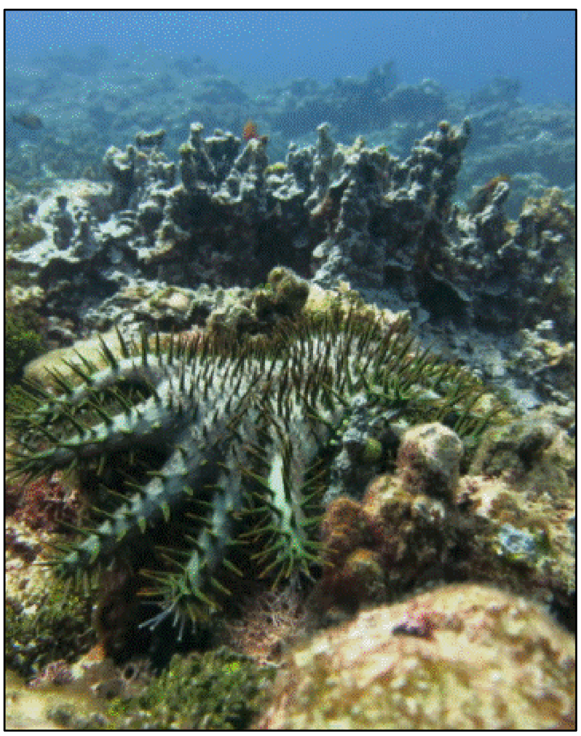


Figure 4-3. *Crown of Thorns Starfish (NOAA Fisheries)*

Guam is home to one of the most species-rich marine ecosystems, with over 5,100 marine species in its coastal waters. This includes more than 1,000 nearshore fish species and over 400 species of hard corals (Paulay, 2003; Porter et al., 2005). Guam's corals benefit from the proximity to the Indo-Pacific center of coral reef biodiversity (Veron, 2000). Coral reefs are important for protection from ocean storm surges and coastal erosion, tourism, fishing, habitat for thousands of species, nursery grounds, marine pharmaceutical research, and recreation. The condition of Guam's coral reefs varies considerably.

Geology, human population density, degree of coastal development, levels and types of marine resource uses, oceanic circulation patterns, and frequency of natural disturbances (e.g., storms and earthquakes) impact the health of Guam's reefs and will likely be exacerbated in the future due to climate change and population growth. The health of many coral reefs in Guam has declined over the last 40 years. However, in the past, Guam's coral reefs have recovered after drastic declines. For example, a major Crown of Thorn Starfish (COTS) (Figure 4-3) outbreak in 1973 reduced coral cover in some areas from 50-60% down to less than 1%. Twelve years later, the coral cover recovered to 60% in most of those places (Burdick et al., 2008). The 2018 status report for Guam reported COTS are still a major threat to reefs and future outbreaks of COTS are likely to continue (NOAA CORIS, 2018).

Due to the economic link between Guam's coral reefs and tourism, recreational fishing, subsistence fishing, and shoreline protection, the degradation and loss of coral reefs have been linked to the lowering of the quality of life on Guam. The Atlas of Ocean Wealth, produced by The Nature Conservancy (TNC) in 2016, appraised Guam's coral reef resources from reef-based tourism alone as $323 million U.S. Dollars per year (Spalding et al. 2016).

In addition to threatened corals, there are also 32 federally listed threatened or endangered birds, plants, mammals, reptiles and snails. Terrestrial environments support a diverse flora of over 600 species of plants, including more than 100 species of trees. Their distribution is influenced by sharply contrasting soil types between predominantly limestone terrain in northern Guam and predominantly volcanic terrain in southern Guam. The Guam rail, ko'ko' in Chamorro, is the national bird (Figure 4-4) The Guam rail was almost wiped out permanently by the invasive brown tree snake. In 2019 a successful reintroduction of the rail into the wild through a breeding program changed the rail's listing from extinct in the wild to critically endangered.

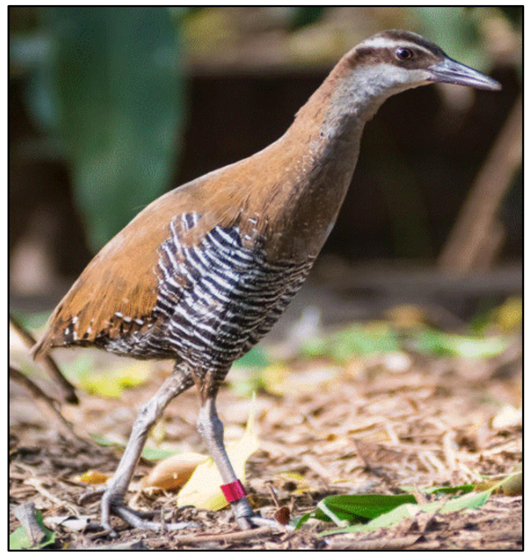


Figure 4-4. *Guam Rail - ko'ko' (photo credit Jamie Greene)*

See Appendix D – Environmental Analysis, for more details and maps of marine ecosystems with important benthic communities such as macroalgae, seagrasses, sponges, and other invertebrates found in Guam.

4.2.4 Water Supply

The NGLA (Figure 4-5), which supplies about 80% of Guam's population with potable water, is the limestone bedrock that underlies the entire northern half of Guam and contains a large permanent body of fresh groundwater. This lens-shaped aquifer is the thickest in the island's interior and thinnest along the island's perimeter. Because fresh water is less dense than seawater, this fresh groundwater lens floats upon saltwater that permeates the bedrock beneath it. Under future conditions, the NGLA is likely to be threatened by saltwater intrusion as ocean levels rise and pumping from supply wells increases in drought years (Grecni, et al. 2020). Pumping may further increase if the anticipated 10% population increase by 2070 is realized.

In southern Guam, the majority of freshwater comes either from streamflow or wells that withdraw water from near the banks of the island's roughly 100 streams. Most rainfall in volcanic areas of southern Guam enters directly to stream valleys. Island streams range from less than 1 mile to more than 3 miles long. They flow in deeply incised and V-shaped valleys in highland areas, or wide and flat-bottomed valleys in coastal lowlands. Parts of southern Guam that are covered by limestone contain accessible groundwater bodies. Areas where limestone is surrounded by volcanic terrain store perched groundwater, which sits within permeable limestone outcrops on top of volcanic rocks of low permeability. These perched systems are sources of main freshwater springs in southern Guam. Increases in the population in southern

Guam will result in increased demand on the water delivery system, as well as increased environmental stressors on the quality of water available.

Detailed maps with the areas water supply may be found in Appendix D – Environmental Analysis.

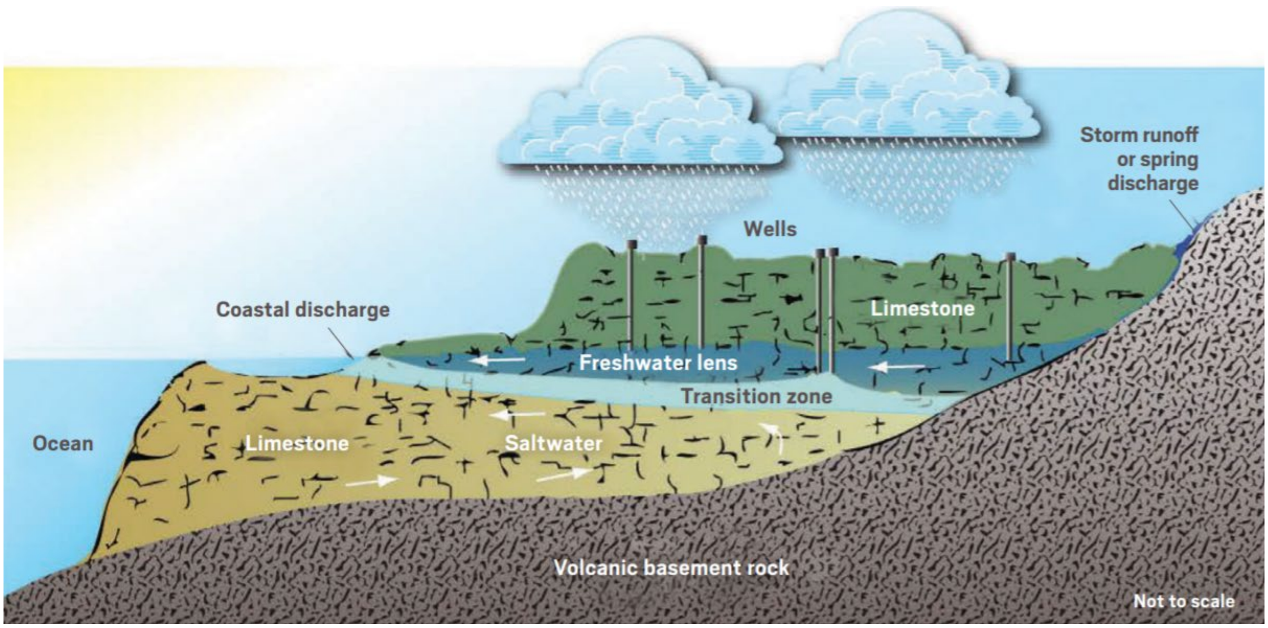


Figure 4-5. *Schematic cross-section of the Northern Guam Lens Aquifer. Source: Pacific Island Regional Climate Assessment. 2020.*

4.3 Flooding

4.3.1 Freshwater Flooding

Guam is vulnerable to riverine and flash flooding, which can result from local and regional rainfall events, as well as those driven by tropical cyclones. Since 1950, 70 riverine flooding events have been recorded on Guam with an estimated total of $1.5 M in damages. Most floods are connected to tropical storms and cyclones; however, large storms tend to create conditions such as saturated soils and high groundwater tables. Once these saturated conditions are present, even light rainfall can result in flooding. For example, in November 2001, rainfall of only 0.87 inches over a 6-hour period caused flooding 2 ft deep at the Guam Waterworks pump station in Upper Tumon. Though projected average rainfall decreases will lead to reduced streamflow (USGS, 2019), (Grecni et al., 2020), (Keener et al., 2015) precipitation is projected to increase 1-15% during tropical cyclone events (Grecni et al., 2020), (PIRCA, 2020).

4.3.2 Coastal Flooding

Coastal flooding is focused along the coast and low-lying coastal communities. Since 1950, high surf and storm surge caused 35 fatalities, 41 injuries (NOAA, 2018), and resulted in over $2 billion in damages when accounting for additional damages that occur during coastal flooding events, such as wind and riverine flooding from tropical cyclones (Guam Homeland Security, 2019). The population often focuses their communication and preparation on local storm events and can be caught off guard when distant storms or ocean circulation produce coastal storm surge under blue skies. While typhoons are arguably the source of the largest flood events, more fatalities occur from high surf. Critical infrastructure such as roads, shelters, hotels, businesses, and harbors are in these low-lying areas which drives consequences.

Based on the USACE high rate of sea level rise (Fig. 4-2), sea levels are projected to increase by 3.0 ft in 2072 and 7.2 ft by 2122. RSLC decreases the ability of the surrounding reefs to reduce storm wave run-up, overtopping, and erosion. The higher future water levels will have a direct effect on coastal infrastructure and exacerbate other coastal stressors (Sections 5.2.1, 5.2.2, 5.2.2.2, 5.2.2.3, 5.2.2.4). RSLC is projected to have the greatest effects on the southern and western portions of the island (Figs. 4-6 and 4-7). The coastal road from Tongan Creek to Inarajan Bay along the southern end of the island will be affected (Appendix C). Along the western side of the island the deep-water port in Apra Harbor and coastal road from Apra Harbor to Apurguan will likely be affected (Appendix C). Along the eastern side Talofoflo Bay, Pago Bay, and the Ylig River crossing are at risk of inundation. Due to the mountainous topography of southern Guam inundation of these roads will prevent people from traversing the island (Section 5.2.2.1).

A vulnerability assessment of built infrastructure near coastal bays under different sea level rise scenarios was carried out by the University of Guam. Table 4-2 displays the percentage of infrastructure within each municipality under a three-foot SLR scenario. Under a three-foot rise scenario 73% of infrastructure in the south and 27% of infrastructure in central Guam will be affected. Cumulatively this comprises 58% of all island infrastructure (King et al., 2020).

Table 4-2 *Percentage of infrastructure impacted within each municipality under a three-foot SLR scenario. (Table from University of Guam)*

Village	Streets (feet)	Highways (feet)	Bridges	Buildings	GovGuam buildings	Power lines (feet)	Power substations	Water lines (feet)	Water pump stations	Production wells	Sewer lines (feet)	Sewage pump stations	Sewage treatment plants
Agana Heights	0	0	0	0	0	0	0	0	0	0	0	0	0
Agat	4.8	1.5	0	9.4	0	9.5	0	4.9	0	0	7.5	0	0
Asan	1.4	2.8	0	3.5	0	0.43	0	4.1	0	0	2.8	0	0
Barrigada	0	0	0	0	0	0	0	0	0	0	0	0	0
Chalan Pago Ordot	0.17	0	0	0	0	5.6	0	0	0	0	28	0	0
Dededo	0	0	0	0	0	0	0	0	0	0	4.6	0	0
Hagatna	2.1	5.5	0	8.2	0	4.1	0	5.4	0	0	5.8	0	0
Inarajan	5.4	12	60	9.4	0	6.9	0	11	0	0	5.5	0	0
Mangilao	0	0	0	0	0	0	0	0	0	0	0	0	0
Merizo	30	66	20	27	0	26	0	39	0	0	11	100	0
Mongmong Toto Maite	0	0	0	0	0	0	0	0	0	0	0	0	0
Piti	28	0	0	28	0	44	0	30	0	0	0	0	0
Santa Rita	19	0	0	11	0	0.54	0	0	0	0	2.1	0	0
Sinajana	0	0	0	0	0	0	0	0	0	0	0	0	0
Talofofo	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamuning	0.21	0	0	2.4	0	1	0	0	0	0	28	0	0
Umatac	1.1	2.8	20	1.2	0	0.61	0	2.3	0	0	4.7	0	0
Yigo	3.0	0	0	0	0	0	0	0	0	0	0	0	0
Yona	4.9	10	0	0	0	1.6	0	2.6	0	0	0	0	0
Total	**100**	**100**	**100**	**100**	**0**	**100**	**0**	**100**	**0**	**0**	**100**	**100**	**0**

4.4 Hazardous Events

4.4.1 Tropical Cyclones

On average, three tropical storms and one typhoon pass within 180 miles of Guam each year and are the major driver of coastal storm surge flooding (Guam Homeland Security, 2019). Guam has experienced 59 tropical storms and typhoons between 1950 and 2019. The highest rainfall intensity recorded in Guam was 7.22 inches in one hour during Typhoon Pongsona in 2002 (Guam Homeland Security, 2019). Typhoon Pamela in 1976 dropped 27 inches of rainfall in 24 hours. Although typhoon activity is increased during El Niño, they can occur at any time of the year and their strength is correlated to their path and time of development.

USACE sea level change guidance, ER 1100-2-8162 (Incorporating Sea level Changes in Civil Works Programs), states:

> "*Concerning the projected future effects of climate change on Tropical Cyclone (TC) activity in all global basins (including the Eastern and Central north Pacific), the World Meteorological Organization (WMO) TC Expert Team [Knutson et al., 2010] concluded, based on atmospheric theory and high-resolution models, that by the late 21st century the number of tropical cyclones could remain at current levels or decrease by up to one-third; that average TC intensity could increase by up to 10%; and that near-storm (~50mi radius) rainfall rates could increase by ~20%.*"

The fifth assessment by the Intergovernmental Panel on Climate Change (IPCC AR%, 2014) similarly states a low confidence in any long-term increases in tropical cyclone activity, and global mean tropical cyclone wind speed and precipitation rates will likely increase (Collins et al, 2019).

The projections of potential increased intensity and rainfall rates are echoed in future conditions modeling completed by NOAA. Specifically, higher ocean temperatures are a driver for typhoon intensity and duration, with tropical cyclone windspeed increases of about 1-10% and a tropical cyclone precipitation rate increase of about 1-15% expected for a 3.6˚ F temperature increase (2˚ C) (NOAA, 2013). NOAA estimates that storm severity has increased by 9.3% and is projected to increase by an additional 10.9% (NOAA/University Princeton, 2018).

Extended storm duration produces heavier rainfall volumes and extended wind and salt spray damage. This creates more frequent inundation and damage to property and infrastructure, increases coastal erosion, and presents a sheltering and emergency supply challenge given the limited availability of safe housing. Longer duration storms mean longer periods without power and water. Adding SLR to present coastal flooding conditions will inundate areas and roads that were once designated as community safe zones.

Figure 4.6 illustrates the probable storm surge under existing and projected future conditions for central Guam. Abrupt elevation changes from Guam's bluffs limit the extent that storm surge can travel inland, thus reducing the spatial extent of flooding. Most low coastal zones experience similar inundation footprints from tidal surges and typhoons, but with increased depths.

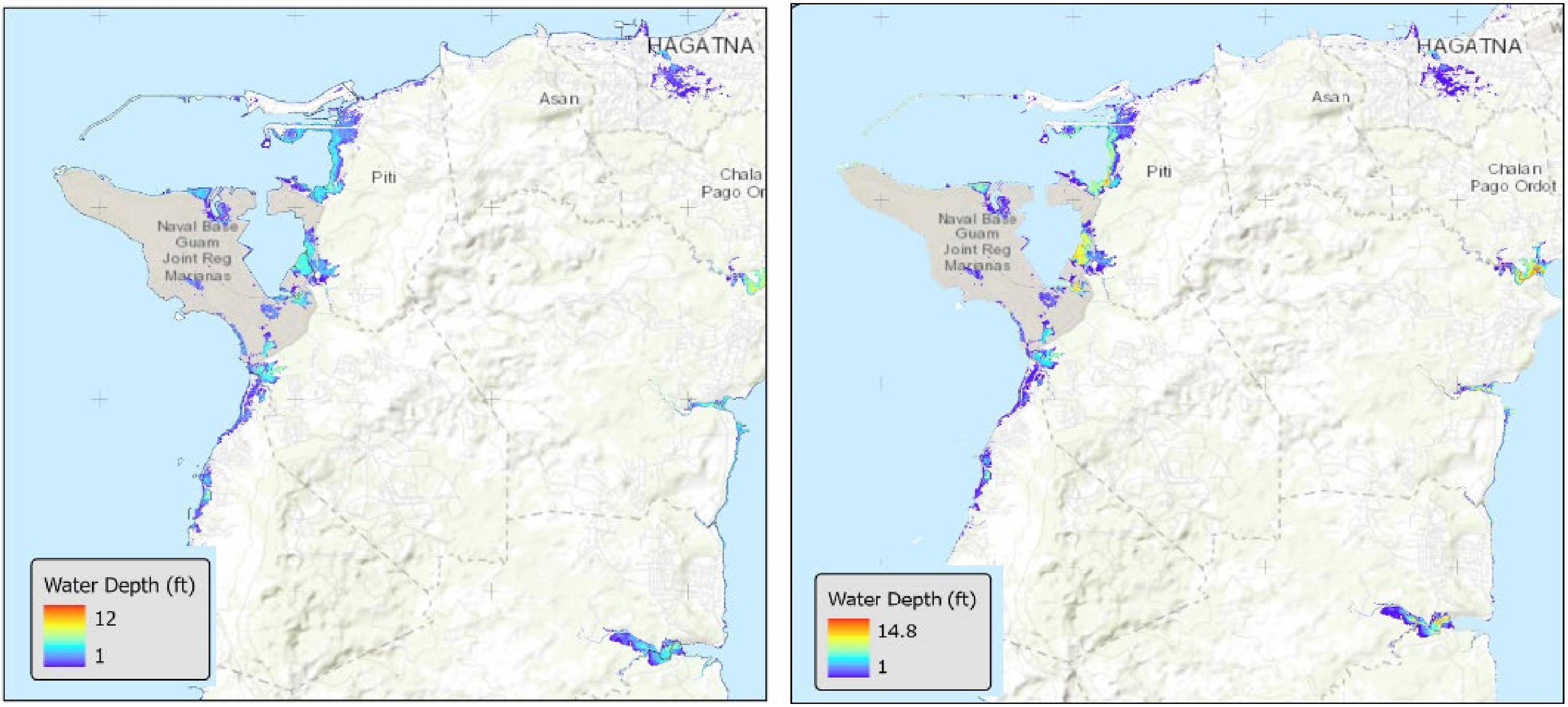


Figure 4-6. *Central Guam, Existing (left) and 2070 FWOP (right) Typhoon Inundation Conditions – (HURREVAC Composite of MEOWs1) [ESRI]*

[1]A probabilistic storm surge was estimated utilizing NOAA (NOAA, 2009) Sea, Lake, and Overland Surges from Hurricanes (SLOSH) modeling and near shore wave "Fast Wave" modeling (SLOSH-FW), where inundation is referenced as a "maximum envelope of water" (MEOW). NOAA typically processes these runs into a combined probabilistic product called a "maximum of the MEOWs" (MOM). The MOM product for Guam was not processed at the time of this assessment, therefore an approximation was created by adding all available MEOW inundation maps into a composite of MEOWs via GIS (downloaded from FEMA HURREVAC.com). According to the NHC, a composite will vary slightly from a MOM product within a slight delta.

4.4.2 Tsunami

Despite the infrequent occurrence of tsunamis, many U.S. coastal communities and Territories remain exposed, and the consequences are extremely high. When they occur, people may have only minutes to hours to respond and reach a safe location. Tsunamis can be caused by earthquakes, volcanoes, sub-marine landslides, seamount collapse, and asteroid strike.

Over the last 161 years, approximately six tsunami events have been confirmed on Guam (NOAA NCEI, 2018). A 7.5 magnitude earthquake in 1849 resulted in 22-foot waves at Agat; coastal inundation spread a quarter mile inland at Umatac Bay, flooded villages, destroyed homes and bridges, caused extensive sand boils, and resulted in one fatality near the Talafofo River. In 1993, a tsunami caused by an 8.1 magnitude earthquake in the Mariana Trench delivered wave heights up to 8 feet and caused over $200M in damages. In this event, the water level in Apra Harbor increased slightly; however, individual accounts note the water rising to chest level within 10 minutes at approximately 15 yards from the shoreline in other locations.

4.4.3 Wildfires

Wildfires on Guam are almost all human caused. Fires are set to clear vegetation and drive pigs and deer into open spaces. Farmers may burn fields for clearing, and homeowners will burn to create firebreaks around their residences. Anthropogenic fires burn approximately 10% of the island's vegetation each year and have resulted in approximately $250,000 in recorded damages, however the dollar value of damages does not represent all consequences (Guam Homeland Security, 2019). Topography, fuel, and weather contribute significantly to wildland fire behavior and can be used to identify wildland fire hazard areas.

Wildfires may increase the potential for landslides, degrade ecosystems, cause threats to human safety, cause erosion and sedimentation into terrestrial and aquatic environments, destroy infrastructure, threaten food security, and promote the spread of opportunistic non-native or invasive vegetation species. In addition to stripping the land of vegetation and destroying forest resources, intense fires can harm the soil, waterways, and the land itself. Soil exposed to intense heat may lose its capability to absorb moisture and support life. Exposed soils erode quickly and enhance siltation of rivers and streams, thereby enhancing flood potential, harming aquatic life, and degrading water quality. Lands stripped of vegetation are also subject to increased debris flow hazards. The indirect effects of wildland fires in Guam can be catastrophic. Fires are not a natural occurrence on the island, which means that the native ecosystem is poorly adapted to burning. More information regarding Wildfires may be found in Appendix D – Environmental Analysis.

4.4.4 People and Structures at Risk

The economic analysis for the WA focuses on direct, event-based economic damages to structures due to flooding in an existing and future scenario that accounts for RSLC using the existing coastal flooding inundation and RSLC data discussed in section 4.2.2 and in more detail within Engineering Appendix C. USACE Institute of Water Resources, Risk Management Center's LifeSim 2.0.1 model (LifeSim) was the analytical tool used to estimate structure damages, road inundation, and areas with population at risk (PAR). Additional details of methodology and LifeSim analysis can be found in Appendix B – Economics and LifeSIM.

The assessment is meant to be a screening level analysis to broadly show the changes to economic damages and rough order of magnitude PAR estimates due to RSLC. Essentially, the goal is to show changes, and not exact results for tests of feasibility. Since the base and future structure inventories and populations will be held constant, the change in damages and PAR can be attributed solely to estimated SLR.

Overall, Guam experiences very large increases of consequences in the future scenario represented by a 212% increase in structure damage values. Unfortunately, due to data limitations in this effort, increases in PAR and number of structures impacted could not be estimated. However, using structure damages as an indicator of what areas see an increased depth, the assumption is made that these areas' PAR will face higher depths of inundation in the future, due to RSLC. Agat and Merizo are the villages that experience the most PAR under the existing conditions (Table 4-3). These villages also see large increases in structure damages from the existing to future scenarios leading to the assumption that the PAR will become greater in the future as well. Figure 4-7 visualizes the exposed PAR, which is the PAR that physically experiences flood depths, not the broader PAR which is the population that is located within the extent of flooding without reference to flood depths. Exposed PAR is a more detailed value, and due to the limitations of the model, carries a higher level of uncertainty than PAR.

Table 4-3 *Guam Population at Risk under Existing Scenario*

Village/County	PAR[1]
Agat	3,253
Asan	1
Chalan Pago-Ordot	48
Hagåtña	3
Inarajan	216
Merizo	911
Piti	124
Tamuning	9
Umatac	32
Yona	3

[1]Estimates of PAR are rough order of magnitude values and should not be used beyond screening level analysis.

