Vulnerability Assessment of Built Infrastructure near Coastal Bays using three Sea Level Rise Scenarios – Guam

Prepared for:
The Government of Guam

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Executive Summary

Global mean sea level (GMSL) is rising and accelerating (IPCC, 2019). Glacier and ice sheet melt is currently the dominant source contributing to GMSL rise (IPCC, 2019). GMSL from tide gauges and altimetry observations increased from 1901 – 2015 (Table 2).

Table 2: GMSL rise, according to altimetry observations and tide gauges. Data is from IPCC 2019.

Period	Increase (mm/yr)
1901 -1990	1.4
1970-2015	2.1
1993-2015	3.2
2006-2015	3.6

GMSL rise is a certain impact of climate change; the questions are when, and how much, rather than if.

Specifically, for Guam, the mean sea level (MSL) trend is 8.60 millimeters/year with a 95% confidence interval of +/- 4.88 mm/yr (NOAA CO-OPS, 2014a), which is equivalent to a change of .88 meters (2.82 ft) in 100 years (See Figure 14). Figure 12 illustrates how a higher sea level can increase inundation during tropical storms and typhoons.

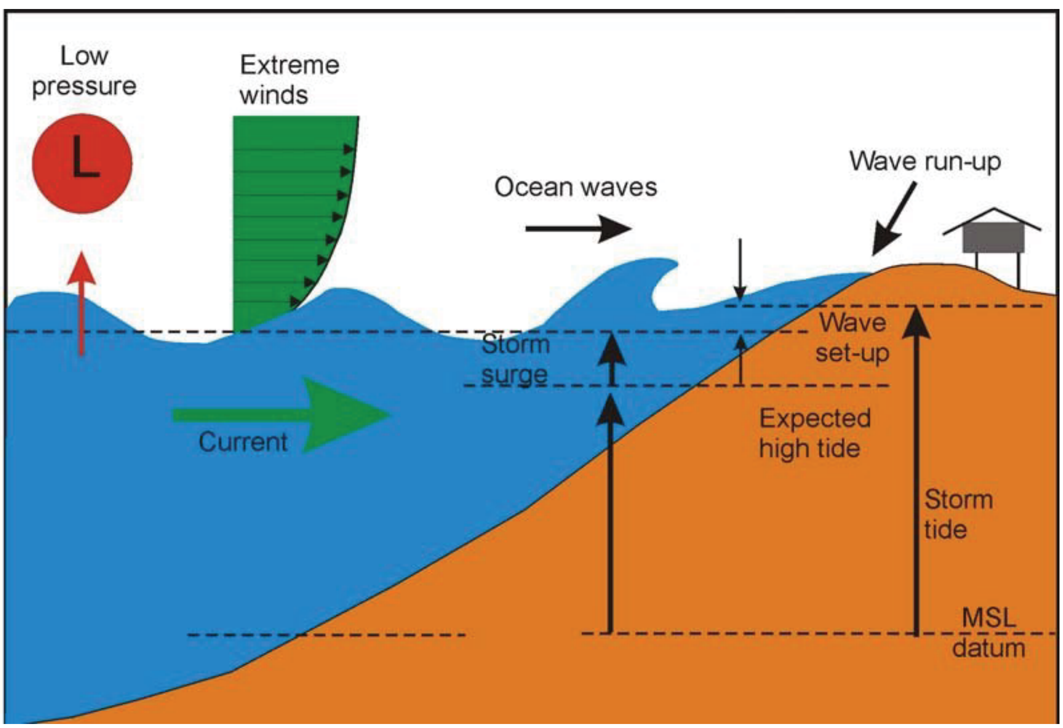

Figure 1: Schematic illustrating how SLR is an increase in the baseline of the ocean (assuming the land is not significantly uplifting). MHHW, Tides, Storm surge, wave runup, low-barometric pressure inducing rise all 'sit' on this baseline. During typhoons coastal flooding my increase. Reprinted from (Mullan et al., 2019).