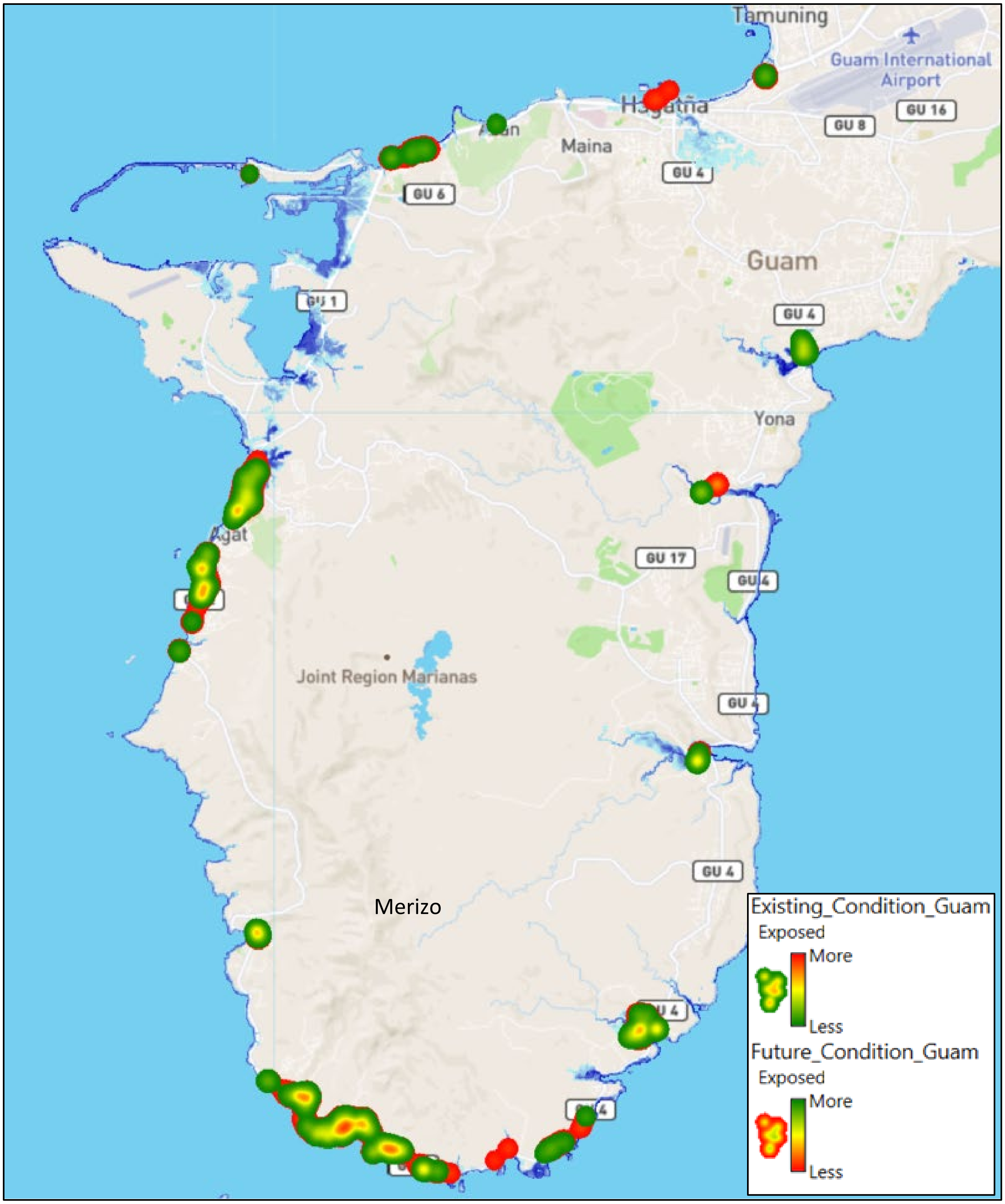


***Figure 4-7**. Heat Map of Areas with Exposure to Flooding for Guam Under the NOAA MEOW Storm Surge Event[3].*

[3] Solid Red Areas Indicate Additional Exposure Under the Future Scenario

The results pertaining to structure damages (Table 4-4) are less about exact numbers, and more about showing which areas receive the greatest change and are therefore vulnerable to RSLC. For example, the village of Piti receives over 7 times more damage in the future scenario, highlighting the vulnerability to the risk of RSLC at the structure level.

Table 4-4 *Existing and Future with SLR Damages. Source: USACE, 2021.*

Place	Damage Existing	Damage Future[1]	Increased Damage in Future
Agat	$2,184,163	$7,986,350	266%
Asan	$16,408	$49,158	200%
Chalan Pago-Ordot	$256,097	$703,748	175%
Hagåtña	$0	$80,038	New Risk[2]
Inarajan	$941,167	$3,033,755	222%
Merizo	$4,510,906	$12,210,745	171%
Piti	$95,967	$788,929	722%
Tamuning	$55,696	$373,560	571%
Umatac	$260,262	$800,076	207%
Yona	$75,031	$198,151	164%
Total	**$8,395,697**	**$26,224,511**	**212%**

[1]Estimates are rough order of magnitude and should not be used beyond screening level.
[2]Risk only appears in future model, not existing.

Overall, western Guam experiences very large increases of risk in the future scenario via a 212% increase in structure damages. Due to data limitations in this effort, increases in PAR and number of structures impacted could not be estimated. However, using structure damages as an indicator of what areas see an increased risk, the assumption is made that these areas will also have an expanded PAR in the future, due to RSLC.

4.5 Cultural Resources

Cultural resources are a term used to describe the places, objects, sites, oral histories, and traditional practices that connect individuals, communities, or even a nation to their past. They can be viewed within watershed planning as a key component contributing to the resilience of a community by reinforcing a sense of place or reflecting the cultural identity of people. An assessment of Guam's watersheds and resources would be largely incomplete without addressing the myriad of cultural resources present throughout the landscape and its surrounding waters.

Typical inventories for cultural resources focus on preserving tangible properties such as a sites, buildings, structures, objects, or districts under state, territorial, and federal historic preservation law. It is also necessary for this watershed assessment to consider the intangible cultural resources that play an important role in maintaining cultural identity across the territory today. The sections below summarize the human history of Guam, organized according to archaeologically and historically defined temporal periods. These temporal periods will help contextualize certain cultural resources and provide an indication of their cultural and historical significance.

4.5.1 Summary of Prehistoric Cultural Resources

The "prehistoric" period of Guam is understood by studying the physical evidence of human activity left behind by the indigenous people of the Mariana Islands, the Chamorro people. The initial settlement of the Mariana Islands began around 4,000 years ago, and possibly earlier, according to archaeological research. Ancient seafarers believed to be the ancestors of the modern-day Chamorro people arrived on the islands from Southeast Asia. Archaeological sites from this period of early settlement are uncommon, however the few Pre-Latte sites recorded by archaeologists were located by the coast buried in rocky or sandy deposits at beach environments, rock shelters, or inland caves. The Chamorro cultural group did not leave behind any written records, requiring researchers to reconstruct its prehistoric past through archaeological evidence. Guam's Historic Resources Division has divided the islands prehistoric contexts into five distinct periods (Table 4-5).

Table 4-5 Historic Periods of Guam

Historic Context	Date
Early Pre-Latte Period	3500-2500 B.P.*
Intermediate Pre-Latte Period	2500-1600 B.P.
Latte Period	800-1000 A.D.**
Mid-Latte Period	c. 1300 A.D.
Late Latte/Early Historic Period	1521-1700 A.D.

**Before Present (B.P.) which is based on the number of years before the year 1950.*
***Anno Domini (A.D.) is used by archaeologists and historians in reference to the years after the birth of Jesus of Nazareth.*

The material culture associated with the Pre-Latte Periods includes redware pottery, surface, and subsurface scatters of ceramic sherds (shattered remains of pottery), midden deposits, and ecofacts such as faunal remains or marine shell. Pre-Latte Period sites are often found to be in poor condition due to impacts from natural transformational processes near the shoreline, as well as human activity and development which persisted into the historic era (Carson, 2008).

By 1000 A.D., the Chamorro population increased and allowed for the expansion of settlements and villages outside of the usual coastal environments. This era is defined as the Latte Period. Large limestone pillars with capstones known as a *latte* were constructed in two parallel rows at villages. Other significant cultural resources include *lusong* (basalt or limestone grinding mortars), *lummok* (stones used like a pestle), quarries, hearths, cooking debris, food storage features, lithic debitage from tool making activities, burials, pictographs, and remnants of abandoned village sites. There are more Latte Period sites identified in Guam compared to Pre-Latte Period sites.

4.5.2 Summary of Historic Resources

The historic period for the Mariana Islands begins at around 1668 with the establishment of a Jesuit mission in Guam. This period of European contact falls within the Spanish Missionization and Chamorro Spanish Wars (1668-1699) (Guam HPO, 2007). Spain's attempts to colonize the island were met with resistance and wars by the Chamorro people. Past inventories have documented 17th century latte archaeological sites, historic sites, remnants of Spanish structures, war sites, and shipwrecks. Historic archives for this period are also plentiful with Spanish journals and chronicles documenting the location of battles between the Spanish and Chamorro, including the location of past mission chapels established at villages (Guam Historic Preservation Office, 2007).

By the start of the Spanish Colonial Period in 1700 the population of the Chamorro people decreased dramatically, along with their traditional cultural practices and beliefs. Churches, public buildings, and wealthy residential houses were introduced into village settlements still occupied today (Guam Historic Preservation Office, 2007). In addition to societal and cultural change by the Spanish, migrants from the Caroline Islands arrived around 1880 establishing Carolinian communities amongst the Chamorros. The material culture of the Spanish Colonial Period consists of archaeological sites, Spanish colonial buildings, structures such as stone bridges, and defensive fortifications.

The First American Colonial Period beginning in 1898 is depicted by the U.S., Germany, and Japan's attempts to establish control over the Mariana Islands. The start of World War II in 1941 was met with the Japanese Army invading Guam and building defensive fortifications on landing beaches. Guam's native communities were forced into physical labor and thrown into internment camps before liberation of the island by the U.S. on July 21, 1944. Historic sites associated with the American Colonial and World War II Periods include pillboxes, man-made tunnels, defensive gun placements, military airfields, anti-aircraft positions, trenches, sunken ships, straggler caves, natural caves containing human remains, and World War II mass grave sites. Isolated artifacts associated with World War II is prevalent across the island.

After World War II, a decision was made for the Mariana Islands to be under the control and administration of the United States. Guam would be established as a U.S. flag territory and governed under the U.S. Navy. The people of Guam were given more agency as well as self-determination for their own politics after the 1949 Guam Congress walk-out and the passage of the United States Congressional 1950 Organic Act of Guam (Guam Historic Preservation Office, 2007). Historic properties commonly associated with the Political and Economic Development Period are military structures, Quonset huts, churches, government buildings, and the historic reuse of World War II facilities and buildings (Guam Historic Preservation Office, 2007).

Overall, a total of 134 listed historic properties, spanning Guam's 19 villages, were identified on the National Register of Historic Places (NRHP) database. Historic properties are a codified term defined under 54 U.S. Code § 300308 and are defined as any significant prehistoric or historic district, site, building, structure, or object that is listed or eligible for the NRHP. This can include places of traditional religious and cultural importance to Chamorro communities. Guam's listed historic properties include prehistoric and historic buildings, structures, sites, districts, and objects.

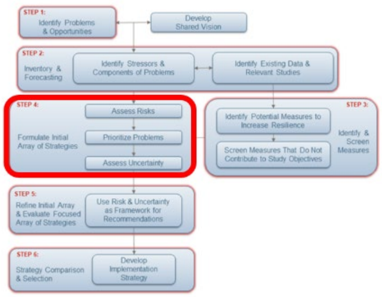
4.5.3 Summary of Intangible Cultural Resources

Identifying and preserving intangible cultural resources can be challenging, yet also presents an opportunity to consider a unique class of historic properties during this watershed assessment. Intangible cultural resources have become an important part of Chamorro and Pacific Islander communities, connecting them to their language, oral history, community values, ceremonial practices, maritime activities, folklife, folklore, and traditions (Guam Historic Preservation Office, 2007). Administrative management and occupation by Spain, Japan, and the U.S., has resulted in the loss of land and traditional customs for the Chamorro people. Defining the boundaries of intangible cultural resources can be difficult and requires close consultation with Chamorro cultural groups.

The National Register Bulletin 38 has addressed this issue by defining a category of protected cultural resources known as Traditional Cultural Properties (TCP). This guidance defines a TCP as a historic property eligible for inclusion in the National Register of Historic Places because of significance associated with cultural practices or beliefs for a living community's history and maintaining their cultural identity (Parker and King, 1990).

Although the Chamorro people of Guam have taken on a more westernized lifestyle, everyday customs surrounding their past traditions, such as maritime activities related to fishing, seafaring, or the management of marine habitats and natural resources, helps to maintain their traditional connection to the land and sea (Allen, 2008). By maintaining and enhancing their intangible cultural heritage, the Chamorro community can revive their sense of cultural identity and connection to their traditional lands and resources.

5 Risk Assessment and Evaluation



To prioritize water resources problems and subsequent actions, a risk-based approach was utilized to identify the highest risks for which near-term efforts should focus. Risks within the study area are already occurring, with the potential for increased probability and consequences under future conditions. These risks, identified and evaluated through review of existing documentation as well as a series of partner engagement meetings with federal and territorial agencies, largely fall within one or more of four categories: life loss, economic, social, and environmental. This aligns with benefit categories defined in the USACE Policy Memorandum "Policy Directive – Comprehensive Documentation of Benefits in Decision Documents," dated January 5, 2021, which calls for *"equal consideration of economic, environmental, and social categories."* The principles of this policy directive were applied to inform the risk-based prioritization of identified problems.

A series of virtual scoping charrettes and several one-on-one calls were held with stakeholders to gain input on the problem categories, prioritize areas of risk, and curate an initial array of recommendations. Stakeholder input at these meetings identified stressors and later validated the risk assessment. Additional details on stakeholder engagement can be found Section 2.1 and Appendix A – Interagency Engagement.

5.1 Risk Assessment Overview

To qualitatively assess the stressors outlined in Section 3.1, the team reviewed existing documentation and held a series of partner and stakeholder engagement meetings (Table 2-1, Section 2.1). The risk assessment accounted for both likelihood and consequence of stressors contributions to the risk indices. Risk ratings were evaluated based on current circumstances but did include flexibility for risks that are expected to worsen with climate change or exacerbated environmental stress. The four risk metric categories (economic, life loss, social, and environmental) were evaluated based off the criteria described in Section 5.2. The complete documentation of the collaborative risk assessments can be found in Appendix A – Interagency Alignment.

5.2 Risk Assessments by Category

The results of this risk assessment are summarized in the sub-sections below. The red dashed line shown in these figures was qualitatively placed to designate the relative highest risk stressors. For social and environmental metrics, these were risks where permanent impacts have occurred. The relative highest economic risks where those where widespread impacts occur with high frequency. Highest life loss risks consider the magnitude of potential life loss and frequency of the stressor occurring. The range for life loss highest risk spans from frequent events with low magnitude life loss to infrequent events with the potential for high magnitude life loss. The highest relative risk rankings for each risk metric are categorized as catastrophic. A yellow dashed line also designated a minor risk category to denote the relative lowest risk stressors for each risk metric. Stressors falling between minor and catastrophic are considered a major risk.

5.2.1 Economic Risk

Economic risk estimates the combination of likelihood and consequences of harm to property, infrastructure, and other assets as well as economic systems (measured in monetary terms). The following ratings shown in Table 5-1 and Table 5-2 were applied to each of the stressors for economic risk. To identify the highest relative economic risks, the catastrophic category (above the red dashed line) was defined as those stressors that occur often and can result in catastrophic impacts, as well as those that occur often and are increasing in frequency, resulting in territory-wide impacts.

Table 5-1 *Qualitative Probability Definitions for Economic Risks*

Probability	Definition
Not Likely	It is not anticipated a stressor will contribute to this risk.
Could Occur	It is possible a stressor will contribute to this risk.
Has Occurred	The stressor has directly contributed to this risk.
Has Occurred and Increasing	The stressor has directly contributed to this risk and will contribute more often in the future.
Occurs Often	The stressor frequently contributes to this risk.
Occurs Often and Increasing	The stressor frequently contributes to this risk and will contribute more often in the future.

Table 5-2 *Qualitative Consequence Definitions for Economic Risks*

Magnitude of Consequences	Definition
No Impact	No impacts are anticipated.
Household Impact	Impacts are anticipated to affect a single household.
Town/Village Impact	Impacts are anticipated to affect a community.
Watershed Impact	Impacts are anticipated to affect multiple communities.
Territory-wide Impact	Impacts are anticipated to affect the entire territory.
Catastrophic Impact	Impacts are anticipated to affect the entire territory with severe economic consequences.

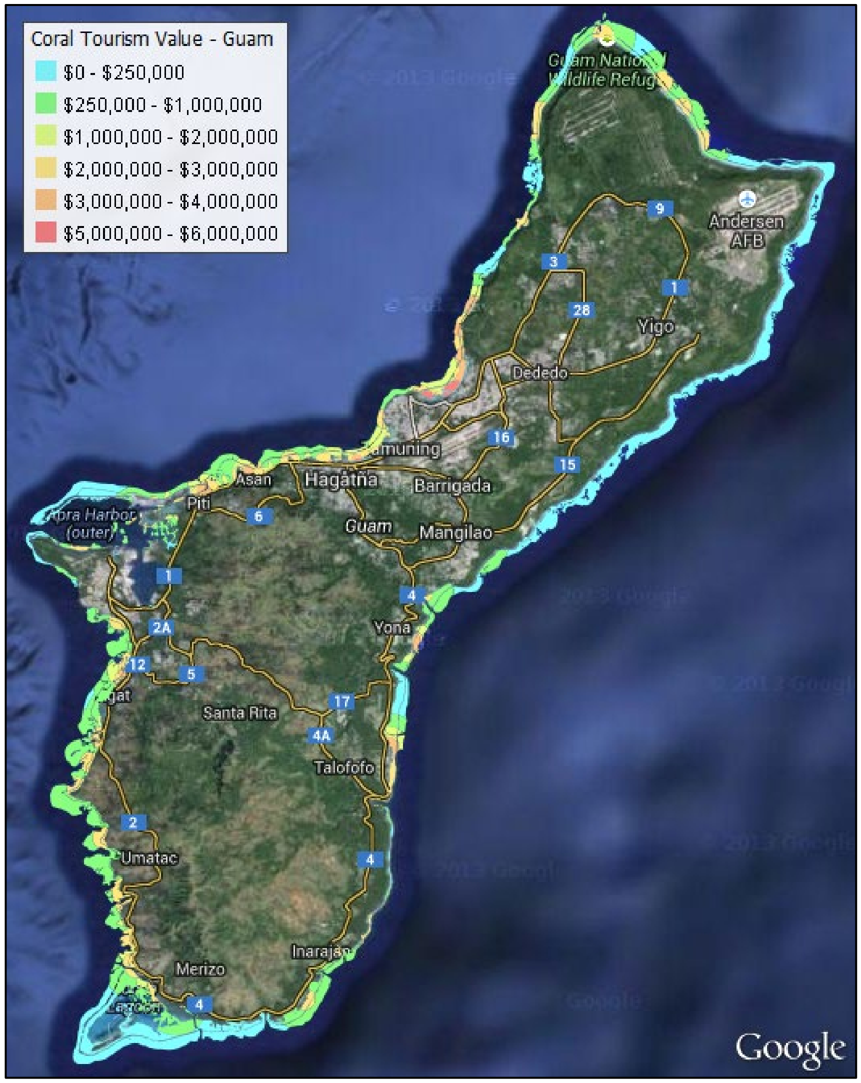
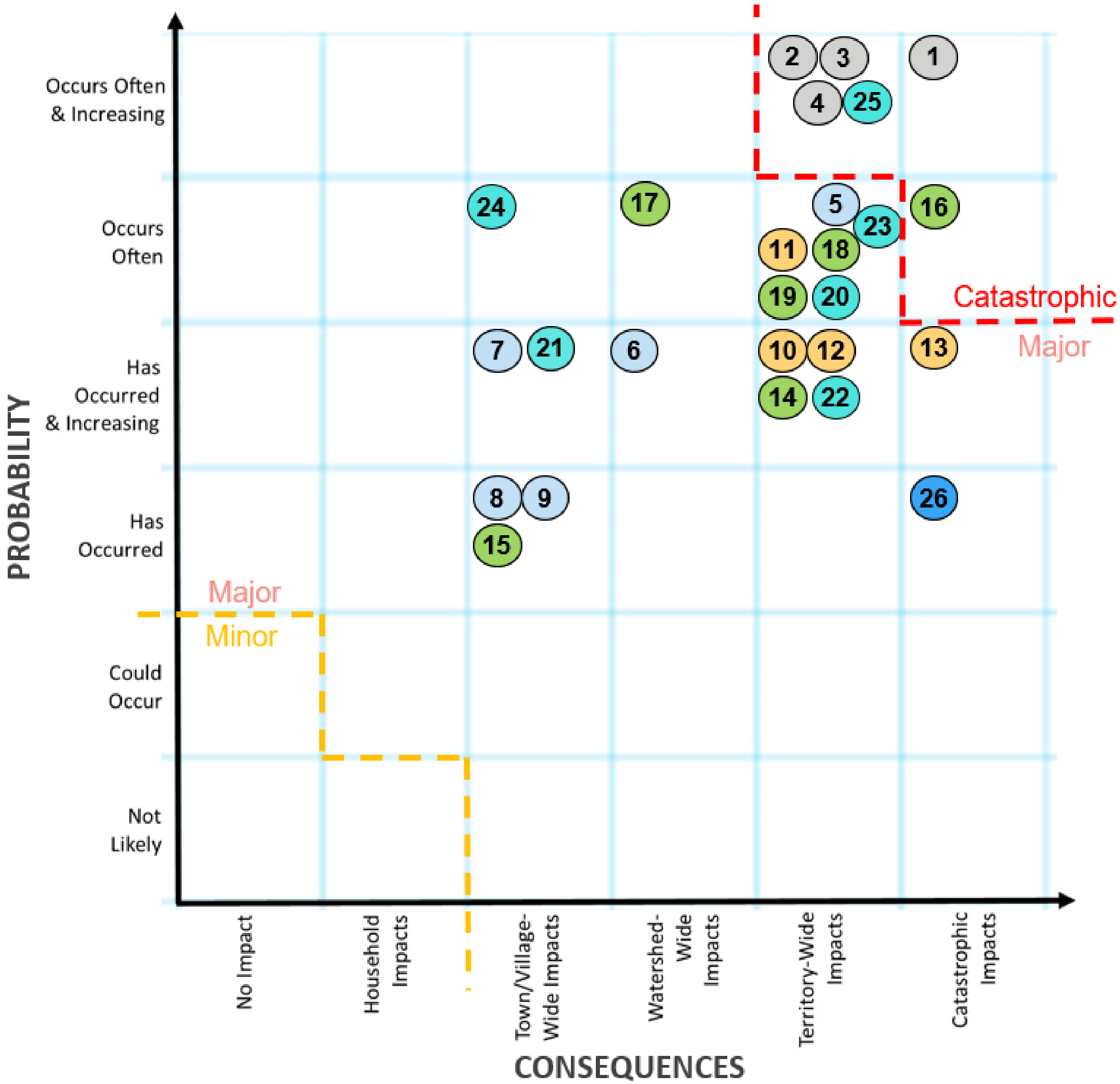


Figure 5-1. *Coral Tourism Value (Image Courtesy of University of Guam Marine Laboratory,2016)*

The main water resources stressors that drive economic risk are related to tropical cyclones. High winds have the capacity to damage or remove roofs and cause loss of power island wide. Sources of power, fuel tanks, and the lines that distribute power are all potentially affected.
Coastal flooding during tropical cyclones coupled with loss of power also results in disruptions to ports, a source of needed resources during events and provider of employment on the island. Risks associated with tropical cyclones are projected to increase in the future with territory wide impacts.
Coral reef degradation was also identified as a catastrophic economic risk. According to the Guam Coral Reef Initiative, the annual expected benefits of coral reefs are over 257,000 people and $5.99M of infrastructure protected from waves. The loss of fisheries and tourism would have a deleterious effect on the economy of Guam. Coral tourism is a significant source of income for the island's economies though recreation opportunities and subsistence and commercial fisheries (Figure 5-1). The loss of corals has already occurred, and the impacts of the loss are long lasting to permanent throughout the Territory.

Urban development has had a significant effect on the natural stormwater drainage system, resulting in frequent economic consequences. As undeveloped land is converted to impervious surfaces, runoff increases and is discharged to streams, wetlands, lagoons, or near-shore bays. This increased volume can result in flooding of infrastructure and other economic losses.

Economic risk results are shown in Figure 5-2.



1	Coastal flooding	Cyclone
2	Loss of power	Cyclone
3	High winds	Cyclone
4	Sea level rise	Cyclone
5	Flash flooding	Freshwater
6	Riverine flooding	Freshwater
7	Erosion	Freshwater
8	Landslide/Mudslide	Freshwater
9	Sedimentation	Freshwater
10	Saltwater spray	Coastal
11	Loss of living breakwater	Coastal
12	Coastal erosion	Coastal
13	Sea level rise	Coastal
14	Loss of fish habitat	Habitat
15	Sedimentation	Habitat
16	Coral reef degradation	Habitat
17	Nutrient loading	Habitat
18	Wildfires	Habitat
19	Invasive species	Habitat
20	Nutrient loading	Water Supply
21	Sedimentation	Water Supply
22	Drought	Water Supply
23	Over-use of NGLA	Water Supply
24	Pollution near water supply wells	Water Supply
25	Storm water management issues	Water Supply
26	Tsunami	T

Figure 5-2. *Economic Risks of Identified Problems*

5.2.2 Other Social Effects

The social effects, also referred to as "social vulnerability," observed by natural hazards are just as important as environmental and economic effects. Viewing these effects at a community level gives a comprehensive picture of potential short-term and long-term consequences of problems and stressors. As laid out in *Other Social Effects: A Primer* by the Institute for Water Resources (2013), the team performed assessments of social vulnerability risk categories utilizing three risk factors:

- *Social Connectedness* – Sustaining a sense of connection to the community and neighborliness. This can include the displacement of people, businesses, farms, and also refers to the loss of intangible cultural resources such as folklore, traditions, language, and cultural knowledge.
- *Health and Safety* – Health and Safety accounts for effects on security, life, health, safety, and emergency preparedness.
- *Subsistence* – Subsistence is the ability to be self-sustaining by relying on natural resources to support a community and individual livelihoods.