While there are many impacts of climate change, this technical report focuses on one impact of climate change for Guam – SLR. A mixed-method approach was used to assess the vulnerability of Guam's built environment to three SLR scenarios (three, five, and ten-foot), engage community participation, and obtain local knowledge and expertise. The approaches used are as follows:

1. GIS Analysis estimating the percentage of impacted infrastructure in each of the three SLR scenarios
2. Participatory GIS exercise at All-Planners Climate Training Workshop[1] to obtain various perspectives and viable adaptation solutions regarding SLR from planners, engineers, developers, private citizens, local and federal employees, NGOs, and academics
3. Local Early Action and Planning (LEAP) exercise to engage community participation and understand what the community values and understands
4. Social Vulnerability index identifying the most vulnerable municipalities on Guam, by analyzing a series of variables from the US Census.

The results are as follows:

GIS Analysis
GIS SLR scenario analyses resulted with

- 58% of total infrastructure impacted by a 3-ft SLR (Table 19),
- 74% impacted by a 5-ft SLR (Table 20), and
- 84% impacted by a 10-ft SLR (Table 21).

Of the villages, the greatest percentage of infrastructure impacted were southern villages:
- 3ft SLR – southern 73% and central 27% (Figure 18);
- 5-ft SLR – 64% southern, 29% central, and 7% northern (Figure 19); and
- 10-ft SLR – 56% southern 31% central, and 13% northern (Figure 20).

The remaining villages with zero percent impact in the 13 infrastructure categories to all three SLR scenarios were Agana Heights, Barrigada, and Mangilao (Figure 18, Figure 19, and Figure 20).

Participatory GIS
Table 5 displays the ranking of concerns and solutions noted during the All-Planners Climate Change mapping exercise. Of 180 responses, frequency ranking by concern resulted as:

- 102 for infrastructure – *high concern*,
- 41 for natural – *moderate concern*, and
- 37 for culture – *low concern*.

Concerns were organized into subcategories and ranked from highest to lowest frequency of responses:

[1] The All-Planners Climate Change Workshop was conducted on 08 April 2019 at the Hyatt Resort and Hotel in Tumon Guam, in conjunction with the 10th Annual Center for Island Sustainability Conference. A list of attendees are available in Appendix A.

Built environment
- infrastructure – utilities (40),
- commercial building displacement (39),
- highway loss (19), and
- residential displacement (11);

Natural Environment
- natural – marine ecosystem change or loss (15),
- freshwater ecosystem change or loss (12),
- beach or natural landmark loss (9),
- erosion or landslide (4),
- and unfavorable upland conditions (1);

Cultural Resources
- cultural – historical site loss (15),
- cemetery displacement (8),
- tourism loss (5),
- aquaculture displacement (4),
- farmland loss (4), and
- fishing site loss (1).

LEAP

The 2019 LEAP exercise indicates that the community of Guam mark their climate history with major weather events, specifically typhoons that cause significant damage to infrastructure and have a high monetary cost of recovery (Figure 24). Of the 49 typhoons that passed over Guam from 1970 – 2018, the consolidated timeline for Guam shows only 12 "perceived" typhoons from 1970 to the present day (Figure 24).

Social Vulnerability Index

The CDC SVI ranked Guam's municipalities based on the overall sum of fifteen indicators of social vulnerabilities (Table 23). The three most vulnerable villages are Agat, Mongmong-Toto-Maite (MTM) and Hagatna and the three least vulnerable villages are Piti, Santa Rita, and Asan-Maina (Table 43).

Recommendations

The primary recommendation is to create a climate change adaptation plan that addresses the vulnerabilities identified in this technical report. It is suggested that the adaptation plan incorporate the following goals for the coastal zone:

1) Maintain functioning and healthy coastal ecosystems
2) Reduce exposure and vulnerability of the built environment
3) Strengthen governance frameworks for coastal adaptation
4) Maintain livelihood opportunities and diversify options
5) Reduce risks to human health and safety

It is also recommended that further research be conducted on the viability of nature-based solutions (NBS) as potential adaptation responses to SLR. It is also recommended that serious consideration be given to aligning the United Nations' sustainability development goals (SDGs) to future adaptive measures, with a focus on reducing poverty (SDG 1). Reducing poverty can increase socioeconomic status which can decrease overall social vulnerability to climate change.

List of Acronyms

AR5	IPCC Fifth Assessment Report
AOSIS	Alliance of Small Island States
BSP	Bureau of Statistics and Plans (GovGuam)
CAP	Conservation Action Plan
CBA	Community Based Adaptation
CBDAMPIC	Capacity Building for the Development of Adaptation Measures in Pacific Island Countries
CCN	Community Conservation Network
CCRC	Climate Change Resiliency Commission (GovGuam)
CCU	Guam Consolidated Commission on Utilities
CDC	Center for Disease Control
cm	centimeter
CNMI	Commonwealth of the Northern Mariana Islands
CO_2	carbon dioxide
COFA	Compact of Free Association
CO-OPS	Center for Operational Oceanographic Products and Services (division of NOAA)
CVI	Coastal Vulnerability Index
CZM	Coastal zone management
DAg	Department of Agriculture (GovGuam)
DAWR	Division of Aquatics and Wildlife Resources (GovGuam DAg)
DLM	Department of Land Management (GovGuam)
DOC	US Department of Commerce
DOI	US Department of the Interior
DOT	US Department of Transportation
DPW	Department of Public Works (Gov Guam)
EBM	Ecosystem-based management
ENSO	El Niño Southern Oscillation
EO	Executive Order
EPA	U.S. Environmental Protection Agency
FEMA	U.S. Federal Emergency Management Agency
FSM	Federated States of Micronesia
Ft	foot
GCM	Global Circulation Models
GCMP	Guam Coastal Management Program (part of GovGuam BSP)
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse gases
GIP	Gross Island Product
GIS	Geographical Information Systems/Science
GMSL	Global Mean Sea Level Rise
GovGuam	Government of Guam

GPA	Guam Power Authority
GU	Guam
GWA	Guam Water Authority
HCA	Hawaii Conservation Alliance
IGCI	International Global Change Institute
IIED	International Institute for Environment and Development
IPCC	Intergovernmental Panel for Climate Change
IREI	Island Research & Education Initiative
km	kilometer
LEAP	Local Early Action & Planning Management Tool
LiDAR	Light Detection and Ranging
LMSL	Local mean sea level
MARC	Micronesia Area Research Center
MIRAB	Migration, Remittances, Aid, Bureaucracy
m	meter
MHHW	mean higher high water
mm	milimeters
MSL	Mean Sea Level
NBS	Nature-based solution
NC4	U.S. Fourth National Climate Assessment
NCEH	National Center for Environmental Health
NEP	New Environmental Paradigm
NOAA	National Oceanic Atmospheric Administration
NRCS	Natural Resource Conservation Service (part of USDA)
OHA	Overseas Housing Allowance
OIA	Office of Insular Affairs (part of DOI)
OTPER	Office of Terrorism Preparedness and Emergency Response
PCB	Polychlorinated biphenyls
PDO	Pacific Decadal Oscillation
PGIS	Participatory GIS
pH	power of Hydrogen (concentration of hydrogen ions in an aqueous substance)
PIC	Pacific Island Country
PICASC	Pacific Islands Climate Adaptation Science Center, formerly known as PICSC
PICSC	Pacific Islands Climate Science Center (part of USGS), currently known as PICASC
PIMPAC	Pacific Islands Managed and Protected Area Community
ppm	parts per million
RCP	Representative Concentration Pathway
RMI	Republic of the Marshall Islands
RS	Remote sensing
RSL	Relative Sea Level
SDG	Sustainable development goal
SHPO	Guam State Historic Preservation Office
SIDS	Small Island Developing States

SLR	sea-level rise
SOPAC	South Pacific Islands Applied Geoscience Commission
SPREP	South Pacific Regional Environment Programme
SRES	Special Report on Emissions Scenarios
SVI	Social Vulnerability Index
TEV	Total Economic Value
TNC	The Nature Conservancy
UH	University of Hawaii
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environmental Programme
UOG	University of Guam
UOG ML	University of Guam Marine Laboratory
US	United States
USA	United States of America
USAPI	United States Affiliated Pacific Islands
USD	United States dollar
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WERI	Water Energy Research Institute (UOG)