The highest risks to other social effects are coastal flooding and RSLC, as detailed in the sections below. The following ratings shown in Table 5-3 and

Table **5-4** were applied to each of the stressors for other social effects risk. To identify the highest relative social risks, the catastrophic category (above the red dashed line) was defined as those stressors that have resulted in permanent impacts and probability and/or consequences are anticipated to increase.

Table 5-3 *Qualitative Consequence Definitions for Other Social Effects Risks*

Magnitude of Consequences	Definition
Temporary Impact Possible	It is possible for a stressor to cause temporary impacts to community/cultural/environmental resources.
Temporary Impact Possible and Increasing	It is possible for a stressor to cause temporary impacts to community/cultural/environmental resources, and they may become more severe.
Long-Term Impact Possible	It is possible for a stressor to cause long-term impacts to community/cultural/environmental resources.
Long-Term Impact Possible and Increasing	It is possible for a stressor to cause long-term impacts to community/cultural/environmental resources, and they may become more severe.
Permanent Impact Possible	It is possible for a stressor to cause permanent impacts to community/cultural/environmental resources.
Permanent Impact Possible and Increasing	It is possible for a stressor to cause permanent impacts to community/cultural/environmental resources, and they may become more severe.

Table 5-4 *Qualitative Probability Definitions for Other Social Effects Risks*

Probability	Definition
Not Likely	It is not anticipated a stressor will contribute to this risk.
Not Likely but Increasing	It is not anticipated a stressor will contribute to this risk, but it could happen.
Could Occur	It is possible a stressor will contribute to this risk.
Could Occur and Increasing	It is possible a stressor will contribute to this risk and is becoming more likely.
Has Occurred	The stressor has directly contributed to this risk.

Has Occurred and Increasing	The stressor has directly contributed to this risk and will contribute more often.

5.2.2.1 Social Connectedness

No stressors were determined to present a catastrophic risk to displacement. Coral reef degradation, over-use of the Northern Guam Lens Aquifer (NGLA), and drought were all identified as stressors that have occurred, and the probability of occurrence is increasing. The NGLA is main source of drinking water for 80% of the island's residents. If the NGLA is overdrawn, the aquifer is at high risk of saltwater intrusion. This problem is exacerbated by drought conditions when rainfall cannot permeate and replenish the aquifer. Without a native source of water, water will need to be imported – increasing the costs of living. Should these costs become too high, this may lead to emigration off Guam.

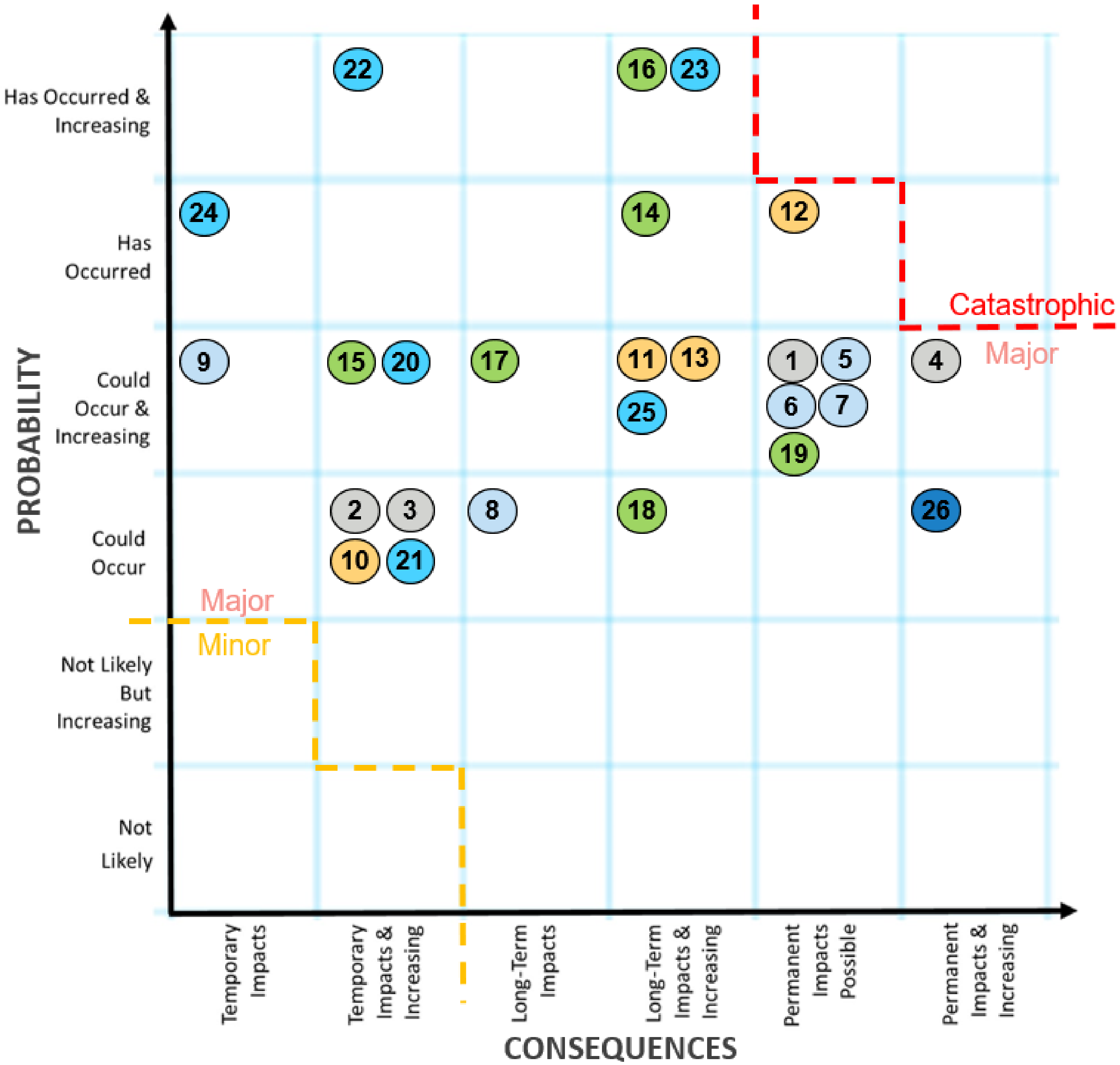
As coral reef degradation worsens, fisheries will not be sustainable and the loss of economic revenue from corals may also drive people to find other sources of food and revenue, which may not be on Guam.

The rising seas could lead to the permanent displacement of coastal communities and the loss of key historical and cultural sites. Sites such as Tumon Bay, where shell beads and tools carved from bones and Tridacna shell are found; and Humåtak Village, the site of 19th century Spanish forts will be lost. Cemeteries in Agat and the villages of Anana and Inarajan have already been affected. Utilizing NOAA's SLR vulnerability mapping tool, no areas in Guam were identified as having high social vulnerability. This may be because, according to the 2010 Census, 80.8% of the population lives below the defined U.S poverty threshold of $32,000. Additionally, the minority group are the Chamorro, but they are also the largest ethnic group (37.3%).

SLR is projected to leave the coastal road in southern Guam inundated during storm events vulnerable to loss from erosion leaving groups and individuals isolated from medical care, employment, and social connection. Longer distances will need to be traveled using alternative routes which will disadvantage those who rely on public transportation.

Any recommendations carried out for implementation by federal agencies must consider Executive Order 14008 'Tackling the Climate Crisis at Home and Abroad' (2021), Executive Order 12898 'Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations', (1994) and the Assistant Secretary of the Army for Civil Works' Interim Implementation Guidance for Environmental Justice (Mar 15, 2022). All recommendations to improve resiliency would require coordination and collaboration with residents.

Social connectedness risk results are shown in Figure 5-3.



1	Coastal flooding	Cyclone
2	Loss of power	
3	High winds	
4	Sea level rise	
5	Flash flooding	Freshwater
6	Riverine flooding	
7	Erosion	
8	Landslide/Mudslide	
9	Sedimentation	
10	Saltwater spray	Coastal
11	Loss of living breakwater	
12	Coastal erosion	
13	Sea level rise	
14	Loss of fish habitat	Habitat
15	Sedimentation	
16	Coral reef degradation	
17	Nutrient loading	
18	Wildfires	
19	Invasive species	
20	Nutrient loading	Water Supply
21	Sedimentation	
22	Drought	
23	Over-use of NGLA	
24	Pollution near water supply wells	
25	Storm water management issues	
26	Tsunami	T

Figure 5-3. *Risk of Social Connectedness*

5.2.2.2 Health and Safety

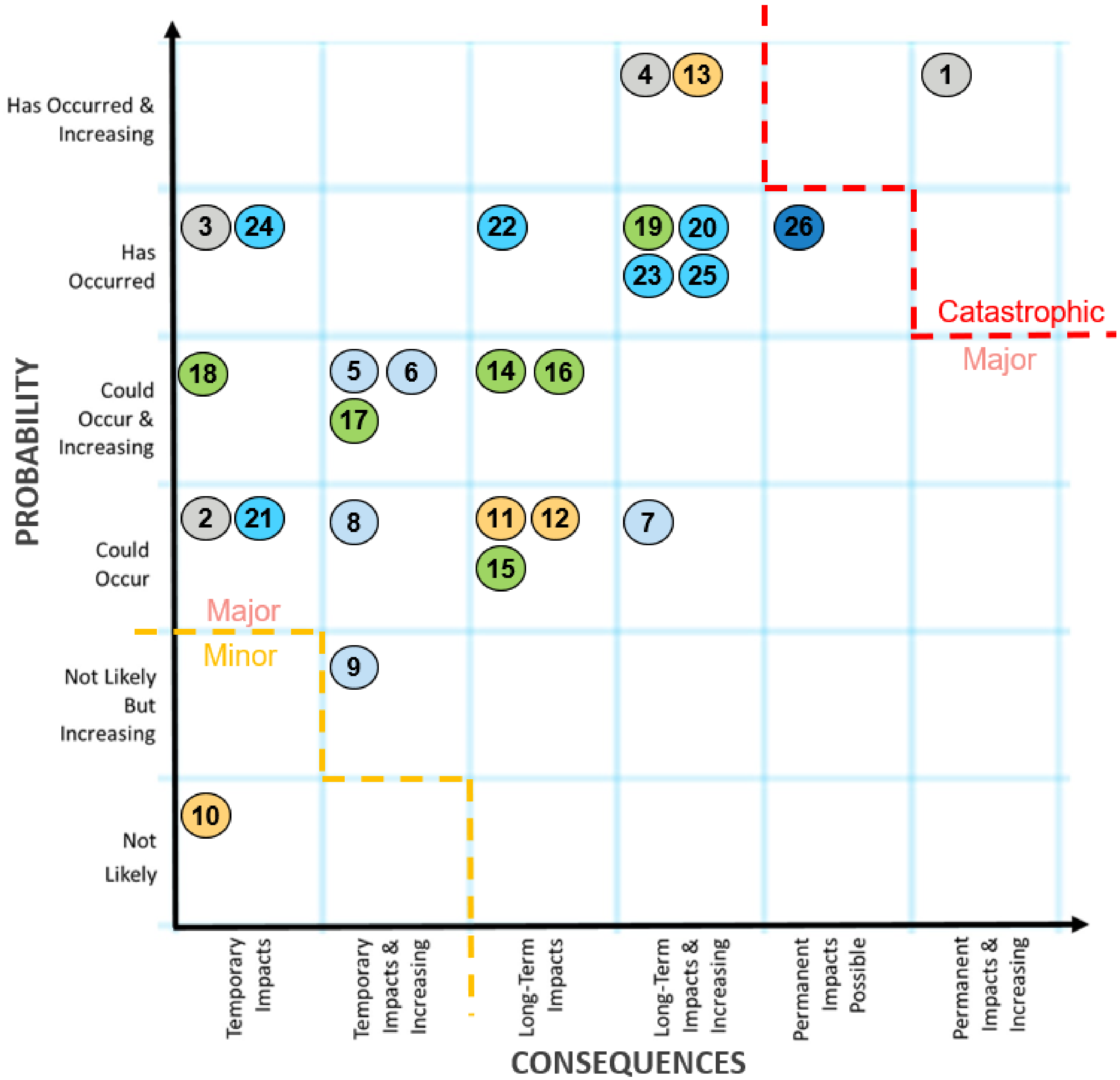
Health and Safety accounts for effects on security, life, health, safety, and emergency preparedness. Coastal flooding due to cyclones was determined to present a catastrophic risk to health and safety. Coastal flooding events and higher tides are expected to affect coastal properties creating an environment for mildew and mold which pose serious health hazards. Flooded or recently flooded areas are subject to electrical hazards, damaged fire protection systems, and structural instability. Persons in flood waters are subject to hypothermia, exhaustion, and drowning.

Coastal flooding may also affect housing, food and water supplies, sanitation facilities, and disrupt transportation in the case of damaged coastal roadways. Liquified petroleum gas tanks and underground storage tanks can break away from their supports and float in flood waters, causing hazards from their released contents.

During a flood, local water systems may become contaminated. A variety of sources of contamination include animal and human waste, dead and decaying animals, or chemicals accidentally released during flooding. Water supply contamination can lead to waterborne illnesses. Food exposed to floodwaters or stored without refrigeration during extended loss of power during flooding can lead to food-borne illnesses. Individual homes that are unable to keep their perishables and medicine cold are at risk and more so if water and power distribution systems are impacted leaving households without the ability to create potable water by boiling.

Critical infrastructure cannot continue to provide life support systems and the response times of emergency responders will also be delayed putting individuals at greater risk.

Health and safety risk results are shown in Figure 5-4.



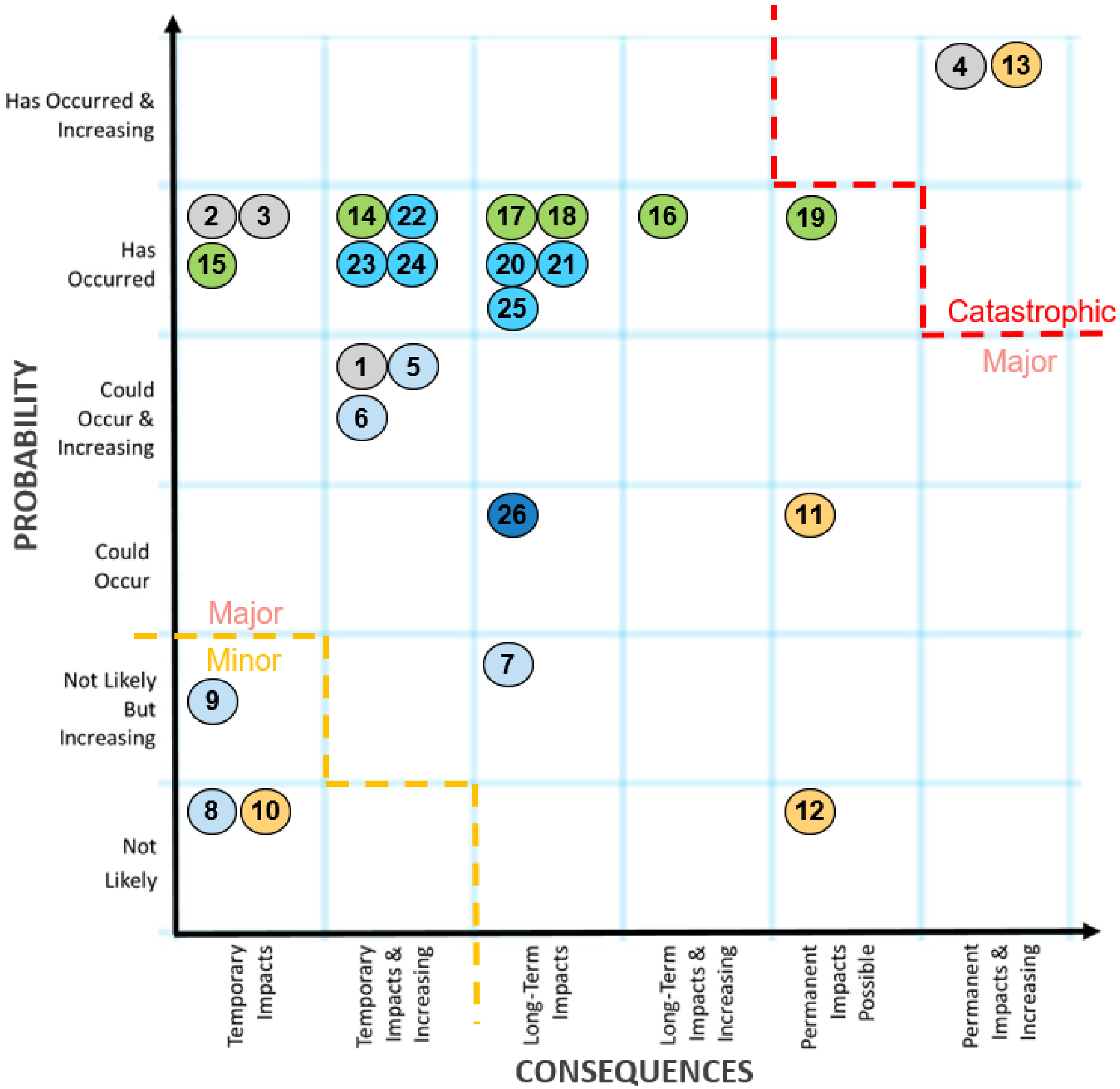
1	Coastal flooding	Cyclone	
2	Loss of power		
3	High winds		
4	Sea level rise		
5	Flash flooding	Freshwater	
6	Riverine flooding		
7	Erosion		
8	Landslide/Mudslide		
9	Sedimentation		
10	Saltwater spray	Coastal	
11	Loss of living breakwater		
12	Coastal erosion		
13	Sea level rise		
14	Loss of fish habitat	Habitat	
15	Sedimentation		
16	Coral reef degradation		
17	Nutrient loading		
18	Wildfires		
19	Invasive species		
20	Nutrient loading	Water Supply	
21	Sedimentation		
22	Drought		
23	Over-use of NGLA		
24	Pollution near water supply wells		
25	Storm water management issues		
26	Tsunami	T	

Figure 5-4. *Risk to Health and Safety*

5.2.2.3 Subsistence

Subsistence refers to the ability to be self-sustaining by relying on natural resources to support a community and livelihoods. SLR poses potentially catastrophic subsistence risks and elevates risks associated with tropical cyclones. SLR permanently alters and inundates coastal areas leaving land and habitat unsuitable. This is particularly catastrophic to subsistence fishing since these activities are located nearly exclusively on or along the shore, as further described in Section 5.2.3.1. As sea levels rise, saltwater intrusion may pose a threat to the aquifer, raising the cost of treatment or rending wells unusable. As most of the food for Guam is imported through ports, rising sea level and storm surges may damage port facilities interfering with shipping and distribution.

Subsistence risk results are shown in Figure 5-5.



1	Coastal flooding	Cyclone
2	Loss of power	
3	High winds	
4	Sea level rise	
5	Flash flooding	Freshwater
6	Riverine flooding	
7	Erosion	
8	Landslide/Mudslide	
9	Sedimentation	
10	Saltwater spray	Coastal
11	Loss of living breakwater	
12	Coastal erosion	
13	Sea level rise	
14	Loss of fish habitat	Habitat
15	Sedimentation	
16	Coral reef degradation	
17	Nutrient loading	
18	Wildfires	
19	Invasive species	
20	Nutrient loading	Water Supply
21	Sedimentation	
22	Drought	
23	Over-use of NGLA	
24	Pollution near water supply wells	
25	Storm water management issues	
26	Tsunami	T

Figure 5-5. *Risks to Subsistence*

5.2.2.4 Summary Risk to Other Social Effects

For other social effects risk, stressors were evaluated for each risk index: social connectedness, health and safety, and subsistence. The single highest ranking between indices in the social categories was carried through for the overall social risk assessment.

Assessments of social risk places coastal flooding during tropical cyclones and SLR in the catastrophic risk category. Coastal flooding and SLR poses a risk with permanent impacts to cultural resources and social connectedness. The rising seas will lead to the permanent displacement of coastal communities and the loss of key historical and cultural sites.

Health and safety are also affected by coastal flooding during cyclones and SLR. Coastal flooding events and higher tides are expected to affect coastal properties creating an environment for mildew and mold which pose serious health hazards. Coastal flooding may also affect housing, food and water supplies, sanitation facilities, and disrupt transportation in the case of damaged coastal roadways.

Subsistence is also at risk, as higher seas threaten to bring saltwater contamination into the NGLA and supply wells. As most of the food for Guam is imported through ports, rising seas and storm surges may damage port facilities interfering with shipping and distribution.

A summary of risks to other social effects is shown in Figure 5-6.

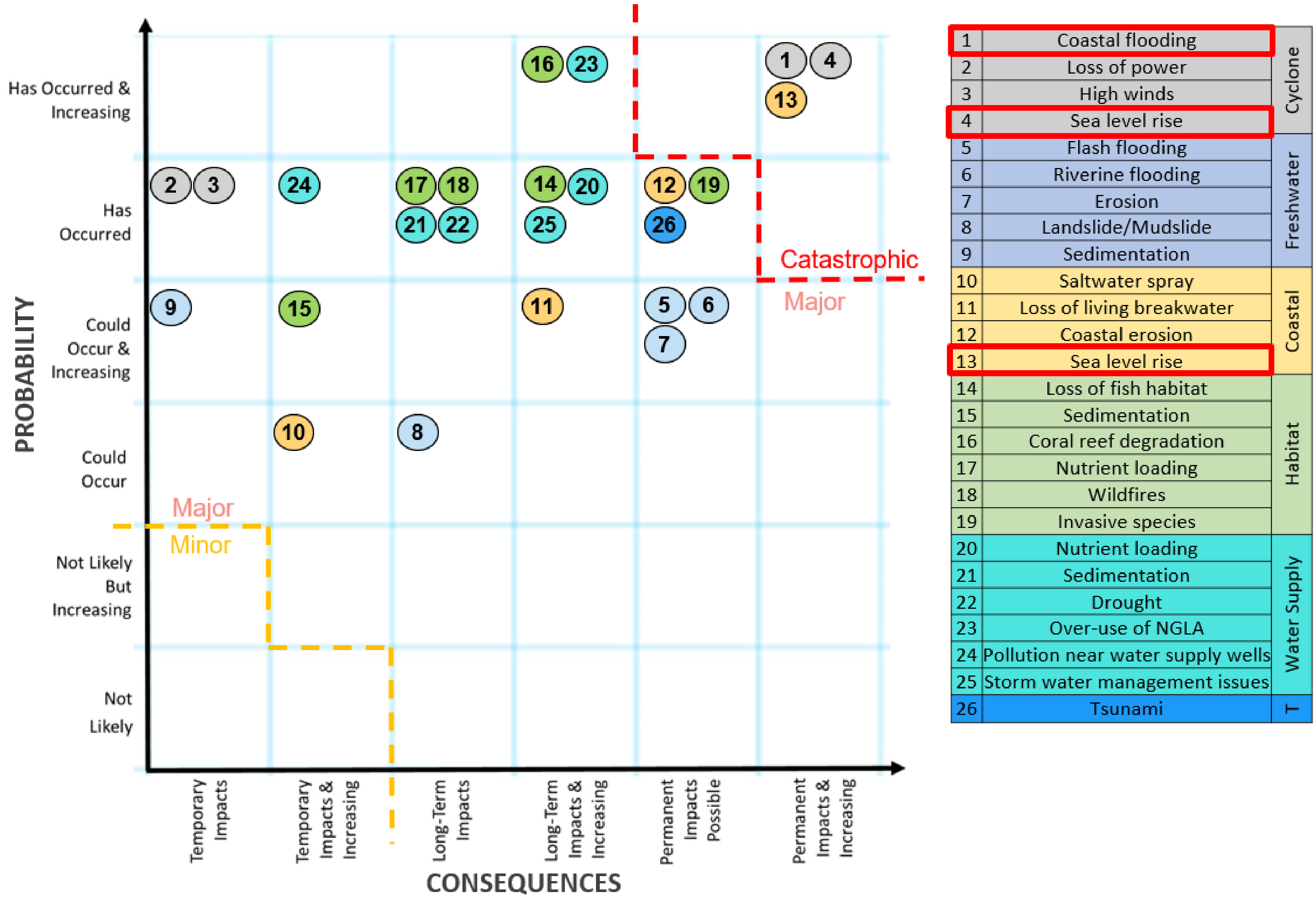


Figure 5-6. *Summary of Risk to Other Social Effects*

5.2.3 Environmental Risk

The environmental risk category was also assessed through four risk factors: ecosystem services impacts, species loss, habitat loss, and cultural resources. The highest risk problems and stressors to the environment are from coral reef degradation, loss of fish habitat, loss of living breakwater, and SLR as detailed in the sections below.

The following ratings shown in Table 5-5 and Table 5-6 were applied to each of the stressors for other social effects risk. To identify the highest relative environmental risks, the catastrophic category (above the red dashed line) was defined as those stressors that have resulted in permanent impacts and probability and/or consequences are anticipated to increase.

Table 5-5 *Qualitative Probability Definitions for Environmental and Other Social Effects Risks*

Probability	Definition
Not Likely	It is not anticipated a stressor will contribute to this risk.
Not Likely but Increasing	It is not anticipated a stressor will contribute to this risk, but it could happen.
Could Occur	It is possible a stressor will contribute to this risk.
Could Occur and Increasing	It is possible a stressor will contribute to this risk and is becoming more likely.
Has Occurred	The stressor has directly contributed to this risk.
Has Occurred and Increasing	The stressor has directly contributed to this risk and will contribute more often.

Table 5-6 *Qualitative Consequence Definitions for Environmental and Other Social Effects Risks*

Magnitude of Consequences	Definition
Temporary Impact Possible	It is possible for a stressor to cause temporary impacts to community/cultural/environmental resources.
Temporary Impact Possible and Increasing	It is possible for a stressor to cause temporary impacts to community/cultural/environmental resources, and they may become more severe.
Long-Term Impact Possible	It is possible for a stressor to cause long-term impacts to community/cultural/environmental resources.
Long-Term Impact Possible and Increasing	It is possible for a stressor to cause long-term impacts to community/cultural/environmental resources, and they may become more severe.
Permanent Impact Possible	It is possible for a stressor to cause permanent impacts to community/cultural/environmental resources.
Permanent Impact Possible and Increasing	It is possible for a stressor to cause permanent impacts to community/cultural/environmental resources, and they may become more severe.

5.2.3.1 Ecosystem Services

Ecosystem services provided by coral reefs may be summed up into provisioning, regulating, and supporting cultural services. Environmental risks categorized as catastrophic are defined as those having potentially permanent consequences, with increasing probability of occurrence and/or an increasing magnitude of permanent consequences. Coral reef degradation was identified as the only catastrophic risk in this category.

Coral reefs are biologically rich, providing the spawning and nursery grounds fish need to thrive. For coastal communities the reefs provide renewable fisheries and subsistence fishing opportunities. An estimated 35% to 45% of Guam's households were involved in weekly near-shore fishing (Berkering et al. 2007; University of Guam Marine Lab, 2007).

Regulating services associated with the physical structure of the reef are shoreline protection from waves and extreme weather events, and regulation of erosive processes. Coral reefs dissipate upwards of 90% of the energy that would otherwise hit shorelines (Ferrario et al., 2014), thereby decreasing shoreline erosion. Wave run-up is decreased resulting in less damages from flooding and less coastal inundation during tropical cyclones (Figure 5-7).

Additionally, the areas of low energy waves create a favorable environment for seagrasses and mangroves in coastal wetlands (Short et al., 2007; Sheaves, 2009). The supporting services from coral reefs in Guam are the economic gains from tourism. An estimated 6% of the 1.34 million annual visitors go scuba diving while in Guam, amounting to 256,000 and 340,000 dives per year (Berkering et al. 2007).

The Chamorro population developed a fishing culture throughout generations. The migratory return of traditional fish such as ti'ao (baby goat fish) and manahak (baby rabbit fish) is significant in bringing families together to share in harvest. A survey found nearly one quarter of fish consumed in households were caught by a member of the household or by a friend or extended family member (Berkering et al. 2007). This cultural practice of giving large portions of catches to family and the local community is a cornerstone in creating and maintaining social networks and cultural ties (Pinhey et al. 2006; Kotowicz, 2013).

Error! Reference source not found. shows the summary of risks to ecosystem services.

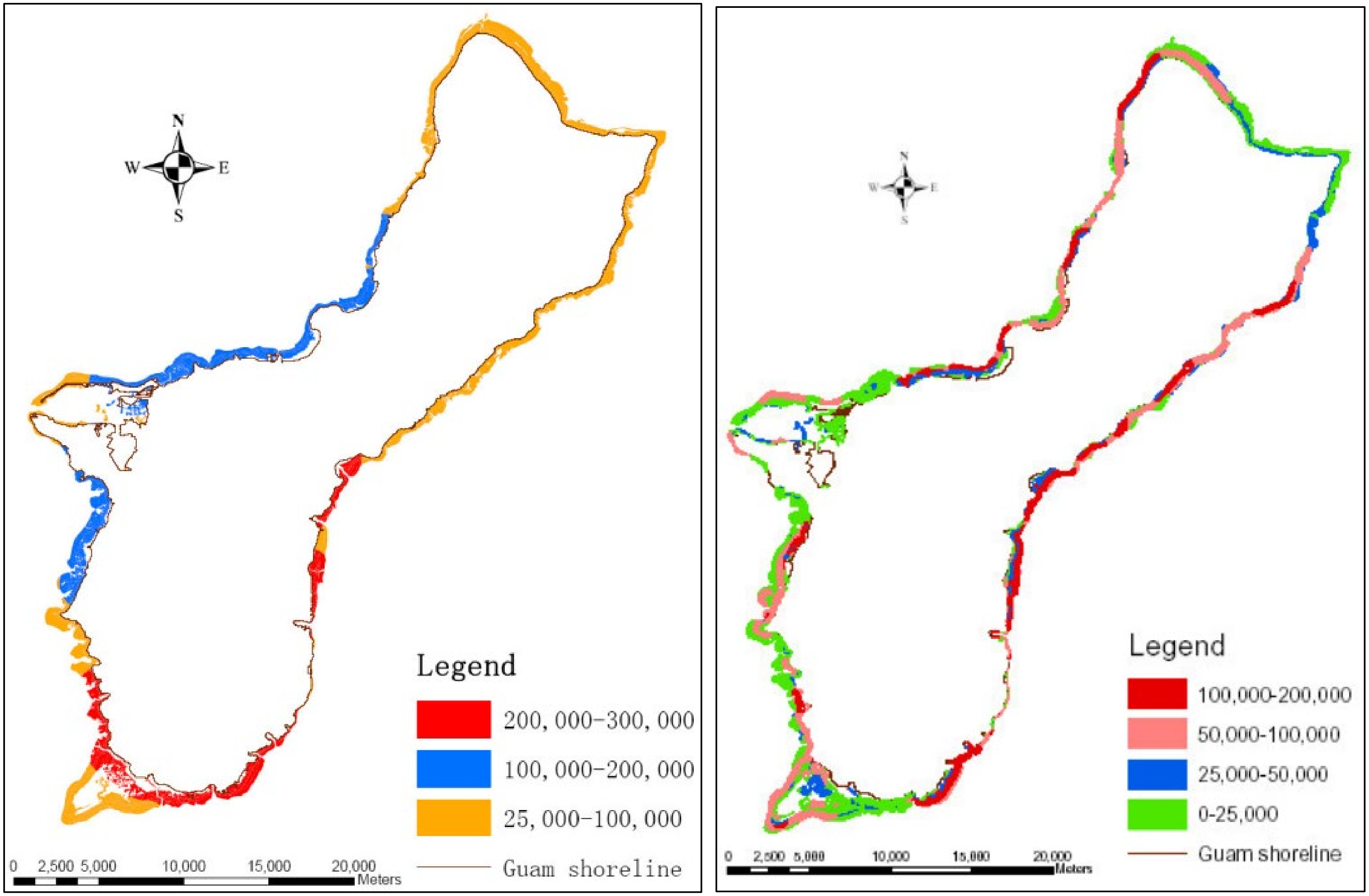
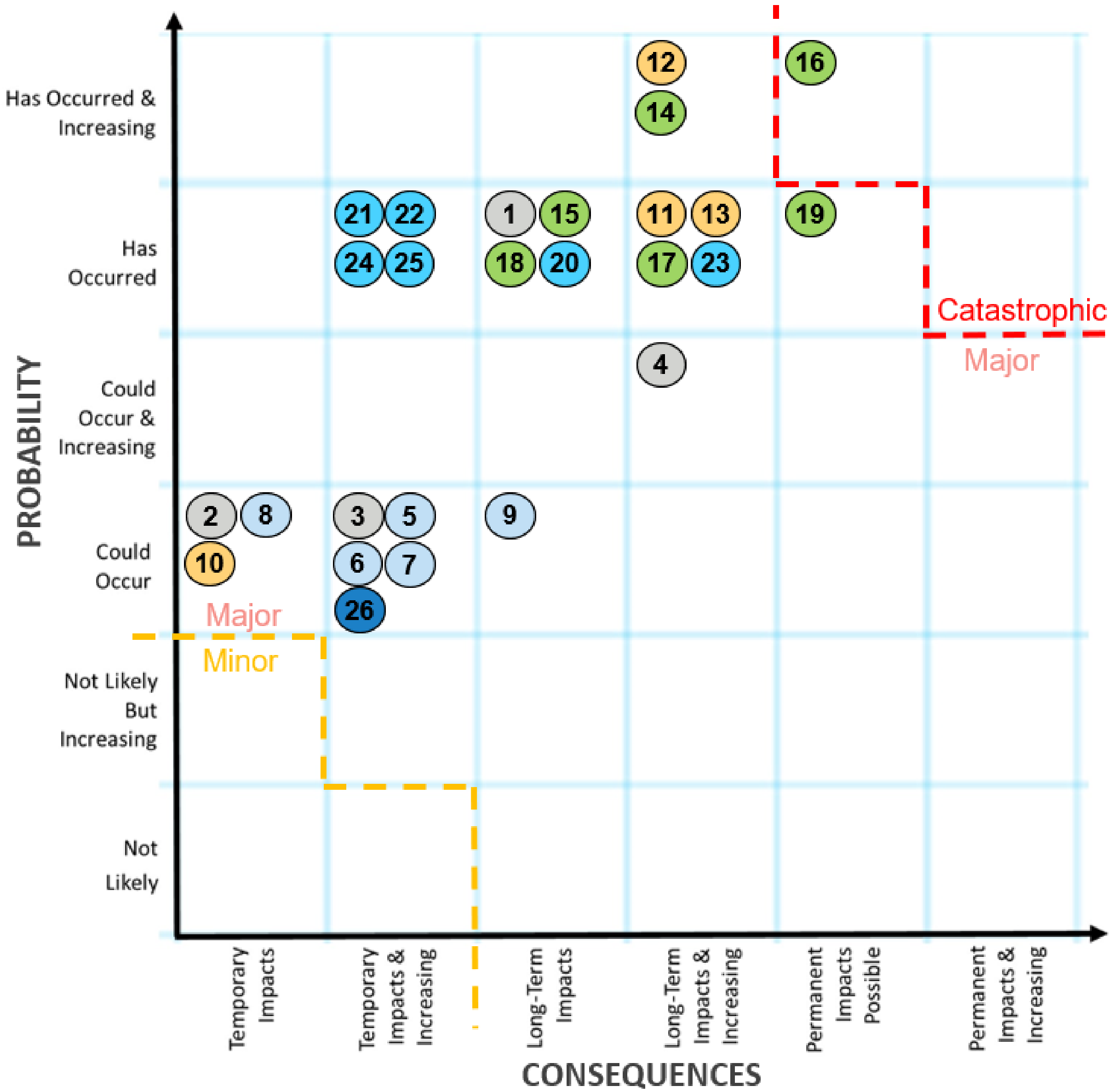


***Figure 5-7**. Coral Reef Fishery Value (left) and Reef Protection Value (right) in USD $ (Images from EPA, 2012).*



1	Coastal flooding	Cyclone
2	Loss of power	
3	High winds	
4	Sea level rise	
5	Flash flooding	Freshwater
6	Riverine flooding	
7	Erosion	
8	Landslide/Mudslide	
9	Sedimentation	
10	Saltwater spray	Coastal
11	Loss of living breakwater	
12	Coastal erosion	
13	Sea level rise	
14	Loss of fish habitat	Habitat
15	Sedimentation	
16	Coral reef degradation	
17	Nutrient loading	
18	Wildfires	
19	Invasive species	
20	Nutrient loading	Water Supply
21	Sedimentation	
22	Drought	
23	Over-use of NGLA	
24	Pollution near water supply wells	
25	Storm water management issues	
26	Tsunami	T

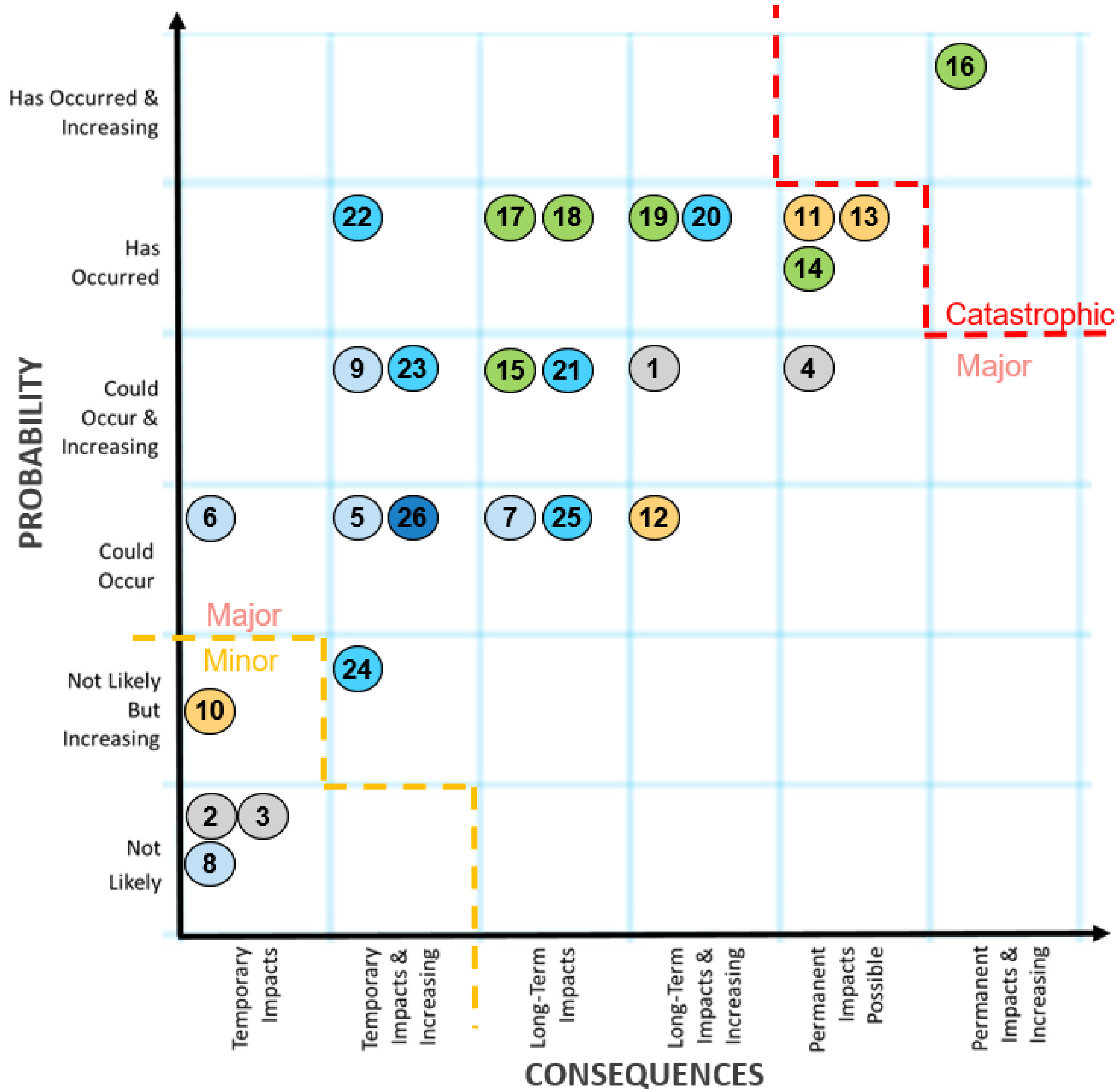
Figure 5-8. *Risk to Ecosystem Services*

5.2.3.2 Species Loss

Coral reef degradation was identified as a catastrophic risk to species loss. Coral reefs are at risk from natural and anthropogenic sources and habitat disturbance increases extinction risk for many species (Graham et al., 2011). The surrounding five marine reserves may not provide a sufficient replacement habitat for fish biodiversity (Jones et al., 2004). Additionally, of the 22 species of coral listed on the threatened species list, three can be found on Guam's reefs. They are the *Acropora globiceps, Acropora retuse,* and the *Seriatopora aculeata.* Animal listings include green sea turtle (*Chelonia mydas)* (endangered); hawksbill sea turtle *(Eretmochelys imbricata)* (endangered); oceanic whitetip shark (*Carcharhinus longimanus)* (threatened); and scalloped hammerhead shark (*Sphyrna lewini)* (threatened). Information on specific corals may be found in the Appendix D attachment.

A well-balanced ecosystem maintains the health of the environment. If a species has a unique function in its ecosystem, its loss can prompt cascading effects through the food chain, impacting other species and the ecosystem itself. Many individual species, such as parrotfish, are important indicators of environmental quality.

The summary of risks to species loss is shown in Figure 5-9.



1	Coastal flooding	Cyclone	
2	Loss of power		
3	High winds		
4	Sea level rise		
5	Flash flooding	Freshwater	
6	Riverine flooding		
7	Erosion		
8	Landslide/Mudslide		
9	Sedimentation		
10	Saltwater spray	Coastal	
11	Loss of living breakwater		
12	Coastal erosion		
13	Sea level rise		
14	Loss of fish habitat	Habitat	
15	Sedimentation		
16	Coral reef degradation		
17	Nutrient loading		
18	Wildfires		
19	Invasive species		
20	Nutrient loading	Water Supply	
21	Sedimentation		
22	Drought		
23	Over-use of NGLA		
24	Pollution near water supply wells		
25	Storm water management issues		
26	Tsunami	T	

***Figure 5-9**. Risk to Species Loss*

5.2.3.3 Habitat Loss

The loss of living breakwater, loss of fish habitat, and coral reef degradation were rated as catastrophic habitat loss risks.

The loss of corals that act as a living breakwater affects coastal habitats. Without protection, waves will erode beaches and cliffs at a higher rate. Coastal erosion results in the long-term increase of water turbidity, stressing corals and interfering with their ability to grow and reproduce (Shadrin, 2013). Aquatic organisms have difficulty finding breeding grounds and are negatively impacted by nutrients or pollutants carried in the sediment.

As corals degrade fish lose their habitat. For species that rely solely on live coral tissues at a food source, like butterflyfishes (*Chaetodontidae species*), declines in corals abundance result in decreased fish populations. Corals also act as a shelter site from predators. Declines in shelter spaces may increase predator-induced mortality or cause fish to vacate the reef (Bostrom-Einarsson et al., 2018).

Coral reefs represent less than 1% of the world's oceans yet are home to almost one quarter of all ocean species. Their degradation contributes to the habitat loss of fish, sponges, sea turtles, and more. Growing at a rate of 0.008 to 0.12 inches per year, coral colonies take a long time to regrow. When stressed, corals lose their algae and when the stress persists the damage is irreversible. The permanent impacts described above from the loss of corals (NOAA, 2021) contributed to the catastrophic rating.

Results of the habitat loss risk assessment are shown in Figure 5-10.

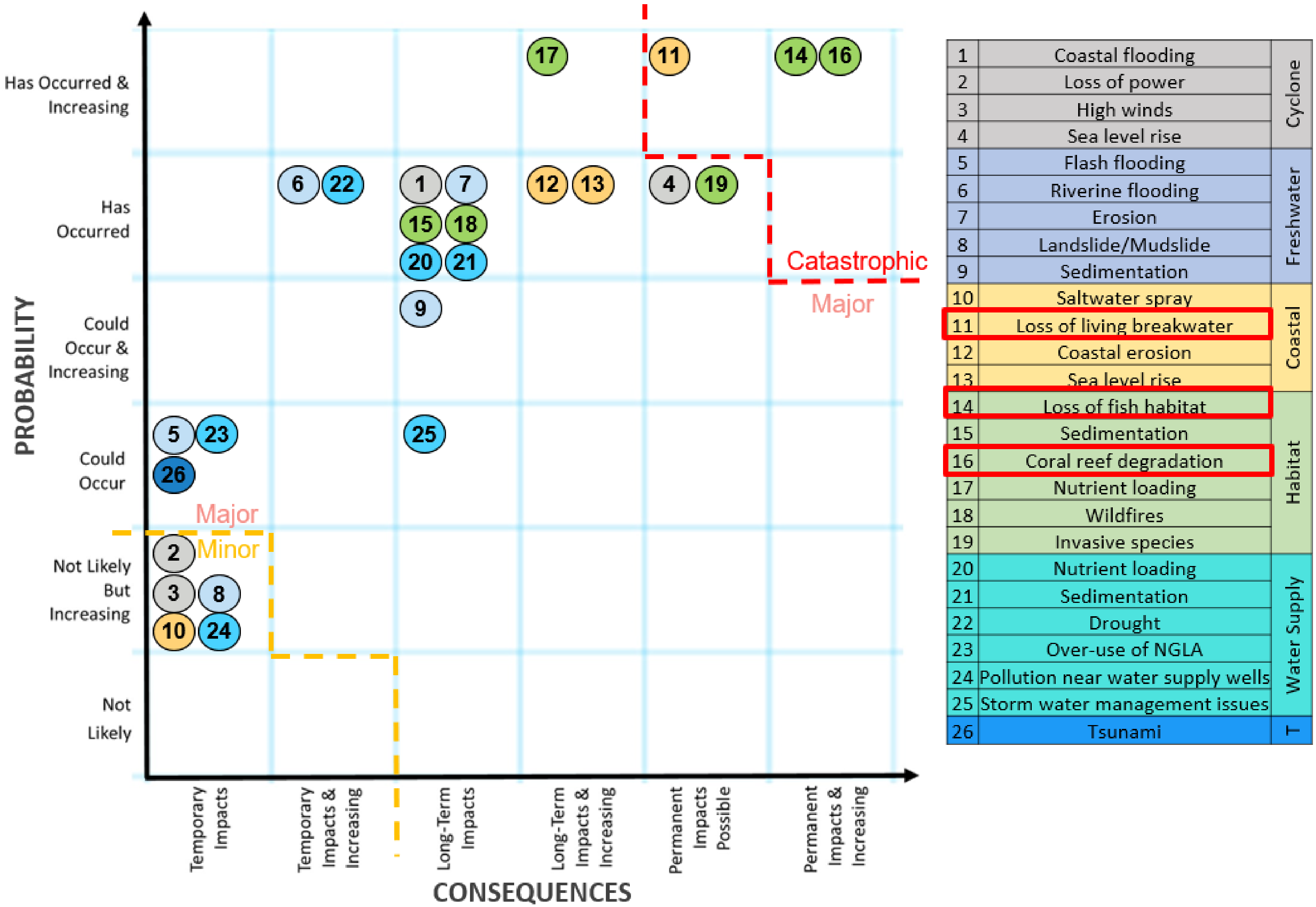


***Figure 5-10**. Risk to Habitat Loss*

5.2.3.4 Cultural Resources Risk

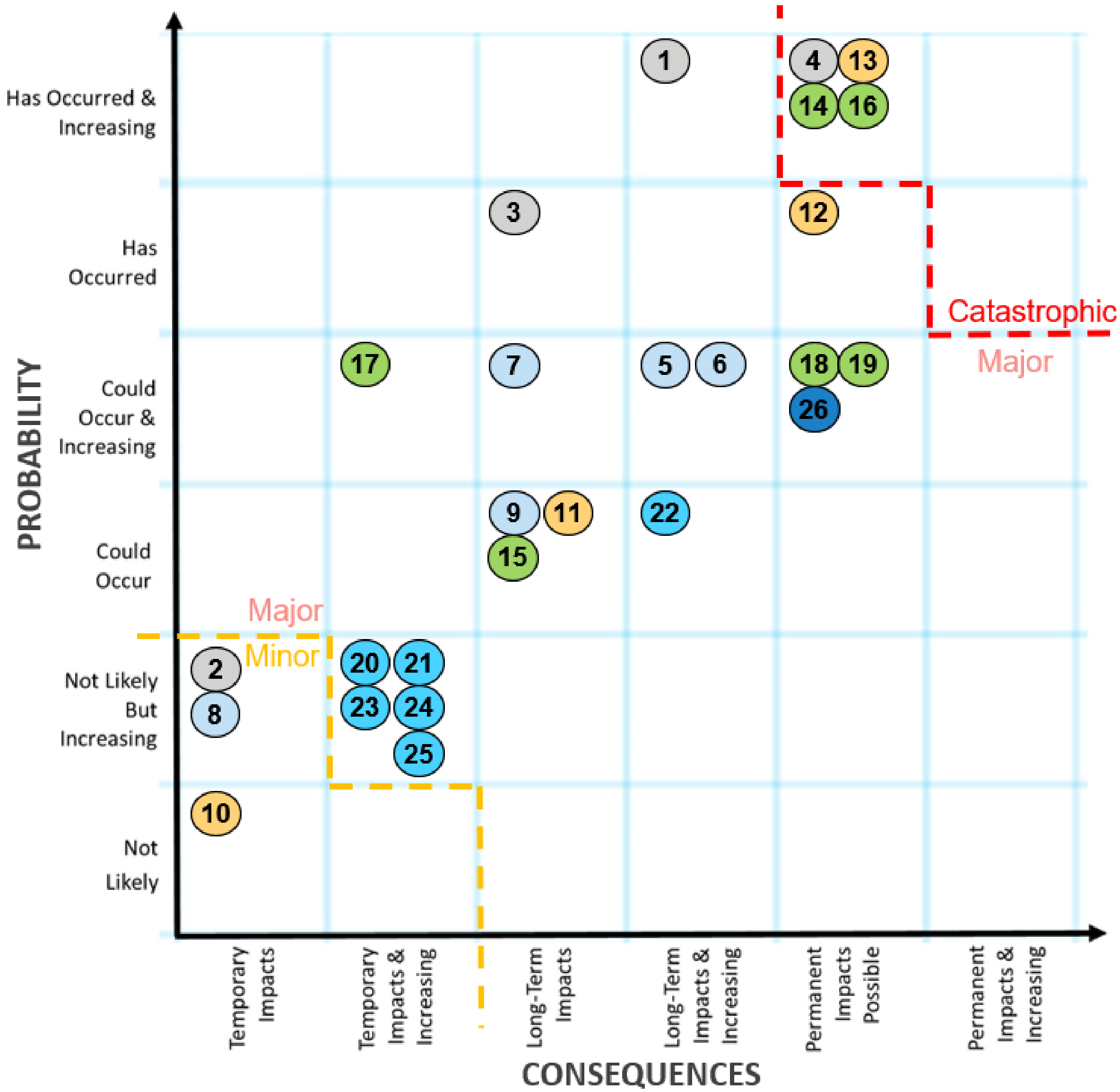
Guam's Historic Preservation Plan has documented irreplaceable damage to tangible cultural resources from natural hazards or disaster events. Destructive winds, storm surge flooding, river and stormwater flooding, high surf, coastal erosion, salt spray, and typhoon events have diminished or destroyed the integrity of archaeological sites and historic built-environment resources. Damage to museums and archival spaces holding important records and artifacts was another issue recorded from typhoon storm flooding (Guam HPO, 2007). The location of archaeological sites depends largely on habitation and settlement patterns, including proximity to marine or natural resources, as well as areas with traditional importance to the Chamorro people. Pre-Latte Period sites documented in the past had relatively small site boundaries and were located along flat elevated coastal areas, near coastal lagoons, or on low terraces above beaches. These sites would most likely face long term impacts related to tsunamis, coastal and riverine flooding, and coastal erosion. Efforts to protect these sites from flooding as well as mitigation either through recording, restoration, and excavation before their significance is lost makes the impacts less than permanent. Impacts for the problems identified above are therefore considered major but not catastrophic.