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Introduction

Project Background and History

In 2016, the U.S. Department of the Interior Office of Insular Affairs Technical Assistance Program awarded 1.5 million USD to the Government of Guam to carry out self-determination educational outreach, public safety, emergency and facility assessments, natural and cultural resource preservation, leadership building for non-governmental organizations, and climate change projects. Of the 1.5 million, 450,000 USD was allocated to support Climate Action Plan Projects, which include:

1) a pilot Climate Geographic Information System (GIS) (83,500 USD);
2) an All-Planners Climate Training Workshop (48,000 USD);
3) multi-sector resiliency workshops (48,500 USD);
4) an updated plan for Storm Water Program and Implementation (80,000 USD); and
5) a Vulnerability[2] Analysis of Built Environments at Coastal Bays (190,000 USD).

Aim and purpose

This technical document provides a "Vulnerability Analysis of Built Environments at Coastal Bays" and presents a comprehensive, GIS-based report on impacts of climate change, specifically sea level rise (SLR), on Guam's infrastructure. Infrastructure includes water, wastewater, road, power networks; and buildings. Three SLR scenarios were used—a three-foot, five-foot, and ten-foot inundation model. In addition to the GIS analysis that calculates the percentage of impacted infrastructure within each SLR scenario, the report also provides a vulnerability analysis of Guam's population utilizing a Social Vulnerability Index (SVI) from the Center for Disease Control and Prevention, which is based on data from the US Census (2010). Additionally, in order to engage the community of Guam, ascertain community values, and obtain local knowledge, a participatory GIS exercise and a Local Early Action and Planning (LEAP) and Management session were conducted at the All-Planners Climate Training Workshop[3] . Results from these endeavors are located in the Results section. The intent of this technical report is to educate the general public, as well as inform responsible policies for resilient infrastructure, sustainable land use, and economic models for Guam.

Challenges

This work was expected to begin in 2016 and be completed in 2019. The original scope of work was supposed to be executed by one post-doctoral student and two graduate research assistants under the supervision of a senior principal investigator at the University of Guam (UOG). Due to a series of unexpected events and delays[4], work did not officially commence until December 2018. Due to the

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[2] **Vulnerability** may be defined as the 'propensity or predisposition to be adversely affected and the term encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt' (IPCC, 2019).

[3] The All-Planners Climate Change Workshop was conducted on 08 April 2019 at the Hyatt Resort and Hotel in Tumon Guam, in conjunction with the 10th Annual Center for Island Sustainability Conference. A list of attendees are available in Appendix A.

[4] The original GovGuam point of contact for climate change, Tricee Limtiaco earned a classified position at the Guam Power Authority and was replaced by Vince Leon Guerrero in 2017. The UOG PI retired in 2017. It took approximately one year for an MOU to be signed between the Government of Guam and UOG, due to the turnover of key personnel. Once the MOU was signed, there were a lack of qualified applicants for

shortened timeline, several decisions were made on methodology in order to produce a report with the best available data in a limited amount of time. For example, each of the community-based endeavors would have benefited with an additional year of follow-up meetings.

Organization of the report

In addition to the Acknowledgements, Executive Summary, List of Acronyms, and Table of Contents, the report has four main sections (Introduction, Methodology, Results & Discussion, and Recommendations). The Introduction gives a project background, states the aim and purpose, lists the challenges, and outlines the research questions and objectives. It also provides a succinct summary of the geography of Guam with sections on climate, population, polity and governance, and built infrastructure. It reviews the impacts of climate change for Guam with a focus on SLR and introduces three studies conducted for this project. These four separate, but related studies (Participatory GIS, GIS analysis of the Built Environment, Social Vulnerability Index, and Local Early Action Planning) have been organized into the remaining three sections: Methodology, Results & Discussion. The final section, Recommendations and Future Research provide suggestions on next steps. There are five Appendices (A-E) that provide additional information.