SLR, loss of fish habitat, and coral reef degradation were rated as catastrophic cultural resources loss risks. The effects of RSLR are particularly catastrophic to cultural resources of Guam because practically all the island's significant cultural resources are located at the coast or shoreline. SLR, coral reef degradation, and loss of fish habitat will have adverse and potentially permanent effects towards cultural resources and traditional cultural properties. Community recreational use, access, or practices can be limited or abolished from these problems. One documented example is for fish habitat loss and coral reef degradation. The Chamorro people of Guam and other Pacific Islander communities continue to depend on fishing and locally caught seafood to preserve their cultural traditions. Prehistoric and World War II cultural heritage sites are usually located by the coastline and may face limited access from SLR. Coral reefs are also considered a significant part of the community's cultural and natural heritage.

Prehistoric and World War II cultural heritage sites are usually located by the coastline and are considered historical landmarks as well as public attractions by tourists. Popular cultural heritage sites include several Spanish defensive forts throughout the island, abandoned village sites like Haputo, which also functions as an ecological reserve, and latte stone sites. Latte Stone Park is one example that serves as an urban park in Hagåtña today. SLR would limit access by residents, researchers, and tourists making the impact fall within the catastrophic category. The practice of sharing fish is used for cultural events by the community for weddings, funerals, neighborhood parties, village fiestas, and church events. More than half of Guam's local fishermen answered in a survey that fish is used not only for sustenance and economic benefit but also for upkeeping their cultural values and practices (Guamapedia, 2021).

Coral reef degradation and loss of fish habitat would most likely impact intangible cultural resources. Guam's subsistence fishing has already been identified as a significant issue for the Chamorro people, who wish to teach local fishing methods to Chamorro youth. Chamorro elders stated that their traditional fishing and maritime practices should be passed on to the younger generations. This is one of their principal ways to preserve their Chamorro cultural identity and practices (Beukering 2007).

The risks to cultural resources are shown in Figure 511.



1	Coastal flooding	Cyclone
2	Loss of power	
3	High winds	
4	Sea level rise	
5	Flash flooding	Freshwater
6	Riverine flooding	
7	Erosion	
8	Landslide/Mudslide	
9	Sedimentation	
10	Saltwater spray	Coastal
11	Loss of living breakwater	
12	Coastal erosion	
13	Sea level rise	
14	Loss of fish habitat	Habitat
15	Sedimentation	
16	Coral reef degradation	
17	Nutrient loading	
18	Wildfires	
19	Invasive species	
20	Nutrient loading	Water Supply
21	Sedimentation	
22	Drought	
23	Over-use of NGLA	
24	Pollution near water supply wells	
25	Storm water management issues	
26	Tsunami	T

Figure 5-11. *Risk to Cultural Resources*

5.2.3.5 Summary Risk to Environmental Factors

For environmental risk, stressors were evaluated for each risk index: ecosystem services, species loss, habitat loss, and cultural resources. The single highest ranking between indices in the social categories was carried through for the overall environmental risk assessment.

The 42 mi^2 of coral reef surrounding the island are susceptible to degredation by coral bleaching, pollution, and sedimentation. The loss of reef presents a high-risk loss of ecosystem services such as fish abundance, shoreline protection, and tourism and recreation. The reef acts as a living breakwater protecting the coast from storm surges during tropical cycles or tsunami events. A loss of coral also equates to a loss of fish habitat, and a loss of biodiversity, which has long-term to permanent effects.

As many cultural heritage sites are in low-lying coastal areas, SLR would limit access by residents, researchers, and tourists, impacting cultural events and practices.

The stressors related to the environmental risks are interdependent and the extent of adverse effects may not be fully realized until a natural hazard or disaster happens.

The summary of risks to environmental resources are shown in Figure 5-12.

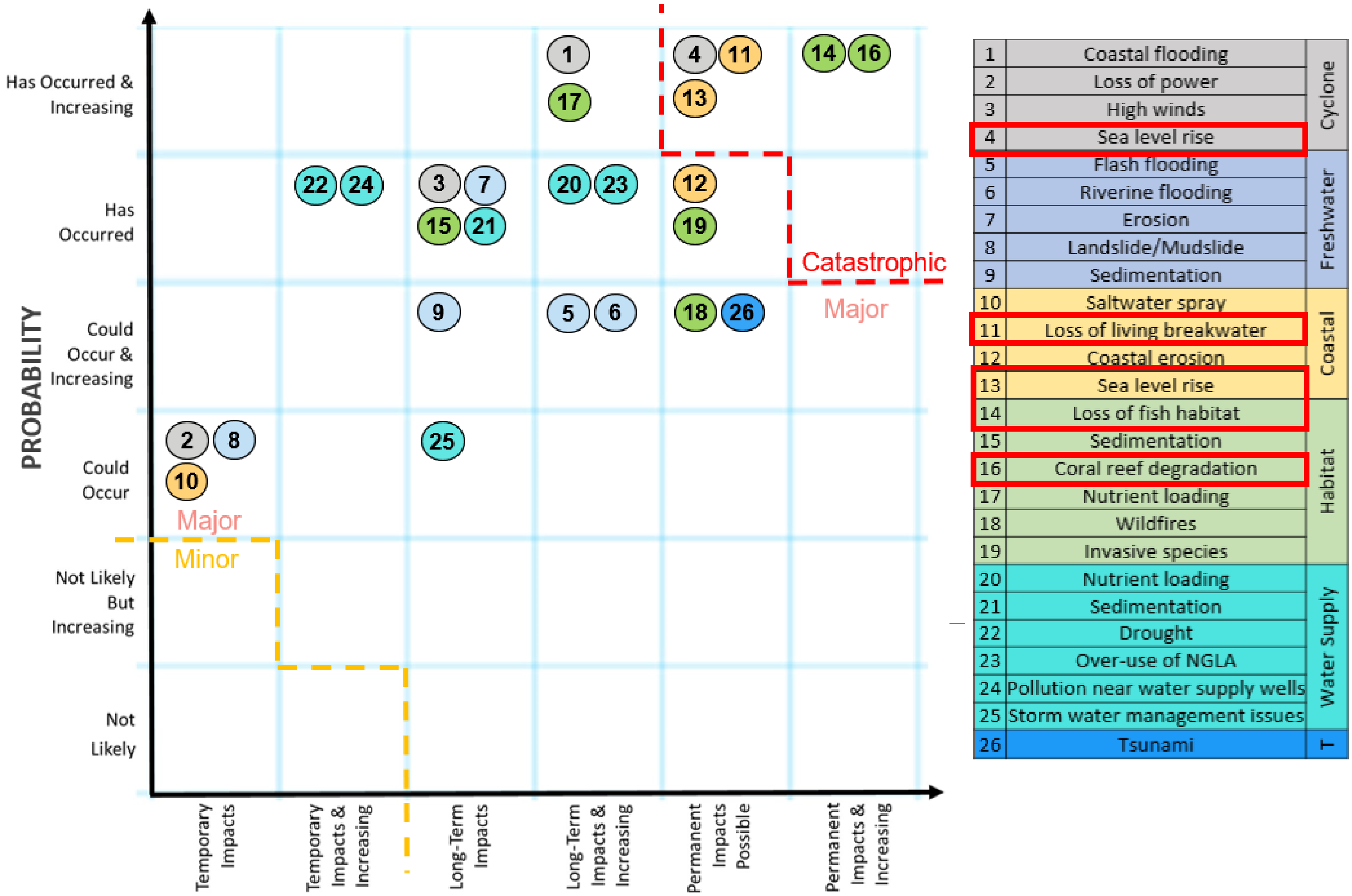


***Figure 5-12**. Summary Risk to Environmental Factors*

5.2.4 Life Loss Risk

Life loss risk was qualitatively assessed based on the probability of a stressor occurring in any given year and the potential scale of consequences that could result from that stressor occurring (Table 5-7 and Table 5-8). For this study, no differentiation was made between life loss directly caused by a stressor and indirect life loss. To identify the highest relative risks to life loss, the catastrophic category (above the red dashed line) was defined as those stressors likely or very likely to result in moderate magnitude life loss and those stressors with any probability of resulting in high magnitude life loss. The problems and stressors identified as potentially resulting in catastrophic life loss were coastal flooding, loss of power and high winds from tropical cyclones, flash flooding during heavy rainfall, and tsunami events. The summary of life loss risks may be found in Figure 513.

During tropical cyclones, storm surges batter the coast and produce rip currents. People near the shore have been swept away by these waves, as well as coastal flooding. Storm surge is likely to become worse with a loss of corals, which diminish wave intensity. Life loss during tropical cyclones also comes from high winds. Debris such as signs, roofs, and other small items become a deadly hazard in the winds that reach 150mph. In previous years, the winds have torn off roofs on multiple houses creating an airborne hazard and leaving residents exposed. The potential for loss of life is also high during tropical cyclones when the island loses power. Critical infrastructure such as hospitals, fire departments, and evacuation centers are impacted. Homes that cannot self-supply electricity may not be able to access potable water or keep potentially lifesaving medicines stored at the correct temperature.

Flash floods can occur suddenly within hours of excessive heavy rainfall. With little or no warning, people are caught unaware and may be seriously injured or lose their life if they are near in or near a river. Debris carried in flash floods may form temporary debris dams, which, upon failure, could send an additional surge of water downstream. This may happen repeatedly during the flash flood.

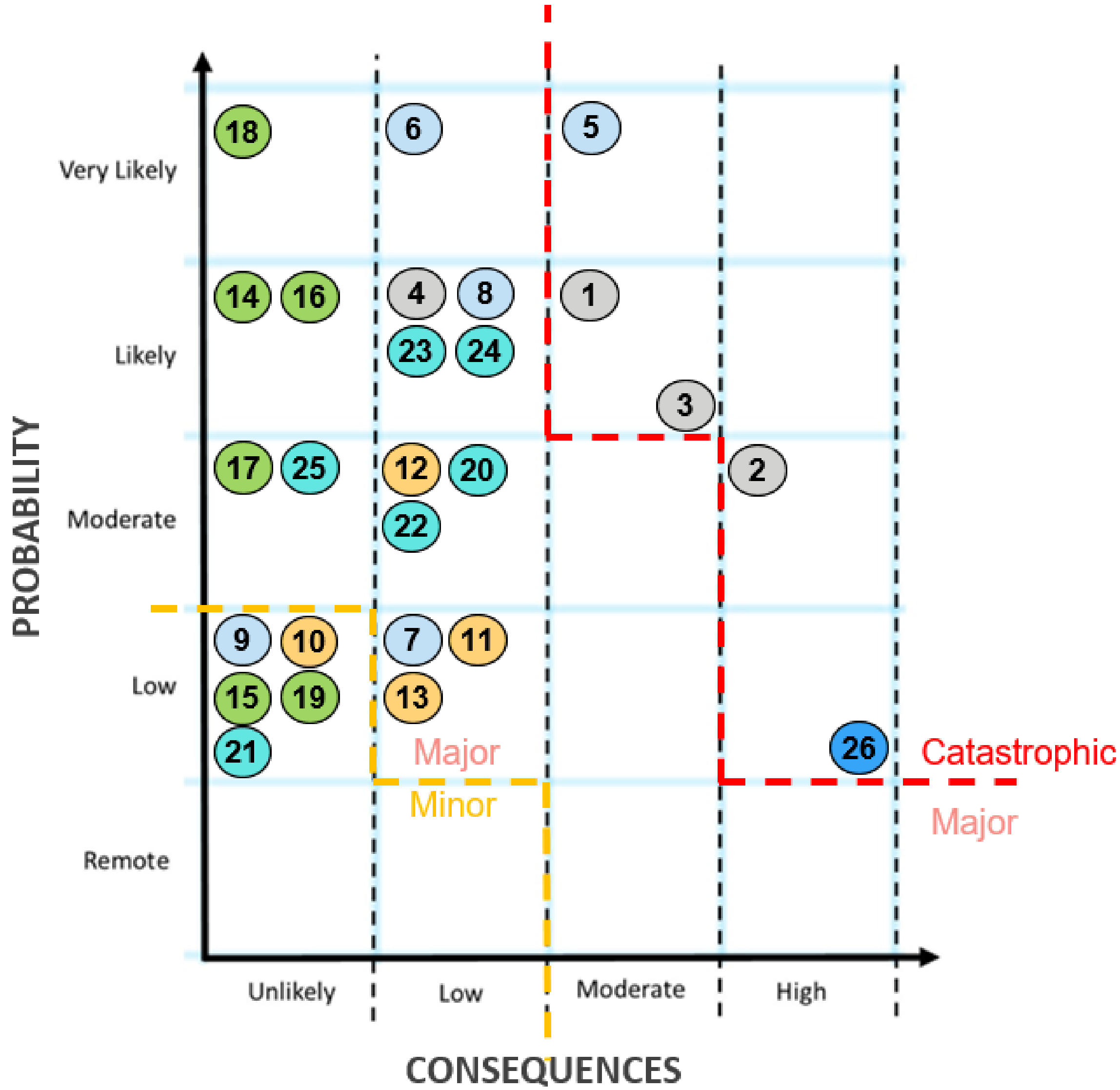
While tsunami events are infrequent (Guam Hazard Mitigation Plan, 2019, NOAA 2012), most of the island’s population resides near the coast and does not have a substantial lead time when warnings for a tsunami are delivered. Tsunami can result in life loss and other life safety risks. The wave runups and receding waters may damage infrastructure and shorelines. Survivors may not be able to access clean drinking water or medical care for injuries. Standing water after a tsunami event may also lead to infectious disease outbreaks.

Table 5-7 *Estimated Life Loss Probability*

Probability	Definition
Remote	It is very unlikely a stressor will occur in any given year.
Low	There is a low chance a stressor will occur in any given year.
Moderate	There is a moderate chance a stressor will occur in any given year.
Likely	It is likely a stressor will occur in any given year.
Very Likely	It is very likely a stressor will occur in any given year.

Table 5-8 *Estimated Consequence of Life Loss*

Consequences	Definition
Unlikely Life Loss	It is not anticipated a stressor will result in any life loss.
Low Magnitude Life Loss	If a stressor occurs, it is anticipated a few lives will be lost.
Moderate Magnitude Life Loss	If a stressor occurs, it is anticipated more than a few lives will be lost.
High Magnitude Life Loss	If a stressor occurs, significant life loss is inevitable.



#	Risk	Category
1	Coastal flooding	Cyclone
2	Loss of power	Cyclone
3	High winds	Cyclone
4	Sea level rise	Cyclone
5	Flash flooding	Freshwater
6	Riverine flooding	Freshwater
7	Erosion	Freshwater
8	Landslide/Mudslide	Freshwater
9	Sedimentation	Freshwater
10	Saltwater spray	Coastal
11	Loss of living breakwater	Coastal
12	Coastal erosion	Coastal
13	Sea level rise	Coastal
14	Loss of fish habitat	Habitat
15	Sedimentation	Habitat
16	Coral reef degradation	Habitat
17	Nutrient loading	Habitat
18	Wildfires	Habitat
19	Invasive species	Habitat
20	Nutrient loading	Water Supply
21	Sedimentation	Water Supply
22	Drought	Water Supply
23	Over-use of NGLA	Water Supply
24	Pollution near water supply wells	Water Supply
25	Storm water management issues	Water Supply
26	Tsunami	T

Figure 5-13. *Life Loss Risk Summary*

5.3 Risk Summary

The stressors that were ranked as the highest relative risk (above the red dashed line) from any metric were categorized as catastrophic. Problems and stressors for which no relative risk ranking fell among the highest risks were categorized as major or minor. The overall comparative risk summary is shown in Figure 514. For problems categorized as catastrophic, immediate steps should be taken to reduce risks through direct actions, evaluation of potential options for reducing risks, or filling data gaps. For problems categorized as major, incremental steps should be taken to reduce these significant risks. No problems were categorized as minor, as each problem was ranked as major or catastrophic for at least one risk metric.

Stakeholder input on individual risk assessment tables based on individual factors can be found in Appendix A – Interagency Engagement.

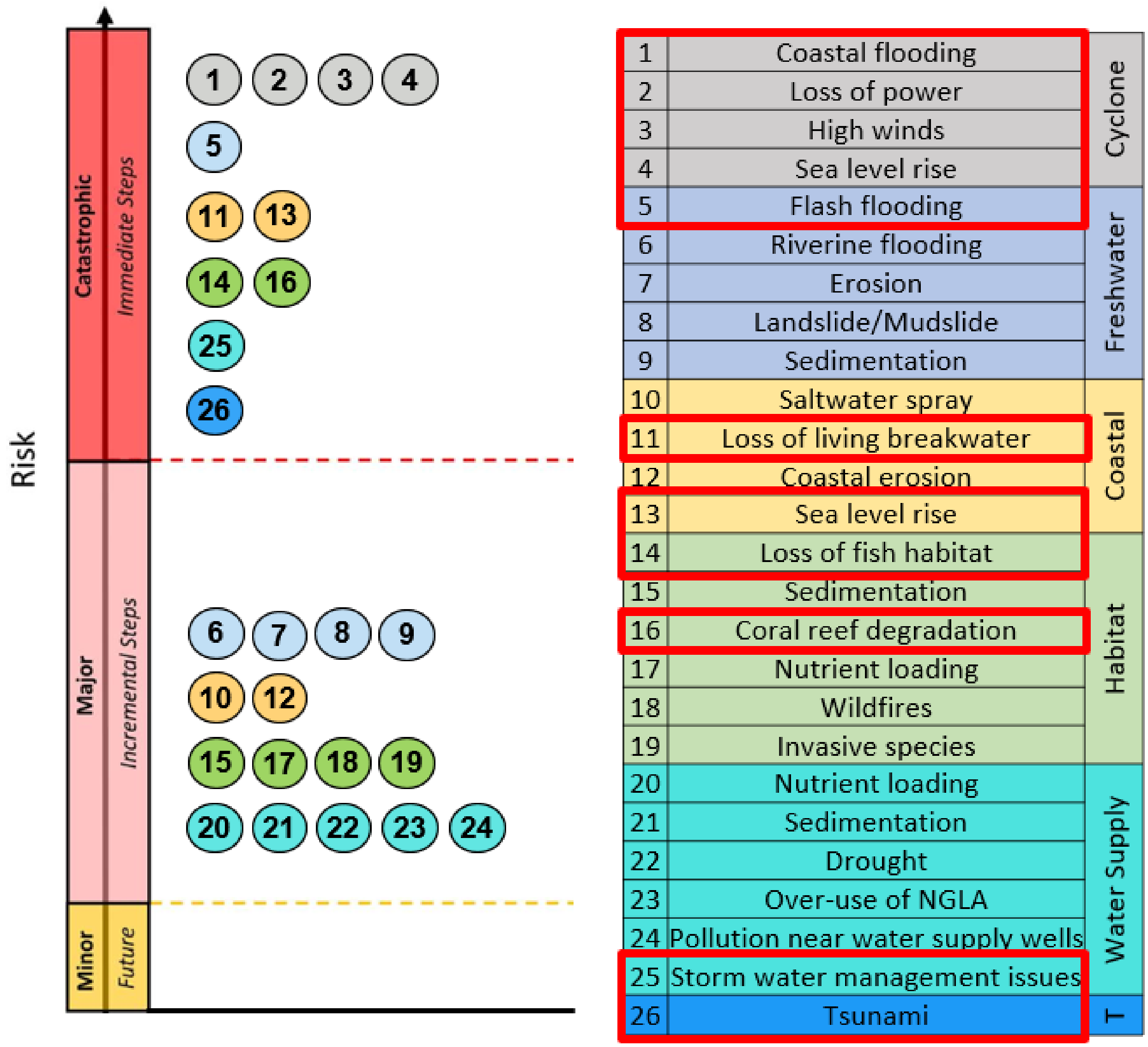


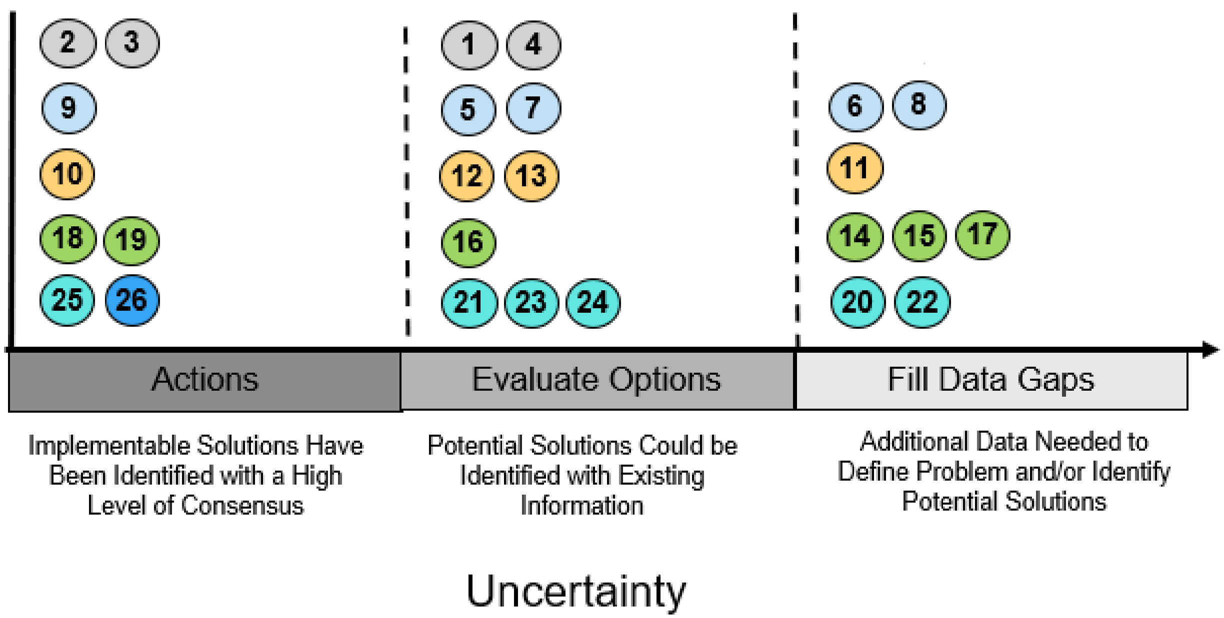
Figure 5-14. *Risk Summary of Identified Problems*

5.4 Uncertainty Assessment

In addition to risk, a qualitative assessment of uncertainty was also performed for each problem and stressor to help identify the appropriate type of recommendations (Figure 5-15Figure 515). This qualitative uncertainty assessment was conducted through a review of existing information and with input from the study partner and stakeholders through a series of collaborative workshops. Appendix A-1 provides details regarding this engagement process.

Uncertainty categories:

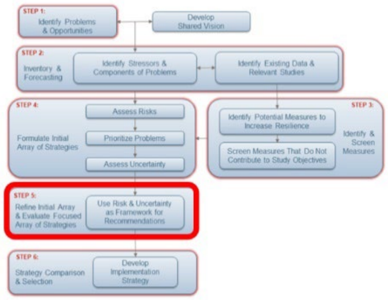
-
- Action: Implementable solutions have been identified with a high level of consensus (*actions* can be recommended);
- Evaluation Options: Potential solutions could be defined with existing information (an *evaluation of potential options* can be recommended); or
- Fill Data Gaps: Additional data would be required to better define the problem and/or identify potential solutions (recommendations focus on *filling data gaps*).



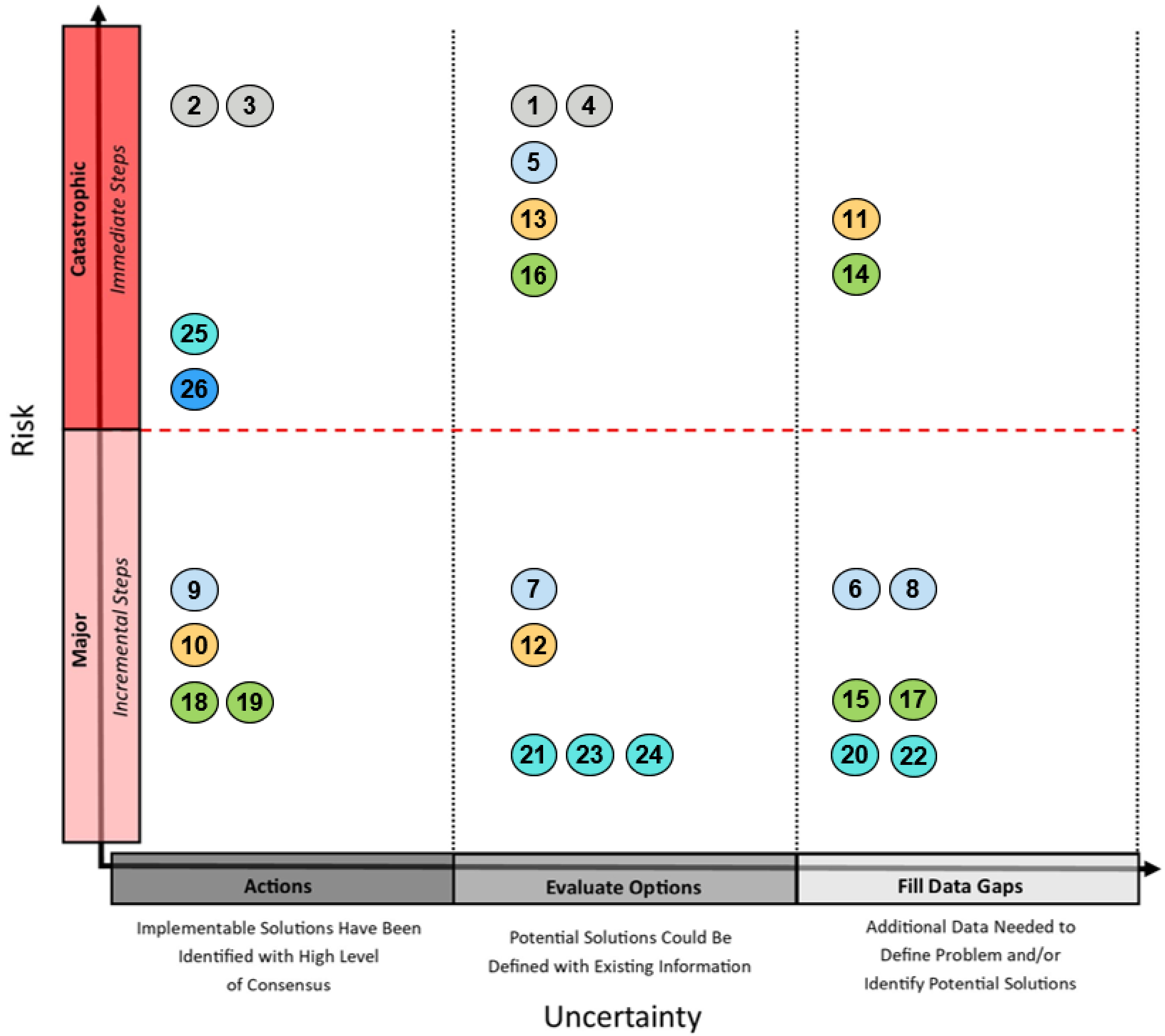
1	Coastal flooding	Cyclone
2	Loss of power	
3	High winds	
4	Sea level rise	
5	Flash flooding	Freshwater
6	Riverine flooding	
7	Erosion	
8	Landslide/Mudslide	
9	Sedimentation	
10	Saltwater spray	Coastal
11	Loss of living breakwater	
12	Coastal erosion	
13	Sea level rise	
14	Loss of fish habitat	Habitat
15	Sedimentation	
16	Coral reef degradation	
17	Nutrient loading	
18	Wildfires	
19	Invasive species	
20	Nutrient loading	Water Supply
21	Sedimentation	
22	Drought	
23	Over-use of NGLA	
24	Pollution near water supply wells	
25	Storm water management issues	
26	Tsunami	T

***Figure 5-15**. Uncertainty of Potential Solutions*

5.5 Using Risk in Framing Recommendations



The risk and uncertainty results (Figures 5-14 and 5-15) were used to develop a framework for the appropriate types (uncertainty-based) and timing (risk-based) for recommendations (Figure 5-16). Near-term actions were identified to reduce potentially catastrophic risks for which implementable solutions were identified with a high level of consensus among agencies and stakeholders; longer-term, incremental actions were identified to reduce major risks with similar uncertainty. Options for near-term evaluation were identified for potentially catastrophic risks where sufficient data and information exists to define potential solutions; options for incremental steps toward evaluation were identified to reduce major risks with similar uncertainty. Data gaps that should be filled in the near-term were identified for potentially catastrophic risks where warranted; incremental steps to fill data gaps were identified for major risks with similar uncertainty.



1	Coastal flooding	Cyclone
2	Loss of power	Cyclone
3	High winds	Cyclone
4	Sea level rise	Cyclone
5	Flash flooding	Freshwater
6	Riverine flooding	Freshwater
7	Erosion	Freshwater
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15	Sedimentation	Habitat
16	Coral reef degradation	Habitat
17	Nutrient loading	Habitat
18	Wildfires	Habitat
19	Invasive species	Habitat
20	Nutrient loading	Water Supply
21	Sedimentation	Water Supply
22	Drought	Water Supply
23	Over-use of NGLA	Water Supply
24	Pollution near water supply wells	Water Supply
25	Storm water management issues	Water Supply
26	Tsunami	T

Figure 5-16. *Resultant Risk- and Uncertainty-Based Recommendations*

6 Recommendation and Implementation Strategy

The recommendation and implementation strategies are based on the risk- and uncertainty-based framework described in Section 5.5. Problems and stressors within each section of the framework are grouped into cohesive recommendations, as shown in Figure 6-1. Two exceptions to this structure are inland erosion and coastal erosion (stressors 7 and 12, respectively). These stressors were grouped with other coastal stressors within the catastrophic category for the purpose of creating cohesive recommendations. This is because flash flooding, steep slopes, and poor stormwater management, each classified as catastrophic, result in erosion. Similarly, rising sea levels and coastal flooding contribute to erosion, which in turn contributes to sedimentation that degrades coral reefs, all of which are classified as catastrophic. Due to the interconnectedness of erosion and these stressors, freshwater and coastal erosion were grouped with other related recommendations in the catastrophic category.

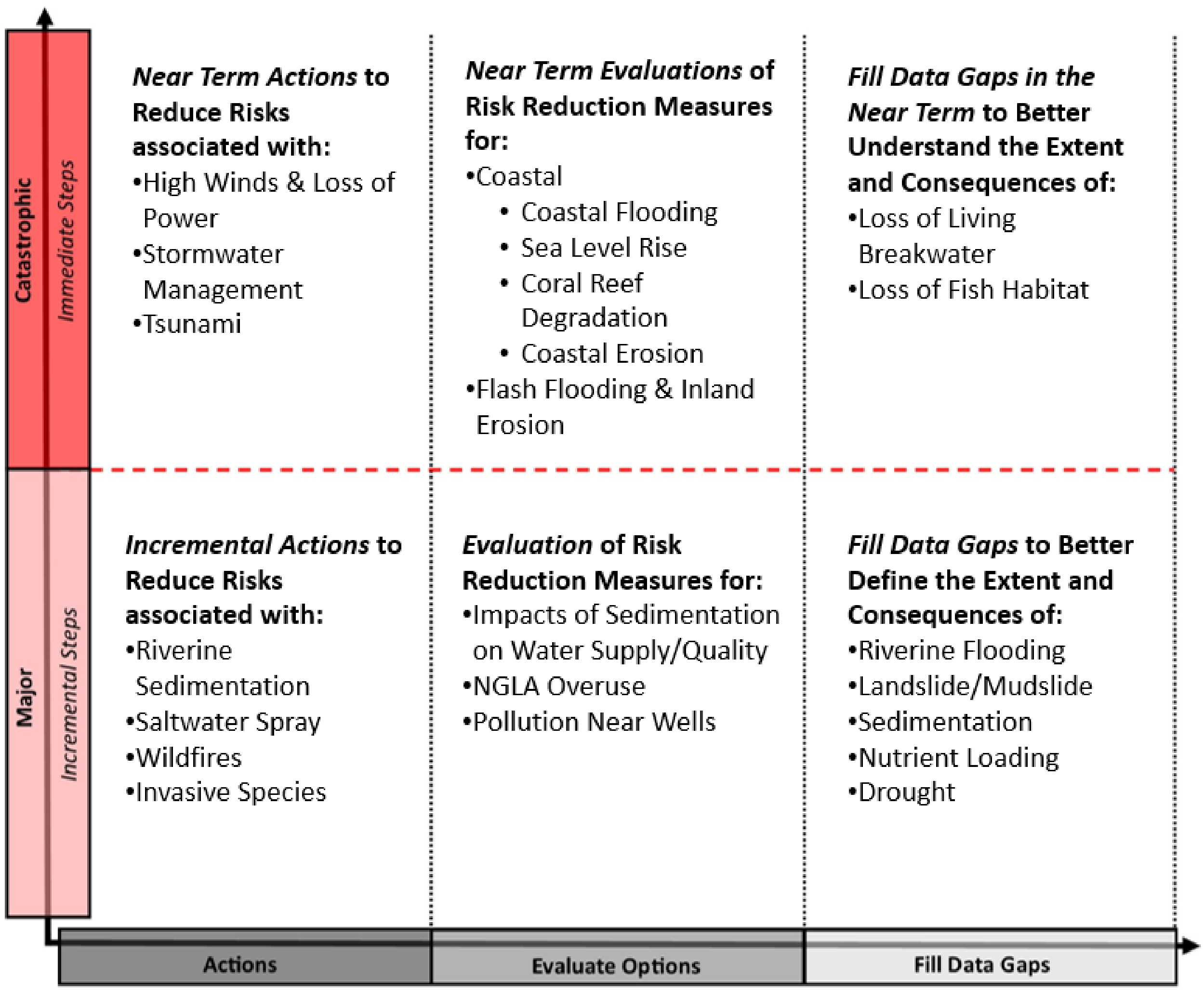
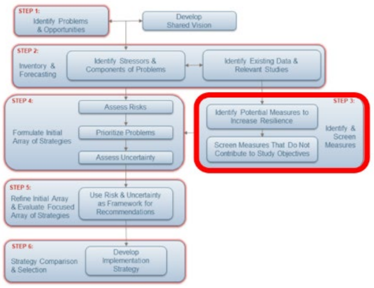
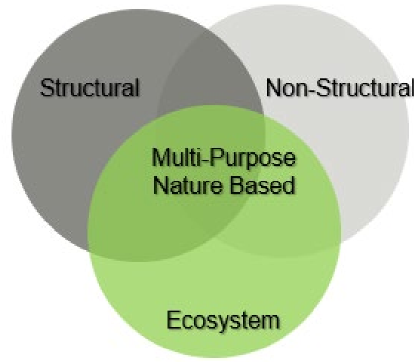


Figure 6-1. *Recommendations and Implementation Strategy*

6.1 Management Measures





A management measure is a feature or activity at a specific location that addresses one or more of the problems and planning objectives. Measures were compiled into recommendations through assessing the risk and uncertainty of problem categories and addressing the most critical needs based on those evaluations. No measures were screened from further consideration, as all identified measures contribute to the identified planning objectives.

Three basic types of measures were identified:

- Structural – physical modifications designed to reduce the frequency or consequence.
- Non-Structural – focus on reducing or solving problems without constructing new structures. Measures include actions such as policies, education, or emergency action exercises.
- Nature based – landscape features that are used to provide engineering functions relevant to risk management, while producing additional economic, environmental, and/or social benefits. These features may occur naturally in landscapes or be engineered, constructed and/or restored to mimic natural conditions.

Consistent with the goals of this WA to focus on nature-based solutions, where appropriate, limited structural measures are considered with a larger emphasis placed on non-structural and nature-based measures. A description of measures is shown in Table 6-1 through Table 6-3.

Table 6-1 *Description of Structural Based Measures*

Structural Measures Description	Tropical Cyclone	Freshwater Flooding	Coastal Hazards	Habitat Loss	Water Supply	Tsunami
Shoreline Protection – structures that protect shorelines from erosion caused by wave action, storm surge, and currents.	X	-	X	-	-	-
Improve Urban Drainage Network – urban drainage systems are a collection of water management features including ditches, sewers, curbs and gutters, detention or retention basins, and pumps, valves, or gates to adjust or control the flow of rainwater runoff to reduce localized flooding. Systems can be improved to increase efficiency of drainage in an integrated fashion.	-	X	-	-	X	-
Septic to Sewer Conversion – convert septic systems to join the sewer network rather than draining via septic fields.	-	-	-	-	X	-
Recurve Seawalls - vertical impermeable seawall with a curved or straight seaward overhang sited at the top of the seawall. The recurve wall reduces wave overtopping by deflecting up-rushing water seawards as waves make impact with the wall.	X	-	-	-	-	-
Increased Use of Solar Panels - solar panels are waterproof and can withstand 140mph winds. Solar panels can continue to provide a residence with power when other forms of power are offline.	X	-	-	-	-	-
Underground Power Distribution – powerlines located underground will prevent power lines being damaged from high winds. Powerlines must be located away from areas susceptible to inundation.	X	-	-	-	-	-
Enhance Stream & Weather Gage Networks - stream and rain gage data are critical datasets in understanding flooding and flood risk. They help to understand the relationship between precipitation and flood elevations, which determine the extent of flooding.	-	X	-	-	-	-
Water Bars on Roads & Public Paths - also called interceptor dikes, are road construction features such as soil berms used to intercept and redirect surface water to prevent erosion on sloping roads or cleared paths. These diagonal channels are placed intermittently across roads and paths to divert surface water into a stable drain.	-	X	-	-	-	-
Freshwater Catchment - an area where rain and run-off waters are collected and allowed to flow to a river, lake or ocean, or into the underground system.	-	-	-	-	X	-

Structural Measures Description	Tropical Cyclone	Freshwater Flooding	Coastal Hazards	Habitat Loss	Water Supply	Tsunami
Slope Drains & Terracing in Steep Terrain – slope drains allow water to flow downward with the aid of pipes or lined channels which extend along a slope. Terracing involves leveling a hillside in sections so the flat areas stack above one another like stairs. Both methods are designed to protect slopes from erosion-causing runoff.	-	X	X	-	X	-
Sediment Settling Basin - a temporary settling basin installed along a waterway or low-lying area to capture eroded or disturbed soil that is washed off during rainstorms to protect the water quality of nearby streams, rivers, lakes, or bays.	-	X	-	X	X	-
Submerged Breakwaters - offshore continuous structure with its top at or below seawater and is usually constructed parallel to the shoreline in shallow water. They are designed to reduce the incident wave energy to protect the coasts against erosion and port channels from sand deposition.	X	-	X	-	-	-
Shoreline Revetment - sloping structures made from erosion-resistant material, constructed directly on an existing slope, embankment, or dike that protect the area from strong waves and currents by dissipating and reducing wave action.	X	-	X	-	-	-
Sediment Control Structures on Streams - sediment traps are temporary or permanent sediment control structures that reduce water velocity and allow soil particles to settle.	-	-	-	-	X	-
Trash Racks Near Water Wells – designed to prevent large floating and submerged debris from entering stormwater and wastewater systems while maintaining water flow. Trash racks must be cleared of debris regularly to avoid clogging and water backups.	-	-	-	-	X	-

Table 6-2 *Description of Non-Structural Based Measures*

Non-Structural Measures Description	Tropical Cyclone	Freshwater Flooding	Coastal Hazards	Habitat Loss	Water Supply	Tsunami
Emergency Preparedness & Outreach - important organizational tool comprised of preparedness, prevention, response, recovery, and mitigation. Include stakeholders with strategies for locating, engaging, and communicating about organizational and personal emergency preparedness.	X	-	-	-	-	-
Emergency Generators for Critical Facilities - secondary sources of power capable of providing power during an outage.	X	-	-	-	-	-
Comprehensive Structure Inventory - asset management strategy needed to keep structures operational for a longer period and to avoid serious problems including deterioration or premature failures.	X	-	X	X	-	-
Wind Resilient New Construction – a strong continuous load path that holds the roof, walls, floors and foundation together, and protects against flying debris during an intense wind event.	X	-	-	-	-	-
Retrofit Buildings to Withstand High Winds - basic, intermediate, and advanced mitigation measures that include enhancing roof sheathing, larger diameter nails, stainless steel fasteners, secondary water barriers, gable end bracing, strengthening vents and soffits, replacing windows, enhancing interior and exterior wall coverings.	X	-	-	-	-	-
Scheduled Maintenance & Drain Cleaning - preventive maintenance that improves the lifespan of drains, manages bad odors, increases drainage speed, reduces clogs, and slows expensive repairs.	X	-	-	-	X	-
Annual Tsunami Drills - improves self-efficacy in tsunami risk management and generates two-way communication between experts and participants.	-	-	-	-	-	X
Tsunami Zone Mapping with SLR - combination of decision analysis, land use planning, public participation, and conflict resolution approaches that can help address the governance challenges faced in responding to SLR.	-	-	-	-	-	X
Tsunami Warning Systems - a network of sensors to detect tsunamis and a communication infrastructure to issue timely alarms to permit evacuation of coastal areas.	-	-	-	-	-	X

Non-Structural Measures Description	Tropical Cyclone	Freshwater Flooding	Coastal Hazards	Habitat Loss	Water Supply	Tsunami
Signage & Hazard Alerts – the tsunami hazard zone should be marked, especially in places where many people congregate like beaches, parks, and developed waterfronts. Escape routes and shelters should be marked.	-	X	X	-	-	X-
Tsunami Education, Outreach, & Risk Communication - to encourage people to prepare, outreach strategies must persuade community members to discuss tsunami hazard issues and to identify the resources and information they need to deal with the consequences a tsunami would pose for them and ensure the community-agency relationship is complementary and empowering.	-	-	-	-	-	X
Tabletop Exercises for First Responders - involves key personnel discussing simulated scenarios in an informal setting. Exercises can be used to assess plans, policies and procedures.	-	-	-	-	-	X
Development Management in Tsunami Zones - entails formulating proper strategies for management of the coastal areas and for the reduction of damage likely to occur due to catastrophic events along the coast.	-	-	-	-	-	X
Education & Land Use Practices to Reduce Runoff - aimed at developing an understanding of the relationship between land use decisions and the environment, pamphlets, newsletters, emails, and websites can be made available and meetings and workshops can be used to educate citizens on ways to reduce runoff. Leaving the soil surface undisturbed from harvest to planting, using pervious surfaces, planting cover crops, and maintaining vegetated buffer strips around fields and streams are ways to reduce runoff.	-	X	-	-	X	-
Regulate & Enforce Agricultural Runoff in Protected Zones – agriculture producers can adopt soil and water conservation practices to reduce the runoff of sediment, nutrients, bacteria, pesticides, and other pollutants from their operations. Regulatory programs should be in place to regulate discharges from irrigated agricultural lands, preventing agricultural discharges from impairing the waters that receive the discharge.	-	X	-	-	X	-

Non-Structural Measures Description	Tropical Cyclone	Freshwater Flooding	Coastal Hazards	Habitat Loss	Water Supply	Tsunami
Education & Outreach on Water Conservation - can help water consumers make sound choices and preserve water resources for the future. These programs include placing efficiency tips in water bills and having specialized staff available to promote water efficiency.	-	-	-	-	X	-
Administration of Best Management Practices - policies, practices, or procedures implemented to mitigate the adverse environmental effects on surface water quality resulting from development.	-	X	-	-	X	-
Building Codes - design of reinforced structures that will have the characteristics required to resist damage from wind, rain, and corrosion.	X	-	X	-	-	-
Corrosion Control Measures - preventing or reduce corrosion, materials selection, non-destructive inspections for corrosion detection, coatings, finishes, cleaning materials and washings, repairs, and other maintenance activities.	-	-	X	-	-	-
Agricultural Protection Measures - may include establishing coastal forests and shelterbelts for increasing protection against wind and sea spray.	-	-	X	-	-	-
Fire Lookouts & Stations – a fire tower, usually located in a rural area, is a structure from which a fire lookout watches for smoke from forest fires, aiding in early detection. A fire station is a structure that houses vehicles, protective gear, fire hoses and other specialized fire equipment used for responding to a variety of fires.	-	-	-	X	-	-
Fire Road Development & Maintenance - unpaved roads built for wildfire control on undeveloped urban hills, foothills, and rural areas. They are built for backburning operations and act as fire containment lines. Due to their remote location, they suffer from adverse effects including erosion and weed invasion and must be maintained.	-	-	-	X	-	-
Community Wildfire Protection Plans - plans may address issues such as wildfire response, hazard mitigation, community preparedness, and/or structure protection. Identifies and prioritizes areas for fuel reduction treatments and recommends the types and methods of treatment.	-	-	-	X	-	-

Non-Structural Measures Description	Tropical Cyclone	Freshwater Flooding	Coastal Hazards	Habitat Loss	Water Supply	Tsunami
Invasive Species Eradication Technology - the application of emerging and dual-use technologies can represent a long-term cost-savings compared to the existing practices in the invasive species toolbox, which are often ineffective and inefficient.	-	-	-	X	-	-
Invasive Species Surveys - a research method used for collecting data from a predefined group of respondents to gain information and insights. Objectives of an invasive species survey might be to detect new invaders early, locate the number of species, prevent spread, mitigate existing infestations, restore native habitats, and continue monitoring populations.	-	-	-	X	-	-
Policy & Enforcement for Invasive Species – there are many state and federal laws that address some aspect of the enforcement, introduction, and spread of invasive species. Federal and local government, non-government organizations, academic institutions, and the public can work together to control invasive species through legislation and policy actions and enforcement.	-	-	-	X	-	--
Increased Invasive Species Outreach & Awareness - designed to increase public awareness of invasive species issues by providing general information and outreach materials.	-	-	-	X	-	-
Ballast Water Treatment - a system designed to remove and destroy/inactive biological organisms from ballast water. Methods of treatment include separation and filtration, ozone, electrical currents or UV radiation, or chemical solutions like biocides or chlorination.	-	-	-	X	-	-
Increased Customs Inspections - ensure comprehensive biosecurity inspections occur prior to arriving. Establish a fully contained animal and plant inspection facility.	-	-	-	X	-	-
Reduce Erosion Activity in Run Off Zones - agronomic practices focus on changes in soil and crop management such as reduced tillage, cover cropping and planting vegetation in critical areas. By intercepting and slowing precipitation hitting the ground, vegetation reduces the volume and rate of stormwater runoff. This helps protect soil from erosion and reduces flash flooding and debris flows.	-	X	-	-	-	-

Non-Structural Measures Description	Tropical Cyclone	Freshwater Flooding	Coastal Hazards	Habitat Loss	Water Supply	Tsunami
Storm Surge Risk Communication - effective risk communication can be thought of as a series of steps. Those at risk need to understand the hazard, receive and understand the message, know it applies to them, and know what to do.	X	-	-	-	-	-
Hydrologic and Hydraulic Modeling of Shoreline, Rivers, and Aquifer - computer software that simulates flow to predict the extent of water levels and flooding and to test ways to reduce the flooding.	X	X	X	-	-	-
Reduce Development in Floodplain via Zoning - zoning regulations can limit the exposure, defined as the number of people or value of assets that can be affected, through restricting development in flood-prone areas.	X	-	X	-	-	-
SLR Inundation Mapping - combination of decision analysis, land use planning, public participation, and conflict resolution approaches that can help address the governance challenges faced in responding to SLR.	X	-	X	-	-	-
Increase Vegetation and Pervious Surfaces - helps reduce runoff by allowing rainwater to infiltrate through the surface and into underlying layers, reducing flooding and erosion and filtering out pollution.	X	X	-	-	-	-
Establish Wellhead Protection Zones - helps to prevent groundwater contamination by managing the areas surrounding public drinking water supply from activities that have the potential to affect the quality of water and adversely affect human health.	-	X	-	-	X	-
Relocate or Elevate Infrastructure - moving structures from one location to another by disassembling and reassembling or raising and transporting. Elevating structures above estimated flood heights is an adaptive and mitigative measure to help reduce susceptibility to future flood damage.	X	-	X	-	-	-

Non-Structural Measures Description	Tropical Cyclone	Freshwater Flooding	Coastal Hazards	Habitat Loss	Water Supply	Tsunami
Master Planning Study - includes analysis, recommendations, and proposals for a site's population, economy, housing, transportation, community facilities, and land use. Sediment-imbalance issues requiring management may include coastal erosion. Plans should include interventions to mitigate the risk of coastal erosion.	-	X	-	-	-	-

Table 6-3 *Description of Nature Based Measures*

Nature Based Measures Description	Tropical Cyclone	Freshwater Flooding	Coastal Hazards	Habitat Loss	Water Supply	Tsunami
Diversions to Roadside Wetlands & Greenspaces - prevent storm water from entering storm drains where it picks up pollutants, such as fertilizers and pesticides which then drains into rivers, lakes, and streams. Diverting storm water to wetlands and greenspaces allows water to be captured and filtered instead of allowing polluted storm water to flow into drains.	X	X	-	X	X	-
Revegetation - the process of replanting vegetation and rebuilding the soil of disturbed land for the principal purpose to rehabilitate or protect degraded land. The process usually involves planting native plants. Direct seeding may also be used.	X	-	X	X	X	-

Nature Based Measures Description	Tropical Cyclone	Freshwater Flooding	Coastal Hazards	Habitat Loss	Water Supply	Tsunami
Horizontal Green Levees - horizontal levees improve water quality and protect coastal levees from the effect of SLR by using vegetation on a slope to break waves. This natural, coastal storm-surge barrier uses the natural flood protection benefits of coastal tidal marshes to reduce the destructive forces of storms. Horizontal 'green' levees are self-maintaining, building in elevation as plant root systems expand.	-	X	X	X	X	-
Plant Coral Fragments/Nubbins - grown in a coral nursery until suitable size, small coral fragments are then transplanted to suitable reef zones where they contribute to the biodiversity of reef habilitation. Coral reefs effectively and naturally protect coasts from erosion and flooding by absorbing wave energy.	X	-	-	X	X	-
Transplant Heat Resistant Corals - taking coral species that have already survived severe heat stress and transplanting them to degraded reefs where they will sow seeds for restoration. Coral reefs effectively and naturally protect coasts from erosion and flooding by absorbing wave energy.	X	-	-	X	X	-
Artificial Reef - 'designed reefs' made from a highly impermeable concrete mixture, used to restore ailing reefs or create new reefs for ecological enhancement, fishing, and beach erosion protection.	X	-	-	X	-	-
Zoning Greenspace with New Development - land that is partly or completely covered with grass, trees, shrubs, or other vegetation. Urban green spaces improve the retention of hydrological systems in urban areas and dampen peak flows from storms that can lead to flooding.	-	X	-	X	X	-
Increase Vegetation & Pervious Surfaces - helps reduce runoff by allowing rainwater to infiltrate through the surface and into underlying layers, reducing flooding and erosion, and filtering out pollution. Alternatives to traditional pavement include pervious asphalt, pervious concrete, interlocking pavers, and plastic grid pavers.	X	-	X	X	-	-
Tree Planting & Restoration of Burned Areas - helps the landscape recover from wildfire, prevents soil erosion, and protects water quality in downstream rivers and lakes. Tree planting ensures that forests provide wildlife habitat, sequester carbon dioxide, and offer recreational opportunities for visitors.	-	X	-	X	-	-

6.2 Potential Funding Opportunities

Existing authorities and programs will be utilized, when possible, to implement recommendations. Identified funding opportunities, both from USACE and other agencies are outlined below. The list of grants and programs is not exhaustive but rather gives an indication of the types of available funding through federal agencies. Additional information may be found online or through coordination with agency representatives.