Research Questions and Objectives

The primary aim of the project is to assess the vulnerability of the built infrastructure in Guam with regard to three SLR scenarios. The objectives are as follows:

1. Utilizing GIS and the best available datasets in order to calculate the percentage of infrastructure for water, power, transportation, and buildings affected within each of the three different sea-level-rise scenarios (three, five, and ten-foot), by municipality
2. Conduct a participatory mapping exercise at the All Planners Climate Change Workshop, using a ten-foot sea level rise scenario
3. Calculate a Social Vulnerability Index (SVI) for each municipality of Guam, utilizing an accepted methodology from the Center for Disease Control (CDC)
4. Analyze the results from the local early action and planning (LEAP) exercise conducted at the All Planners Climate Change Workshop

Geography of Guam

The United States unincorporated territory of Guam is located in the western Pacific Ocean, south of Japan, north of Australia, and east of the Philippines (Figure 2) and is considered part of Micronesia. Guam is the southernmost volcanic island of the Mariana Archipelago, located at 13^{o} 28' N, 144^{o} 45' E (Figure 2).

Guam has an approximate total shoreline length of 244 km, and a maximum elevation of approximately 405 m. The northern half of the island is flat and composed primarily of uplifted limestone; this is where the principal aquifer (i.e., the Northern Guam Lens) is located (Figure 5). The Northern Guam Lens is the island's main source of drinking water. The southern half of the island is comprised of volcanic rock and has considerably more topographic relief (Figure 5) and high erosion potential. From this topography, 19 watersheds have been delineated (Watershed Professionals Network, 2010).

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the post-doctoral position and the position went unfilled for a year. In order to salvage the grant, Dr. King was relieved of teaching responsibilities and detailed to the Micronesia Area Research Center (MARC) for one year (2019), in order to complete the report.

Polity and Governance

The territory elects its Governor, Lieutenant Governor, and a 15-member Senate, as well as a non-voting delegate to the US Congress. The island's capital is Hagatna. The indigenous people are Chamorros, while long-term residents are referred to as Guamanians. Citizens of Guam hold a U.S. passport, but may not vote in U.S. federal elections. Guam is also the largest (541 km^2) and most populated island (159,358 people)[5] in Micronesia (Figure 4). The island is divided into 19 municipalities, often referred to as villages, with distinct historic origins (Figure 4).

Guam was acquired after the Spanish-American War of 1898. This tie to the United States is evident with the presence of two military bases and a local governance structure that mirrors the American federal government. From a military perspective, Guam is strategically important to the United States due to its proximity to Asia. Because of its military strategic geographic location and abundant natural groundwater supply, achieving self-determination in the near future may be a challenge. As a territory, the people of Guam do not have complete control over the island's natural resources which may prove to be a challenge for future climate adaptation policies.

Climate

Guam's climate[6] is almost uniformly warm and humid throughout the year. Generally, temperatures may range from the low 70s to the high 80s Fahrenheit. There are two seasons, dry and wet. The dry season consists of the coolest and least humid months in Guam, typically begins in late November/early December and extends through the end of May. It is usually marked by the prevailing Northeast trade winds. The wet season begins in June and extends until early November. Total average annual rainfall is variable and is approximately, 80-110 inches (2,032-2,794 mm). The majority of precipitation occurs during the wet season between June and December. During the wet season, there is a lack of trade winds, and the Southwest monsoon trough migrates North, toward Guam. Guam lies within the typhoon belt and is periodically struck by tropical storms and typhoons, which are most frequent from June through December. According to the NOAA Storm Events Database for Guam, between 1950-2019, there were 49 recorded typhoons and 51 recorded tropical storms (NOAA - National Centers for Environmental Information, n.d.). According to Federal Emergency Management Agency (n.d.), between 1962 and 2019, 15 out of 17 major disaster declarations resulted from typhoons and tropical storms.

Population

The population of Guam has been steadily increasing since 1910 (see Table 1). The latest official population count (2010) for Guam was 159,358 , only a 2.9% increase from the 2000 census (see Table 1). The spatial distribution of the 2010 census data indicates that most of the population is concentrated in the Northern half of Guam, and Dededo has the highest population (see Figure 4).

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[5] Figure is according to the US 2010 Census (U.S. Census Bureau, 2011).

[6] **Climate** may be generally defined 'as the average weather—or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities—over a period of time ranging from months to thousands or millions of years.' The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. (IPCC 2019)

Key Terms

There are several key terms pertaining to climate change that will be utilized in this report and have been placed in APPENDIX E.

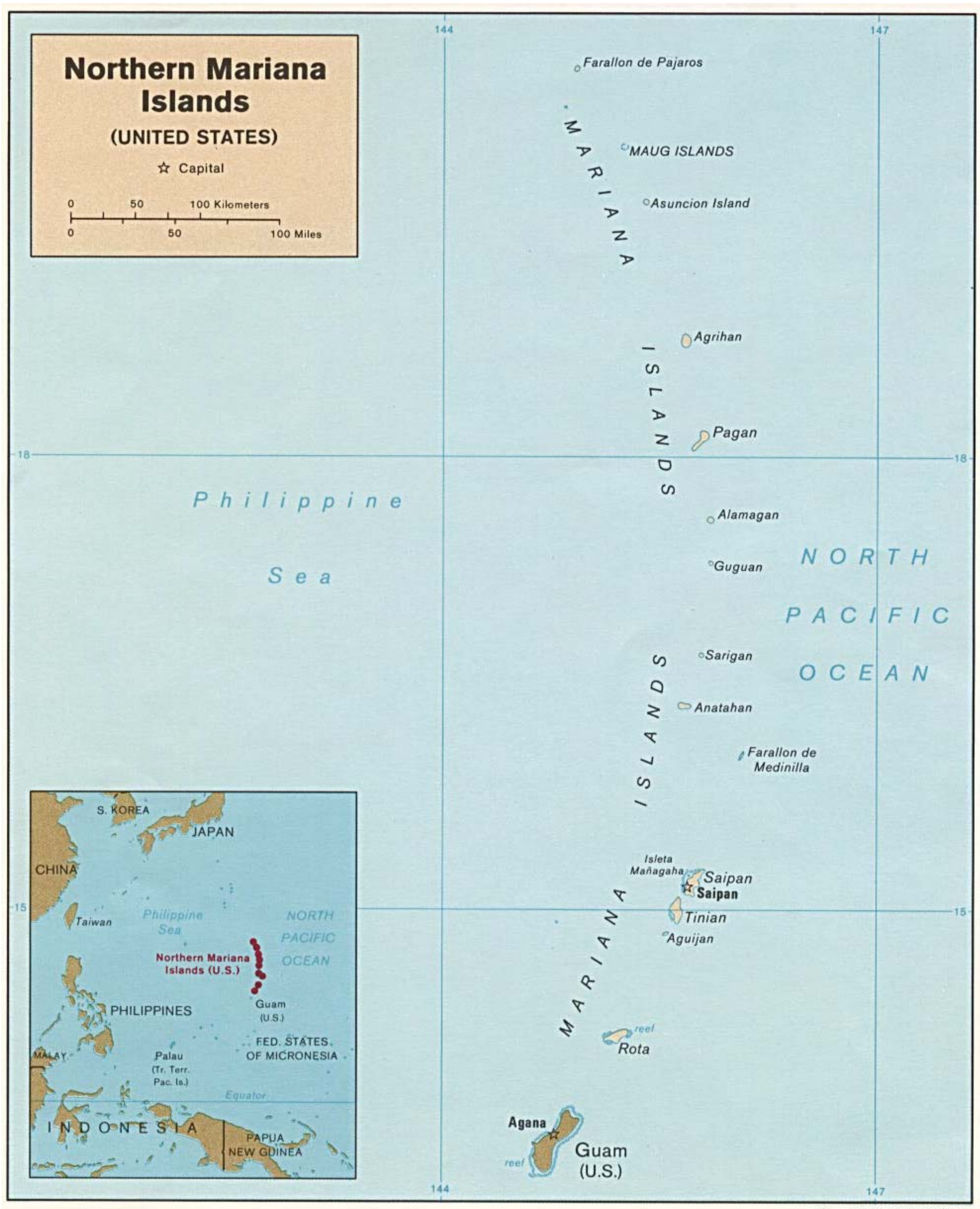

Figure 2: Regional map showing the Marianas Islands Archipelago. Guam is the southernmost island of the chain.