U.S. Army Corps of Engineers (USACE):

Below is a summary of all USACE authorities which are available for planning, feasibility study, or construction efforts. Most authorities require a non-federal cost share, however cost share waivers may be available, per Section 1156 of WRDA 1986, as amended.

- **General Investigation (GI) Studies** – conducts feasibility studies related to its core mission areas of navigation, flood risk management, and ecosystem restoration, to determine if Congressional authorization and implementation of a specific Civil Works project are warranted. The non-federal Sponsor must contribute 50 percent of feasibility study costs plus 25-35 percent of preconstruction, engineering and design costs. Project construction cost share is typically 65 percent Federal and 35 percent non-federal. Requests for assistance should be submitted in the form of a Letter of Intent from a state or local government agency to USACE.

- **Floodplain Management Services (FPMS)** – provides communities with technical and planning services to support effective floodplain management. Under the FPMS, USACE supports both riverine and coastal flood challenges and empowers communities to better understand their risks of flooding and develop plans to communicate and manage those risks. Activities provided under this authority include hydrologic and hydraulic technical services, general planning guidance, education and outreach material, and National Flood Insurance Program support. Funding is typically 100% federally funded, within limits of the authority. The FPMS Program is authorized by Section 206 of the Flood Control Act of 1960.

- **Silver Jackets** –The Guam Silver Jackets teams utilizes authority that provides technical assistance to communities to support all phases of the flood risk management cycle (preparation and training, response, recovery, and mitigation). This interagency team utilizes nonstructural measures to reduce flood risk, including projects such as education and outreach events, emergency planning and training, non-structural education, and data gathering and dissemination. Silver Jackets projects are federally funded with matching in-kind contributions from other federal and local agencies.

- **Planning Assistance to States (PAS)** – Two types of planning assistance, including preparation of Comprehensive Plans and Technical Assistance, are offered through the Planning Assistance to States (PAS) program (authorized by Section 22 of WRDA 1974, as amended).

  - Comprehensive Plans include planning for the development, utilization, and conservation of the water and related resources of drainage basins, watersheds, or ecosystems located within the boundaries of that State, Territory, or Commonwealth (or a group of States/Territories/Commonwealths) to comprehensively address water resources challenges.

- Technical Assistance provided through the PAS program includes support of planning efforts related to the management of water resources, including the provision and integration of hydrologic, economic, or environmental data and analysis in support of water resources management and related land resources development plans. This technical assistance may not include the preparation of site-specific designs or construction. Technical assistance activities through the PAS program are cost shared (50%) with the study partner, and voluntarily contributed funds exceeding the cost share agreement may be provided by the non-federal partner. The cost-share for technical assistance must be provided by funds (not in-kind).

- **Continuing Authorities Program (CAP)** – The CAP is a group of legislative authorities under which the Corps of Engineers can plan, design, and implement certain types of water resources projects without additional project-specific congressional authorization. The purpose of the CAP is to plan and implement projects of limited size, cost, scope, and complexity. The authorities included in the program are shown in Table 6-4.

  For all sections except Section 204 and 111, the initial feasibility phase is federally funded up to $100,000. Any remaining feasibility phase costs are shared 50/50 with the non-federal sponsor after executing a feasibility cost sharing agreement. For Section 204 projects, the Feasibility phase is performed at 100% federal cost. For Section 111 projects, the feasibility phase costs above the initial $100,000 will be cost shared in the same proportion as the cost-sharing provisions applicable to the construction of the federal navigation project causing the shore damages.

  Construction is either cost shared at 65% federal and 35% non-federal, or 75% federal and 25% non-federal, depending on the authority. Projects implemented under CAP have variable cost share requirements and limitations and a per-project federal cost limit. A pilot program for CAP projects in small or disadvantaged communities allows for full federal funding with no cost share requirement. The pilot program will apply for ten projects which meet economic criteria. CAP projects identified in Guam may qualify for this pilot program when it is implemented.

Table 6-4 *CAP Authorities*

Authority	Project Purpose	Per- Project Federal Limit
Section 14, Flood Control Act of 1946, as amended	Emergency streambank and shoreline erosion protection of public works and non-profit public services.	$5.0M
Section 103, River and Harbor Act of 1962, as amended	Protection of facilities and beach erosion. Hurricane and storm damage reduction.	$10.0M
Section 107, River and Harbor Act of 1960, as amended	Navigation improvements of general navigation features.	$10.0M
Section 111, River and Harbor Act of 1968, as amended	Shore damage prevention or mitigation caused by federal navigation projects	$12.5M
Section 204, Water Resources Development Act of 1992, as amended	Sediment management for ecosystem restoration or flood risk management.	$10.0M
Section 205, Flood Control Act of 1948, as amended	Flood damage reduction	$10.0M
Section 206, Water Resources Development Act of 1996, as amended	Aquatic ecosystem restoration	$10.0M
Section 208, Flood Control Act of 1954, as amended	Removal of obstructions, clearing channels for flood control	$0.5M
Section 1135, Water Resources Development Act of 1986, as amended	Project modifications for improvement of the environment	$10.0M

- **Section 7001 Annual Report** – The Section 7001 Annual Report to Congress Process may be used for when study authority does not already exist for an area of interest. In Section 7001 of the Water Resources Reform and Development Act of 2014 (P.L. 113-121; 33 U.S.C. §2282d), Congress established an annual process for identifying proposals for site-specific studies and projects within USACE's water resource mission and authorities. The process includes a call for non-federal proposals, which should be submitted to the Planning Division at the USACE District with an area of responsibility that includes the area of interest (for Guam this is the Honolulu District). Inclusion of a proposal in a Section 7001 annual report does not provide congressional authorization or appropriation. Rather, inclusion of a proposal in a report facilitates congressional consideration of authorizing the proposal.

- **Regional Sediment Management (RSM) Program** – RSM is a research program which implements innovative management strategies to optimize the use of sediment and improve the management of projects. The program supports initiatives that develop and demonstrate sustainable practices that systematically increase benefits and reduce lifecycle costs for the Corps' Navigation, Flood Risk Management, and Environmental missions. RSM provides opportunities to collaborate with stakeholders and other agencies to leverage resources, share technology and data, and develop and implement innovative solutions to improve regional utilization and management of sediments. Proposals are typically solicited once per year in June and are submitted by USACE Districts. Projects do not require a non-federal cost share, however stakeholder and partner engagement and information sharing is strongly encouraged and considered in the proposal selection process.

- **USACE Engineering with Nature (EWN) Initiative** – EWN is the USACE initiative that enables more sustainable delivery of economic, social, and environmental benefits associated with infrastructure. Sustainable water resources infrastructure is achieved through the beneficial integration of engineering and natural systems. With recent advances in the fields of engineering and ecology, there is an opportunity to combine these fields of practice into a single collaborative and cost-effective approach for infrastructure development and environmental management. Triple-win outcomes are achieved throughout EWN by systematically integrating social, environmental, and economic considerations at every phase of a project. The results are innovative and resilient solutions that are more socially acceptable, viable and equitable, and, ultimately, more sustainable.

- **USACE International and Interagency Support (IIS)** – Interagency and International Services is the U.S. Army Corps of Engineers (Corps) program providing technical assistance to non-Department of Defense (DoD) federal agencies, state and local governments, tribal nations, private U.S. firms, international organizations, and foreign governments. Most IIS work is funded on a reimbursable basis. The Corps provides engineering and construction services, environmental restoration and management services, research and development assistance, management of water and land related natural resources, relief and recovery work, and other management and technical services.

Funding Opportunities available from other agencies and organizations:

Federal Emergency Management Administration (FEMA):

- **Hazard Mitigation Grant Program (HMGP)** – Provides funding to rebuild in a way that reduces, or mitigates, future natural disaster losses in their communities. HMGP funding is authorized with a Presidential Major Disaster Declaration. The amount of funding made available to the applicant is generally 15% of the total federal assistance amount provided for recovery from the presidentially declared disaster and is determined by the FEMA-approved Hazard Mitigation Plan.

- **Building Resilient Infrastructure and Communities (BRIC)** – A competitive grant program which supports hazard mitigation projects to reduce the risks from disasters and natural hazards. The BRIC program aims to categorically shift the federal focus away from reactive disaster spending and toward proactive investment in community resilience. As a competitive grant program, applicants must apply on a yearly basis. BRIC encourages public infrastructure projects, projects incorporating nature-based solutions, and the adoption and enforcement of modern building codes.

- **Fire Management Assistance Grant (FMAG)** – Provides funding in the amount of $5,520 per acre affected by wildfires. The funding is for projects that revolve around soil stabilization, flood diversion, and reforestation projects.

- **Emergency Management Performance Grant (EMPG)** – Program provides funding for emergency management agencies that are implementing National Preparedness Systems and Goals. The Goals of preparedness are prevention, protection, mitigation, response, and recovery from the threat of natural hazards.

- **Public Assistance (PA)** – Provides federal grant assistance to permanently repair, replace, or restore disaster-damaged publicly owned facilities. PA provides a minimum of 75% of eligible costs, including updating facilities to current codes and standards and mitigating against future damage. Funds are made available post0disaster on a non0competitive basis.

Environmental Protection Agency (EPA):

- **Agency Clean Water State Revolving Funds** –Program is a federal-state partnership that provides communities low-cost financing for a wide range of water quality infrastructure projects. Types of projects eligible to receive assistance are construction of publicly owned treatment works, nonpoint source, national estuary program projects, decentralized wastewater treatment systems, stormwater, water conservation, watershed pilot projects, energy efficiency, water reuse, security measures at publicly owned treatment works, and technical assistance.
- **319 Grant Program** – Grant money that supports a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source pollution implementation projects.
- **Water Quality Monitoring Grant Program** – Also known as the Section 106 Grant Program, this grant funds efforts to enhance existing monitoring efforts and help them achieve their long-term monitoring program goals.

- **Brownfields Technical Assistance Program** – Provides technical assistance to communities and stakeholders to help address their brownfield sites, and to increase their understanding and involvement in brownfields cleanup, revitalization and reuse.

National Ocean and Atmospheric Administration (NOAA):

- **U.S. Integrated Ocean Observing System (IOOS)** – National-regional partnership working to provide new tools and forecasts to improve safety, enhance the economy, and protect our environment. Integrated ocean information is available in near real time, as well as retrospectively. Easier and better access to this information is improving our ability to understand and predict coastal events - such as storms, wave heights, and sea level change.
- **Regional Integrated Sciences and Assessments (RISA) Program** – Program that supports research teams that help expand and build the nation's capacity to prepare for and adapt to climate variability and change.
- **Community-Based Habitat Restoration** – Provides funding and technical assistance for restoration projects that ensure fish have access to high-quality habitat. The goal of these projects is to recover and sustain fisheries–particularly those species managed by NOAA Fisheries, or those listed as endangered or threatened under the Endangered Species Act. Projects range from improving access to habitat by removing dams and other barriers, to restoring coral and oyster reefs, to rebuilding coastal wetlands.
- **Coral Reef Conservation Program** – Provides annual funding in the form of cooperative agreements to eligible state, territorial, and commonwealth agencies for conservation projects in coral reef jurisdictions. The program provides matching awards of financial assistance that are administered as cooperative agreements. The objective is to support coral reef management and monitoring programs as well as conservation projects that seek to improve the condition of coral reef ecosystem resources.
- **Coastal Zone Management Act** – This act, administered by NOAA, provides for the management of the nation's coastal resources. The goal is to "preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone.
- **Section 309** - Every five years NOAA provides a process under "Section 309" of the Coastal Zone Management Act (as amended) for states and territories to carry out assessments to determine if funding may be available for projects relating to wetland, coastal hazards, public access, marine debris, cumulative and secondary impacts, special area management plans, ocean resources, energy and government facility siting, and aquaculture. To be eligible for 309 funding for the next five-year period, an approved Assessment and Strategy report must be carried out by the territory (or state) by the Coastal Management Program.
- **NOAA Coastal Resiliency Grants -** The NOAA Coastal Resilience Grants program, administered by the National Fish and Wildlife Foundation, implements projects that build resilience through sustainable ecosystem processes and functions and reduce the vulnerability of coastal communities and infrastructure from the impacts of extreme weather events, climate hazards, and changing ocean conditions.

- **National Tsunami Hazard Mitigation Program (NTHMP)**
  - **Mapping and Modeling (MMS)** – As the hazard assessment subcommittee, the MMS brings together expertise on modeling and mapping of tsunami hazards.
  - **Warning Coordination (WCS)** – Through the WCS, the NTHMP provides input to the operational U.S. Tsunami Warning System. Recommendations from the NTHMP help refine warning system messages, graphics, procedures, exercises, and dissemination systems so that warning system products are effective during a tsunami warning.
  - **Mitigation and Education (MES)** – The MES works to reduce tsunami impacts primarily through education and outreach that increase awareness and encourage preparedness. It also promotes and provides guidance on other risk reduction activities, such as evacuation planning and integration of tsunami risk into land-use policy and planning

U.S. Fish and Wildlife Service (USFWS):

- **Habitat Conservation Program Planning Assistance Grants** – Support the development of new habitat conservation programs as well as the renewal or amendment of existing habitat conservation programs for species currently listed as threatened or endangered. Species that are candidates for threatened or endangered lists may also be included.

Housing and Urban Development Disaster Resilience Grants:

- **Community Development Block Grant -** Program is both a flexible and widespread program, reaching over 1,200 local governments in all states and territories. The program's scope and promotion of community-specific solutions makes the grant a tool for climate resilience which requires jurisdictions to incorporate resilience to natural hazard risks into their Consolidated Plan and discuss how climate change will increase those risks and how they plan to address the impacts of climate change on low- and moderate-income residents.

- **Section 108 Loan Guarantee Program -** Provides communities with a source of low-cost, long-term financing for economic and community development projects. Section 108 financing provides an avenue for communities to undertake larger, more costly projects, where they may have limited resources to invest in upfront. Section 108 can fund economic development, housing, public facilities, infrastructure, and other physical development projects, including improvements to increase their resilience against natural disasters.

National Fish and Wildlife Foundation (NFWF):

- **Natural Coastal Resiliency Fund** – Invests in conservation projects that restore or expand natural features such as coastal marshes and wetlands, dune and beach systems, oyster and coral reefs, forests, coastal rivers and floodplains, and barrier islands that minimize the impacts of storms and other naturally occurring events on nearby communities.

- **The Coral Reef Conservation Fund** – One of multiple initiatives to address the decline in both the quantity and productivity of the coral reef ecosystems through conservation initiatives that aim to improve management, increase public awareness, and reduce threats to coral reefs. The program works to support reef resiliency by reducing negative impacts from unsustainable fishing and land-based pollution.

U.S. Department of Agriculture (USDA):

- **Housing Preservation Grants** – Provides grants to sponsoring organizations for the repair or rehabilitation of rural housing units.
- **Decentralized Water Systems Grant Program** – Funds a nonprofit to help individuals how own and occupy a home in a rural area. Funds may be used to construct, refurbish, or service individually owned household water well and septic systems.

USDA Natural Resources Conservation Services Pacific Island Area:

- **Agricultural Conservation Easement Program** helps restore, protect, and enhance wetlands on eligible land. Agricultural land easements protect farmlands and grasslands by limiting non-agricultural uses of the land.
- **Conservation Stewardship Program** - Conservation program designed to help farmers have more robust conservation activities. Agricultural producers and forest landowners looking to build on conservation efforts can receive annual payments for the operation's existing level of conservation and financial assistance for a wide variety of conservation activities.
- **Emergency Watershed Protection Program** - A program that aims to relieve imminent hazards to life and property caused by floods, fires, windstorms, and other natural hazards. Financial and technical assistance is provided to remove debris from streams, protect destabilized streambanks, establish cover on critically eroding lands, repairing conservation practices, and the purchase of flood plain easements.
- **Environmental Quality Incentive Program Conservation Incentive Contracts** – A program providing annual payments for the operation's existing level of conservation and financial assistance for installation of conservation practices or enhancements. Unlike the Conservation Stewardship Program, not all acres under the applicants control need to be enrolled or assessed for eligibility.
- **Watershed and Flood Prevention Operations Program** - helps to protect and restore watersheds up to 250,000 acres. This program supports cooperation between Federal and local agencies to work together to prevent erosion, reduce floodwater and sediment damage, and to further the conservation and proper use of land in authorized watersheds.

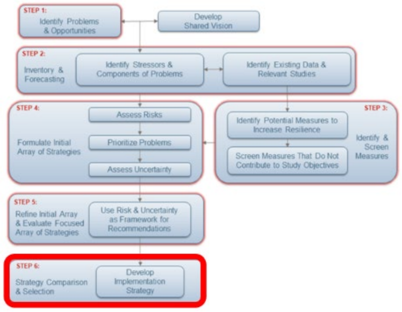
Other Grant Opportunities:

- **USGS Pacific Islands Climate Adaptation Science Center** - Funding is periodically made available through Requests for Proposals from the USGS or from funding announcements from the University Consortium. Announcements are made available on the USGS Pacific Islands Climate Adaptation Science Center website.

  The USGS Pacific Islands Climate Adaptation Science Center identifies research priorities tied closely to the needs of natural and cultural resource managers in the Pacific Islands region. Proposals typically should focus on developing "actionable science" or knowledge that can inform or be applied to specific management challenges, locally or broadly across the Pacific Islands region.

- **University of Hawai'i Sea Grant** - Hawaii Sea Grant funds research that emphasizes solution-based outcomes and applicability to pressing issues. Proposals are requested through a biennial research competition. Program development funds are also provided for select pilot projects throughout the year. Current projects address critical topics such as hazard resilience, ecosystem health, sustainable seafood, and sustainable coastal development.

6.3 Recommendations for Implementation



Recommendations were formulated following the risk- and uncertainty-based framework. Stressors within each category of the framework were grouped based on functional connectivity (i.e., interconnected problems should be addressed together). Structural, non-structural, and nature-based measures were explored to provide a diverse suite of resiliency options. Measures described in Section 6.1 were used to formulate recommendations within each category of the risk- and uncertainty-based framework. Individual measures were then combined into more cohesive recommendations based on type of recommendation being made (e.g., actions, evaluate options, or fill data gaps) and input from the study partner and stakeholders regarding ongoing efforts, potential future opportunities for implementation, and alignment with relevant agency goals and objectives. The study partner and other stakeholders repeatedly expressed the desire for exploration and implementation of nature-based solutions. However, there may be several challenges to overcome, including knowledge-based, political, and technical barriers. By using a combination of natural and conventional processes and materials, natural infrastructure can protect people, homes, and habitats.

Depending upon the selected recommendation, real estate requirements may be encountered, and necessary processes for use or acquisition will need to be followed. Costs included for recommendations are rough estimates and do not include real estate. Costs included for recommendations are rough estimates and are denoted by the following scale:

- $ $0-$1M
- $$ $1M-$5M
- $$$ $5M+

As discussed in Section 5.4, the risk and uncertainty results (Figure 5-14 and 5-15) were used to develop a framework for the appropriate types (uncertainty-based) and timing (risk-based) for recommendations. Risks identified as catastrophic have near-term recommendations for immediate steps, while risks identified as major have incremental actions for longer term steps.

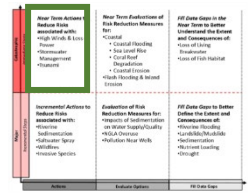
Based upon the risk and uncertainty assessments, recommendations are presented in the following categories:

Catastrophic risks
- Near-term – actions
- Near-term – evaluate options
- Near-term – fill data gaps

Major risks
- Incremental – actions
- Incremental – evaluate options
- Incremental – fill data gaps

An inset of the *Resultant Risk and Uncertainty Based Recommendations* (Figure 5-16) is shown in each of the following sections, with the recommendation category highlighted with a green box for orientation.

6.3.1 Near-Term Actions



These activities should be prioritized and funded in the near term. The actions to mitigate these stressors have a high level of consensus and low uncertainty. Potential partnerships and sources of funding were identified. Coordination to formalize time and resource commitments, and the creation of discrete milestones will be the responsibility of the agencies that initiate future studies.

Stressors within this category include:

- High Winds and Loss of Power.
- Stormwater Management.
- Tsunami.

6.3.1.1 High Winds and Loss of Power

Near-term actions should be taken to reduce economic, life loss, and other risks associated with loss of power and high winds (Table 6-5). The loss of power and structural damage sustained due to high winds can be mitigated with changes to building development and measures to address both power generation and distribution. A comprehensive structure inventory should be developed to better understand the type and location of infrastructure at risk. Other non-structural measures were identified with a high level of community support.

Table 6-5 *Near-Term Actions - High Winds and Loss of Power*

	Focus	Recommendation	Potential Partners and Funding
High Winds And Loss of Power	Power Supply Improvement	*Emergency Generators for Critical Facilities* – Critical facilities such as hospitals, emergency management centers, police stations, and fire stations would benefit from owning their own generators to keep the facility open during utility power outages. Additional protected fuel reserves are needed for backup generators.	**Estimated Cost:** $$ **Potential Funding**: FEMA **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** Guam Homeland Security Office of Civil Defense (GHS-OCD), Guam Power Authority
		Wind resistant solar panels – solar panels may withstand uplifting winds from hurricanes if bolted to roof trusses or ground mounted structures. Made of tempered glass, the panels are unlikely to suffer damage from rain or minor debris.	**Estimated Cost:** $ **Potential Funding**: FEMA **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** GHS-OCD, Guam Power Authorities & Utilities Commission, Private Power Companies

	Focus	Recommendation	Potential Partners and Funding
High Winds And Loss of Power	Power Distribution Improvement	*Underground Power Distribution* – buried power lines are less subject to damage from severe weather or wildfires. The lines do not need to be shut off during high winds. Buried power lines may still be at risk from floods.	**Estimated Cost:** $$$ **Potential Funding**: FEMA **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** Guam Power Authorities & Utilities Commission, GWA, Telecomm Companies, GHS-OCD
	Emergency Preparedness and Response	*Long-term Recovery Planning* – Topics may include but are not limited to: Where to acquire funding and resources. Pre-defined partnerships and responsibilities. Decision making roles and an agreed upon hierarchy of needs. Methods of expediting repairs and a system to deliver provisions.	**Estimated Cost:** $ **Potential Funding**: FEMA **Champion Agencies**: FEMA, BSP **Other Potential Partners/Stakeholders:** USACE, DoT, GHS-OCD, DOI, Silver Jackets, DOE
	Policy & Planning	*Comprehensive Structure Inventory* - Complete a comprehensive structure inventory to record exiting buildings that are deteriorating or capable for being retrofitted to withstand high winds.	**Estimated Cost:** $ **Potential Funding**: USACE **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** DPW, GWA, GPA
		Building Policies - Adopting and enforcing the International Building Code for new structures would require construction techniques such as anchor bolts, impact-resistant glass, and reinforced doors.	**Estimated Cost:** $ **Potential Funding:** FEMA **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** DPW, GPA, Guam Building Code Council

6.3.1.2 Stormwater Management

Effective stormwater management reduces runoff from rainwater into streets, rivers, aquifers, rivers, streams, and coastal waters. In urban and developed areas, a well-maintained drainage system does not allow for sewers to overflow. In rural environments, water that percolates into the soil does not contribute to erosion and water quality is improved before it reaches coastal waters or the NGLA. Recommendations identified in the 2006 Commonwealth of the Northern Mariana Islands and Guam Stormwater Management Manual developed by Guam Bureau of Statistics and Plans should be implemented, followed by further evaluation of other flash flooding concerns. Near-term actions related to stormwater management are shown in Table 6-6.

Table 6-6 *Near-Term Actions - Stormwater Management*

	Focus	Recommendation	Potential Partners and Funding
Stormwater Management	Drainage System Improvements	*Improve Urban Drainage Network* – Drainpipes must have and maintain adequate capacity to carry runoff from storms.	**Estimated Cost:** $ **Potential Funding**: FEMA **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** GEPA, GDPW, Silver Jackets
		Scheduled Maintenance & Drain Cleaning – The continued maintenance and cleaning of storm drains in urban areas will keep water flowing, avoiding stagnation.	**Estimated Cost:** $ **Potential Funding:** EPA **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** GEPA, GDPW, Silver Jackets
		Comprehensive Stormwater Management Manual – Updating existing local stormwater management plans into a comprehensive stormwater management plan for Guam will ensure consistency and effectiveness in reducing flood risks to people, infrastructure, and the environment.	**Estimated Cost:** $ **Potential Funding:** FEMA, USACE Planning and Technical Assistance authorities **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** BSP, FEMA, USACE, GEPA, DPW, UoG
	Engineering with Nature	*Wetland Restoration/Native Plant Reforestation* – Shallow wetlands, natural or constructed, work by having runoff from storms enter the wetland and the long residence time of the water then takes advantage of natural process involving vegetation, soils, and microbes to improve water quality. Constructed wetlands can also meet channel protection requirements.	**Estimated Cost:** $$ **Potential Funding**: USDA, NOAA FEMA, FWS **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** GEPA, GDOAg, DLM, CLTC, Guam Department of Parks

		Reforestation with native plants to aid in stream stabilization, reduction of erosion and sedimentation, improved habitat, and mitigation of wildfire and other disturbances. Riparian buffer zones allow the absorption and filtration of water before it enters the aquifer or local streams.	and Recreation (GPR), Silver Jackets

6.3.1.3 Tsunami

Tsunamis are not a frequent occurrence but have a high life safety risk. The residents of Guam already practice tsunami drills and have ample signs and indicators of evacuation routes and safe areas. A tsunami hazard assessment is under development by the NOAA Center for Tsunami Research and NOAA National Ocean Service.

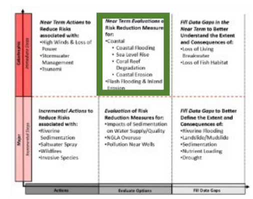
There is generally a high level of consensus around non-structural measures that can reduce the potentially catastrophic consequences of tsunami activity. To further improve resilience, local consideration should be given to managing development in high-risk areas and establishing tabletop exercises for first responders. These exercises are vital in building interagency coordination and delineating areas of responsibility. First responders discuss roles and responsibilities while validating and amending existing plans.

***Table 6-7** Near-Term Actions - Tsunami*

	Focus	Recommendation	Potential Partners and Funding
Tsunami	Policy & Planning	*Development Management in High-Risk Areas* – Use of zoning and relocation of structures to move population density away from vulnerable areas.	**Estimated Cost: $** **Potential Funding**: Silver Jackets, USACE **Champion Agencies**: BSP, FEMA, NOAA **Other Potential Partners/Stakeholders:** DLM, DPW, GHS-OCD, Guam Land Use Commission, Silver Jackets, USACE
		Continue Education, Outreach, & Risk Communication – Education and outreach will give autonomy to residents in an emergency.	**Estimated Cost: $** **Potential Funding:** Silver Jackets **Champion Agencies**: BSP, FEMA **Other Potential Partners/Stakeholders:** GHS-OCD, Silver Jackets, USACE
	Continued Emergency Preparedness & Response	*Continue Annual Tsunami Drills* – Evacuation drills should continue be practiced. There is minimal warning time from a tsunami that originates from the Marianas Trench.	**Estimated Cost: $** **Potential Funding**: FEMA, Silver Jackets **Champion Agencies**: BSP, FEMA, NOAA **Other Potential Partners/Stakeholders:** GHS-OCD, USACE, Silver Jackets, NWS, DPW
		Establish/Continue Tabletop Exercises for First Responders – Exercises may be scaled from a conference room to a fully simulated exercise that may be conducted with public agencies and local businesses.	**Estimated Cost: $** **Potential Funding:** FEMA, USACE **Champion Agencies**: BSP, FEMA **Other Potential Partners/Stakeholders:** Silver Jackets, USACE, GHS-OCD, DPW

	Focus	Recommendation	Potential Partners and Funding
		Maintain/Improve Tsunami Warning System – To maximize the number of people who take the appropriate and timely action to minimize injury, death, and property damage. Multiple types of warning systems that consider the recipients, locations, time of day, special needs, and season should be used.	**Estimated Cost: $** **Potential Funding:** FEMA **Champion Agencies**: BSP, NOAA, FEMA **Other Potential Partners/Stakeholders:** UoG, USACE
		Maintain/Improve Tsunami Zone Mapping with SLR – SLR will change the population and infrastructure at risk. Maps must evolve as SLR models evolve.	**Estimated Cost: $** **Potential Funding:** USACE FPMS **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** UoG, USACE

6.3.2 Near-Term Evaluate Options



Additional studies are needed to identify potential solutions for the stressors related to coastal hazards and inland flash flooding and erosion. Studies should be initiated in the near-term, ideally within 0-5 years and target implementation within 5-10 years.

Stressors within this category include:

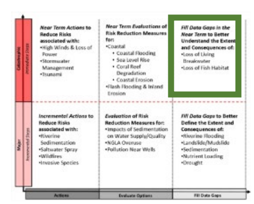
- Coastal Hazards
    - Coastal Flooding
    - SLR
    - Coral Reef Degradation
    - Coastal Erosion
- Flash Flooding and Inland Erosion

***Table 6-8** Near-Term Option Evaluations - Coastal Hazard and Flash Flooding*

	Focus	Recommendation	Potential Partners and Funding
Coastal Hazards	Evaluate Options to Reduce Coastal Risks with a Focus on Engineering with Nature	*Pilot Multi-Purpose Ecosystem Restoration/Coastal Storm Risk Management Study* - Continue to evaluate efforts to restore sediment flow and reduce coastal erosion at Tumon Bay.	**Estimated Cost:** $$ **Potential Funding**: USACE CAP/GI **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** GEPA, DLM, GPR, CLTC, USACE, Silver Jackets, UoG, GDOAg, Guam Department of Parks and Recreation (GPR), Watershed Planning Committee
		Build Interagency Partnerships and Identify Additional Future Options to Evaluate Coastal Risk Reduction – Create multiple partnerships to bring experts with varied backgrounds together to aid in identifying options, considerations, and appropriate goals and metrics of programs and projects.	**Estimated Cost:** $ **Potential Funding**: Silver Jackets **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** Guam Watershed Planning Committee, Silver Jackets, USACE
	Evaluate Options to Reduce Flash Flooding and Inland Erosion Risks with a Focus on Engineering with Nature	*Pilot Multi-Purpose Ecosystem Restoration/Flood Risk Management Study* – Evaluate options to reduce risks identified through the Guam Comprehensive Flood Study, focusing first on the Agat-Santa Rita Area.	**Estimated Cost:** $$ **Potential Funding**: USACE CAP/GI **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** GEPA, DLM, GPR, CLTC, USACE, Silver Jackets, Watershed Planning Committee

	Focus	Recommendation	Potential Partners and Funding
Flash Flooding	Build Partnerships to Evaluate a Diverse Array of Options	*Build Interagency Partnerships* – Continue to build interagency partnerships and identify additional future options to evaluate risk reduction opportunities	**Estimated Cost:** $ **Potential Funding**: Silver Jackets, Government of Guam **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** Silver Jackets, Watershed Planning Committee, USACE
	Signals and Warnings	*Warning Systems* – High water mark indicators to alert people of safe minimum heights and distances. The use of stream gauges and meteorological forecasts to warn residents of potential flash flood conditions. Near shore bathometry for recreational waters.	**Estimated Cost:** $ **Potential Funding**: FEMA **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** FEMA, USACE, Silver Jackets

6.3.3 Near-Term Data Gaps



Filling data gaps to better define risks and opportunities associated with the loss of living breakwater and fish habitat will inform decisions on the path(s) forward. Stressors within this category include:

- Loss of Living Breakwater and Fish Habitat

6.3.3.1 Loss of Living Breakwater and Fish Habitat

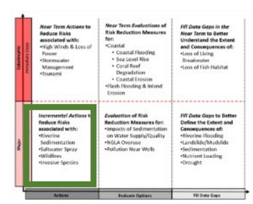
Further data should be collected in the near-term to document the current and projected impacts to the existing living breakwater along the shoreline. The living breakwater provides significant ecological value and contributes to the economy through tourism, while reducing risks associated with coastal flooding, storm surge, and coastal erosion. The ecological and monetary value of the living breakwater should be quantified from a multi-purpose perspective. A better understanding of the problem will inform potential solutions.

Further data should be collected in the near-term to document the extent of and stressors contributing to the loss of fish habitat. A better understanding of the extent and consequences of the problem will inform potential solutions. An assessment of existing data should be developed and shared among pertinent agencies, researchers, etc. A data sharing agreement should be developed to ensure continued communication and collaboration among Guam fisheries agencies and researchers. The Guam Endangered Species Act should be reviewed and revised on an "as needed" basis.

***Table 6-9** Near-Term Data Gaps - Loss of Living Breakwater and Fish Habitat*

	Focus	Recommendation	Potential Partners and Funding
Loss of Living Breakwater and Fish Habitat	Better Defined Risks and Opportunities Associated with Loss of Living Breakwater that Surrounds the Island and the Fish Habitat it Provides	*Focus on Areas and Opportunities Identified in the Bureau of Statistics Coastal Atlas* - The Coastal Atlas outlines ecosystems in near and offshore benthic habitats. These areas may be studied and evaluated for prioritization and ecosystem service monetary valuation.	**Estimated Cost:** $ **Potential Funding:** Silver Jackets USACE PAS, FEMA, USACE FPMS, Coral Reef Initiative **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** GDOAg/Coral Reef Initiative, USACE, Silver Jackets, NOAA, UoG
		Build Interagency Partnerships and Identify Additional Future Opportunities	**Estimate Cost:** $ **Potential Funding:** Silver Jackets, Watershed Planning Committee **Champion Agency**: BSP **Other Potential Partners/Stakeholders:** Silver Jackets, NOAA, EPA, USACE, UoG, GDOAg, Watershed Planning Committee

6.3.4 Incremental Actions



Incremental actions can be taken to reduce the economic, social, and environmental risks associated with each of the risk categories identified as major risks. Structural, non-structural, and measures were identified with a high level of community support. The study focused on gaining stakeholder insight and collaboration for catastrophic risk recommendations. As such, recommendations for incremental actions, evaluation of options and studies, and filling data gaps do not have potential partners listed.

These recommendations should initiate implementation within 0-10 years. These problems are important to address in the near-term and pose a significant risk to lives, property, the environment, or the economy. However, with limited resources, these recommendations may be taken as incremental steps to make continuous progress towards enhancing resiliency.

Stressors within this category include:

- Riverine Sedimentation.
- Saltwater Spray.
- Wildfires.

- Invasive Species.

6.3.4.1 Riverine Sedimentation

Incremental actions should be taken to reduce economic, social, and environmental risks associated with riverine sedimentation. Nature based solutions to slow, divert, or capture water will mitigate sedimentation and erosion, lessening its effects on coastal habitats. Land use policies near rivers would also be effective. The following measures, defined in Section 6.1, should be considered in order to reduce risks associated with riverine sedimentation:

- Improve Urban Drainage Network.
- Enhance Stream and Weather Gage Networks.
- Water Bars on Roads and Public Paths.
- Slope Drains and Terracing in Steep Terrain.
- Sediment Settling Basin.
- Education and Land Use Practices to Reduce Runoff.
- Regulate and Enforce Agricultural Runoff in Protected Zones.
- Administration of Best Management Practices.
- Reduce Erosion Activity in Run Off Zones.
- Increase Vegetation and Pervious Surfaces.
- Master Planning Study.
- Diversions to Roadside Wetlands and Greenspaces.
- Zoning Greenspace with New Development.
- Tree Planting and Restoration of Burned Areas.

6.3.4.2 Saltwater Spray

Incremental actions should be taken to decrease the economic consequences associated with saltwater spray, to include creating a comprehensive inventory of vulnerable structures and standardizing corrosion control measures for the structures though building codes or local policies. The following measures, defined in Section 6.1, should be considered to reduce risks associated with saltwater spray:

- Shoreline Protection.
- Shoreline Revetment.
- Comprehensive Structure Inventory.
- Building Codes for Highly Corrosive Environment.
- Corrosion Control Measures.
- Agricultural Protection Measures.

6.3.4.3 Wildfires

Incremental actions should be taken to reduce risks associated with wildfires. Factors that contribute to wildfire, weather, fuel, and topography have been identified in the Guam Hazard Mitigation Plan (HMP). Asset mapping as well as vulnerable populations were identified using GIS. Current initiatives include the replanting of trees and education and outreach programs. Stakeholders may wish to include additional measures such as addition of fire lookouts and fire road development. The following measures, defined in Section 6.1, should be considered in order to reduce risks associated with wildfires:

- Emergency Preparedness and Outreach.

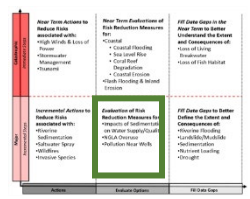
- Comprehensive Structure Inventory.
- Fire Lookouts and Stations.
- Fire Road Development and Maintenance.
- Community Wildfire Protection Plans.
- Revegetation.
- Tree Planting and Restoration of Burned Areas.

6.3.4.4 Invasive Species

Incremental actions should be taken to reduce environmental, economic, and other risks associated with invasive species. Non-structural measures revolve around education and outreach programs. Programmatic changes to customs process, field surveys, and eradication efforts could also aid in mitigating the adverse effects of invasive species. The following measures, defined in Section 6.1, should be considered in order to reduce risks associated with invasive species:

- Invasive Species Eradication Technology.
- Invasive Species Surveys.
- Policy & Enforcement for Invasive Species.
- Increased Outreach & Awareness.
- Ballast Water Treatment.
- Increased Customs Inspections.
- Revegetation.
- Tree Planting and Restoration of Burned Areas.

6.3.5 Incremental Evaluate Options



Incremental steps should begin to evaluate options for reducing risks associated with impacts from sedimentation to the water supply, overuse of the NGLA, and pollution near supply wells. An integrated, multi-purpose approach is warranted to identify and evaluate the full spectrum of potential actions that could be taken by federal, territorial, and local agencies to reduce risks.

Stressors within this category include:

- Impacts of Sedimentation on Water Supply and Quality.
- Overuse of the NGLA.
- Pollution Near Supply Wells.

6.3.5.1 Impacts of Sedimentation on Water Supply and Quality

Incremental steps should be taken to evaluate options for reducing sedimentation risks to water supply and quality. The following measures, defined in Section 6.1, should be evaluated and considered, as appropriate:

- Improve Urban Drainage Network.
- Slope Drains & Terracing in Steep Terrain.
- Sediment Settling Basin.
- Sediment Control Structures on Streams.
- Freshwater Catchment.
- Administration of Best Management Practices.
- Establish Wellhead Protection Zones.

- Diversions to Roadside Wetlands and Greenspaces.
- Revegetation.
- Zoning Greenspace with New Development.
- Hydraulic and Hydrologic Modeling.

6.3.5.2 Overuse of the NGLA

Incremental steps should be taken to evaluate options to reduce risks associated with overuse of the NGLA. The following measures, defined in Section 6.1, should be evaluated and considered, as appropriate:

- Freshwater Catchment.
- Education and Outreach on Water Conservation.
- SLR Inundation Mapping.
- Hydraulic and Hydrologic Modeling.
- Establish Wellhead Protection Zones.
- Diversions to Roadside Wetlands and Greenspaces.

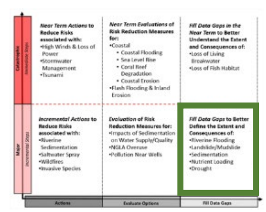
6.3.5.3 Pollution Near Supply Wells

Incremental steps should be taken to evaluate options to reduce risks associated with pollution near water supply wells. The following measures, defined in Section 6.1, should be evaluated and considered, as appropriate:

- Septic to Sewer Conversion.
- Administration of Best Management Practices.
- Establish Wellhead Protection Zones.
- Diversions to Roadside Wetlands and Greenspaces.
- Zoning Greenspace with New Development.

6.3.6 Incremental Data Gaps

Further data should be collected to better define the extent and consequences of riverine flooding, landslides and mudslides, sedimentation, nutrient loading, and drought. A better understanding of these problems, opportunities, and available tools will inform potential solutions.



Stressors within this category include:

- Riverine Flooding.
- Landslide/Mudslide.
- Sedimentation of Streams and Nearshore Coastal Waters.
- Nutrient Loading.
- Drought.

6.3.6.1 Riverine Flooding

Incremental steps should be taken to fill data gaps in order to better understand risks associated with riverine flooding. Additional stream gauge and monitoring data, particularly real-time data, will allow for improved advance flood warning and preparedness. GIS data development and further study should be pursued to aid in identifying suitable areas for stormwater collection and other system improvements. Development of a comprehensive structure inventory would result in a better understanding of potential consequences of future floods. The following measures, defined in Section 6.1, should be evaluated and considered, as appropriate:

- Enhance Stream and Weather Gage Networks.
- Comprehensive Structure Inventory.
- Hydrology and Hydraulic Modeling of Shoreline and Rivers.

6.3.6.2 Landslide/Mudslide

Incremental steps should be taken to fill data gaps regarding landslides and mudslides to inform future decisions with regard to risk. Improved data and mapping on specific risks by studying areas where landslides may occur could aid in identifying risk areas. Developing an inventory of critical facilitates and infrastructure can aid in identifying potential areas of high consequences, by using GIS to identify and map landslide hazard areas. The following measures, defined in Section 6.1, should be evaluated and considered, as appropriate:

- Enhance Stream and Weather Gage Networks.
- Comprehensive Structure Inventory.
- Revegetation.
- Tree Planting and Restoration of Burned Areas.

6.3.6.3 Sedimentation of Streams and Nearshore Coastal Waters

Incremental steps should be taken to fill data gaps regarding sedimentation of streams and nearshore coastal waters. To define management actions to reduce sediment loading for streams and nearshore coastal waters, it is necessary to determine the location of erosion and the mechanisms by which sediment is eroded and introduced into the system. Data points could be an inventory of upland streambanks and classification of exposed soils, and identification of near channel sources such as ravines and gullies. The following measures, defined in Section 6.1, should be evaluated and considered, as appropriate:

- Hydrologic and Hydraulic Modeling of Shoreline and Rivers.
- Master Planning Study.

6.3.6.4 Nutrient Loading

Incremental steps should be taken to fill data gaps regarding nutrient loading. Data involving current ecosystems, agricultural practices, and researching existing ordinances that can affect activities on private property should be considered. Evaluation of agricultural watersheds to estimate nitrogen and phosphorus loadings and avenues of delivery to rivers and streams in all major watersheds could provide a better understanding of the extent of the problem. Evaluation of municipal and industrial wastewater treatment facilities and related urban stormwater discharge sources could inform potential focus areas. Examination of current stewardship programs or incentives and encouragement of the Territory to work with federal agencies, conservation districts, private landowners and other stakeholders could aid in identifying mechanisms to reduce risks. Filling data gaps associated with the following measures, defined in Section 6.1, should be considered in order to better define the location of areas of concern and inform next steps:

- Septic to Sewer Conversion.
- Education and Land Use Practices to Reduce Runoff.
- Regulate and Enforce Agricultural Runoff in Protected Zones.
- Administration of Best Management Practices.
- Diversions to Roadside Wetlands & Greenspaces.
- Zoning Greenspace with New Development.

6.3.6.5 Drought

Incremental steps should be taken to fill data gaps regarding drought. Additional monitoring of climate forecasts and current aquifer levels may aid in drought planning and preparedness. The following measures, defined in Section 6.1, should be evaluated and considered, as appropriate:

- Enhance Stream and Weather Gage Networks.
- Freshwater Catchment.

6.4 Implementation Strategy

To help prioritize limited time and resources, a general timeline for recommendation implementation is provided in Table 6-10 and Table 6-11. Recommendations reflect the level of readiness to implement with a greater emphasis put on accelerating implementation of recommendations for catastrophic risks. The timeline provided is an estimate based on the urgency of addressing the stressor and possible implementation roadblocks, such as knowledge gaps, local approval, and funding (determined through the uncertainty analysis). Generally, near-term actions should be implemented within five years. Near-term options should be evaluated within zero to five years and implemented as soon as possible. Incremental options should be implemented as soon as possible but may have additional time available to implement as the corresponding stressor was assessed to be a major risk. Evaluating options to address major stressors should occur within zero to ten years with implementation occurring soon thereafter.

Table 6-10 *Near Term Strategies*

Priority	Stressor	Recommendation	0-5 yrs.	5-10 yrs.	10+ yrs.
Near-term actions	High Winds and Power Outages	*Wind Resistant Solar Panels*	Implement	-	-
		Emergency Generators for Critical Facilities	Implement	-	-
		Underground Power Distribution	Evaluate	Implement	-
		Long-term Recovery Planning	Evaluate	Implement	-
		Comprehensive Structure Inventory	Implement	-	-
		Building Policies	Implement	-	-
	Stormwater Management	*Improve Urban Drainage Network*	Implement	-	-
		Scheduled Maintenance & Drain Cleaning	Implement	-	-
		Stormwater Management Planning	Implement	-	-
		Wetland/Vetiver Grass Restoration	Evaluate	Implement	-
	Tsunami	*Development Management in High-Risk Areas*	Evaluate	Implement	-
		Continue Education, Outreach, & Risk Communication	Implement	-	-
		Continue Annual Tsunami Drills	Implement	-	-

Priority	Stressor	Recommendation	0-5 yrs.	5-10 yrs.	10+ yrs.
		Establish/Continue Tabletop Exercises for First Responders	Implement	-	-
		Maintain/Improve Tsunami Warning System	Implement	-	-
		Maintain/Improve Tsunami Zone Mapping w/ Sea Level Rise	Implement	-	-
Near-term evaluate options	Coastal Hazards	*Pilot Multi-Purpose Ecosystem Restoration/Coastal Storm Risk Management Study*	Evaluate	Implement	-
		Build Interagency Partnerships and Identify Additional Future Options to Evaluate Coastal Risk Reduction	Evaluate	Implement	-
	Flash Flood and Inland Erosion	*Build Interagency Partnerships*	Evaluate	Implement	-
		Warning Systems	Evaluate	Implement	-
		Pilot Multi-Purpose Ecosystem Restoration/Flood Risk Management Study	Evaluate	Implement	-
Near-term data gaps	Loss of Living Breakwater and Fish Habitat	*Focus on Areas and Opportunities Identified in the Guam Coastal Atlas*	Evaluate	Implement	-
		Build Interagency Partnerships and Identify Additional Future Opportunities	Implement	-	-

Table 6-11 *Incremental Strategies*

Priority	Stressor	0-10 yrs.	10-15 yrs.	15+ yrs.
Incremental Actions	Riverine Sedimentation	Evaluate	Implement	-
	Saltwater Spray	Implement	-	-
	Wildfires	Implement	-	-
	Invasive Species	Implement	-	-
Incremental evaluate options	Sedimentation of Water Supply	Evaluate	Evaluate	Implement
	Overuse of NGLA	Evaluate	Implement	-
	Pollution Near Water Supply Wells	Fill data gaps	Evaluate	Implement
Incre	Riverine Flooding	Fill data gaps	Evaluate	Implement

	Landslide	Fill data gaps	Evaluate	Implement
	Sedimentation of Streams and Nearshore Coastal Waters	Fill data gaps	Evaluate	Implement
	Nutrient Loading	Fill data gaps	Evaluate	Implement
	Drought	Fill data gaps	Evaluate	Implement

7 Conclusion

The purpose of the WA is to assist with future decision-making and strategic planning in the Territory of Guam to rehabilitate and improve the resiliency of infrastructure and natural resources, while reducing risks to human life and property from future natural disasters in Guam. This comprehensive WA incorporates the best available scientific literature and robust engagement with federal, Territorial, and local agencies and other stakeholders.

Throughout the study, the partner and stakeholders were consulted to ensure recommendations satisfied the objectives of the study and the standards laid out in ER 1105-2-100, the Planning Guidance Notebook.

This WA in conjunction with other relevant studies and efforts can be used to initiate follow on studies or projects that meet Guam's priorities and greatest needs. Table 7-1 displays how the proposed recommendations address the problem areas while fulfilling the specific study objectives and USACE principals of resiliency.

The study objectives included:

Objective 1: Improve the ability of Guam to anticipate, prepare for, and adapt to changing conditions.

Objective 2: Improve the ability of Guam to withstand, respond to, and recover rapidly from disruptions.

The USACE Principles of Resilience are:

Prepare – Considers the needs of a community or system to better withstand future disruptions.

Absorb – Enhances the ability of a community or system to endure a disruption and limit subsequent damage. This principle can also be used as an opportunity to consider adding system component robustness, redundancy, and increased reliability.

Recover – Stresses wise and rapid repair or functional restoration of a community or system following a disruption.

Adapt – Considers modifications to a project component or system that maintains or improves future performance based on lessons learned from previous events.

***Table 7-1** Recommendations Addressing the Objectives*

Type	Stressor	Recommendation	Objective 1	Objective 2	Resilience Principal Achieved
Near-term actions	High Winds and Power Outages	Wind Resistant Solar Panels	X	X	Prepare, Absorb
		Emergency Generators for Critical Facilities	X	X	Prepare, Absorb, Recover
		Underground Power Distribution	X	-	Prepare
		Comprehensive Structure Inventory	X	-	Prepare, Adapt
		Building Policies	X	X	Prepare, Absorb, Adapt
	Stormwater Management	Improve Urban Drainage Network	-	X	Absorb
		Scheduled Maintenance & Drain Cleaning	X	-	Prepare
		Stormwater Management Planning	-	X	Absorb
		Wetland Restoration/Native Plant Reforestation	-	X	Absorb, Recover
	Tsunami	Development Management in High-Risk Areas	X	X	Prepare, Absorb
		Continue Education, Outreach, & Risk Communication	X	-	Prepare, Adapt
		Continue Annual Tsunami Drills	X	X	Prepare, Absorb
		Establish/Continue Tabletop Exercises for First Responders	X	X	Prepare, Absorb, Recover, Adapt
		Maintain/Improve Tsunami Warning System	X	X	Prepare, Absorb
		Maintain/Improve Tsunami Zone Mapping with SLR	X	-	Prepare, Adapt
Near-term evaluate options	Coastal Hazards	Pilot Multi-Purpose Ecosystem Restoration / Coastal Storm Risk Management Study	-	X	Absorb, Recover
		Build Interagency Partnerships and Identify Additional Future Options to Evaluate Coastal Risk Reduction	X	X	Prepare, Adapt
	Flash Flood and Inland Erosion	Build Interagency Partnerships	X	X	Prepare, Recover, Adapt
		Warning Systems	X	-	Prepare
		Pilot Multi-Purpose Ecosystem Restoration / Flood Risk Management Study	X	X	Prepare, Absorb, Adapt
Near-term data gaps	Loss of Living Breakwater and Fish Habitat	Focus on Areas and Opportunities Identified in the Guam Coastal Atlas	X	X	Prepare, Absorb
		Build Interagency Partnerships and Identify Additional Future Opportunities	X	-	Prepare

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