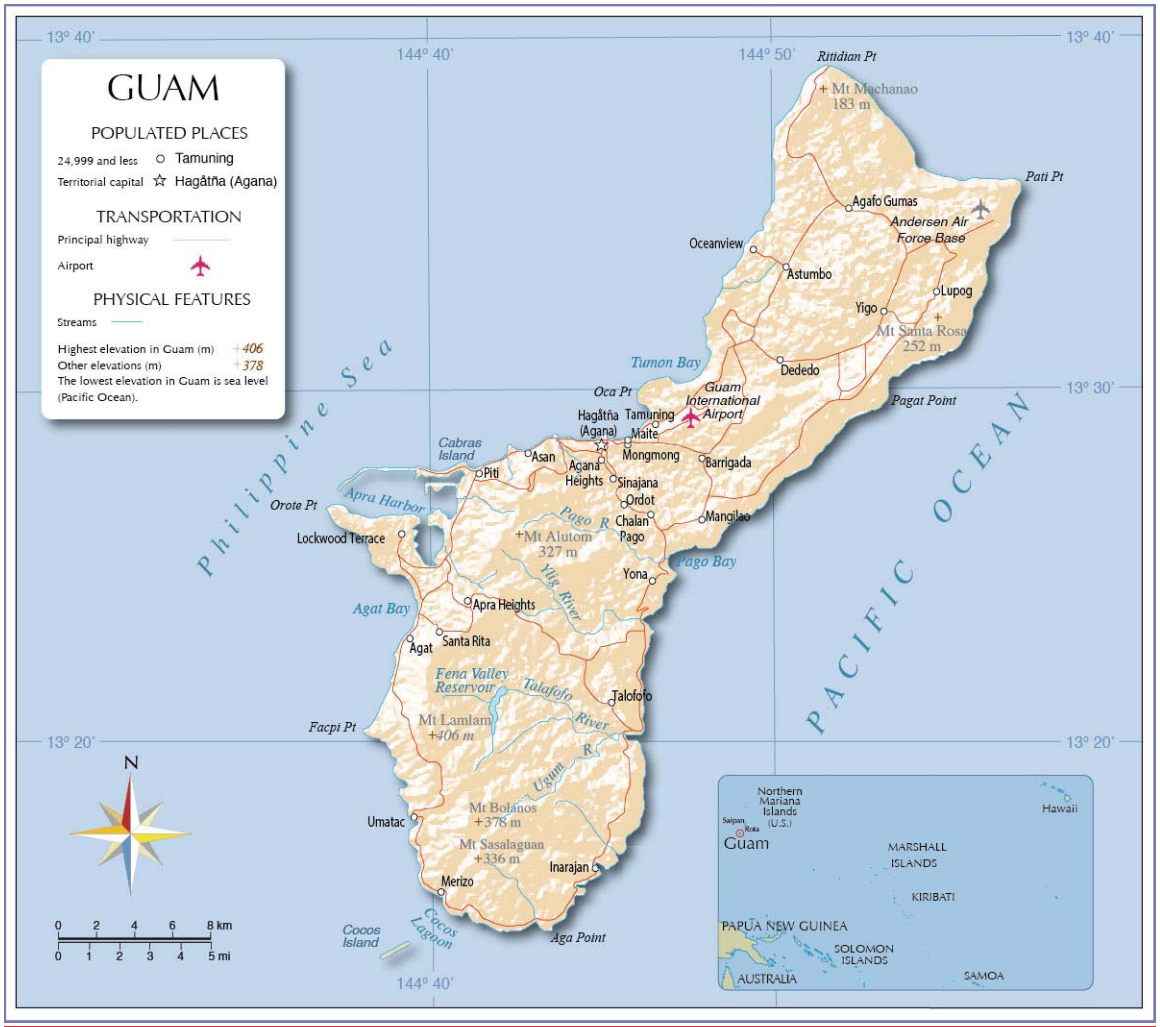

Figure 3: General map of Guam

Table 1: Population of Guam for each decade from 1910 – 2010. Data is from the U.S. Census Bureau.

Census Year	Total Population	Percent Change in Population (%)
1910	11,806	—
1920	13,275	12.4
1930	18,509	39.4
1940	22,290	20.4
1950	59,498	166.9
1960	67,044	12.7
1970	84,996	26.8
1980	105,979	24.7
1990	133,152	25.6
2000	154,805	16.3
2010	159,358	2.9

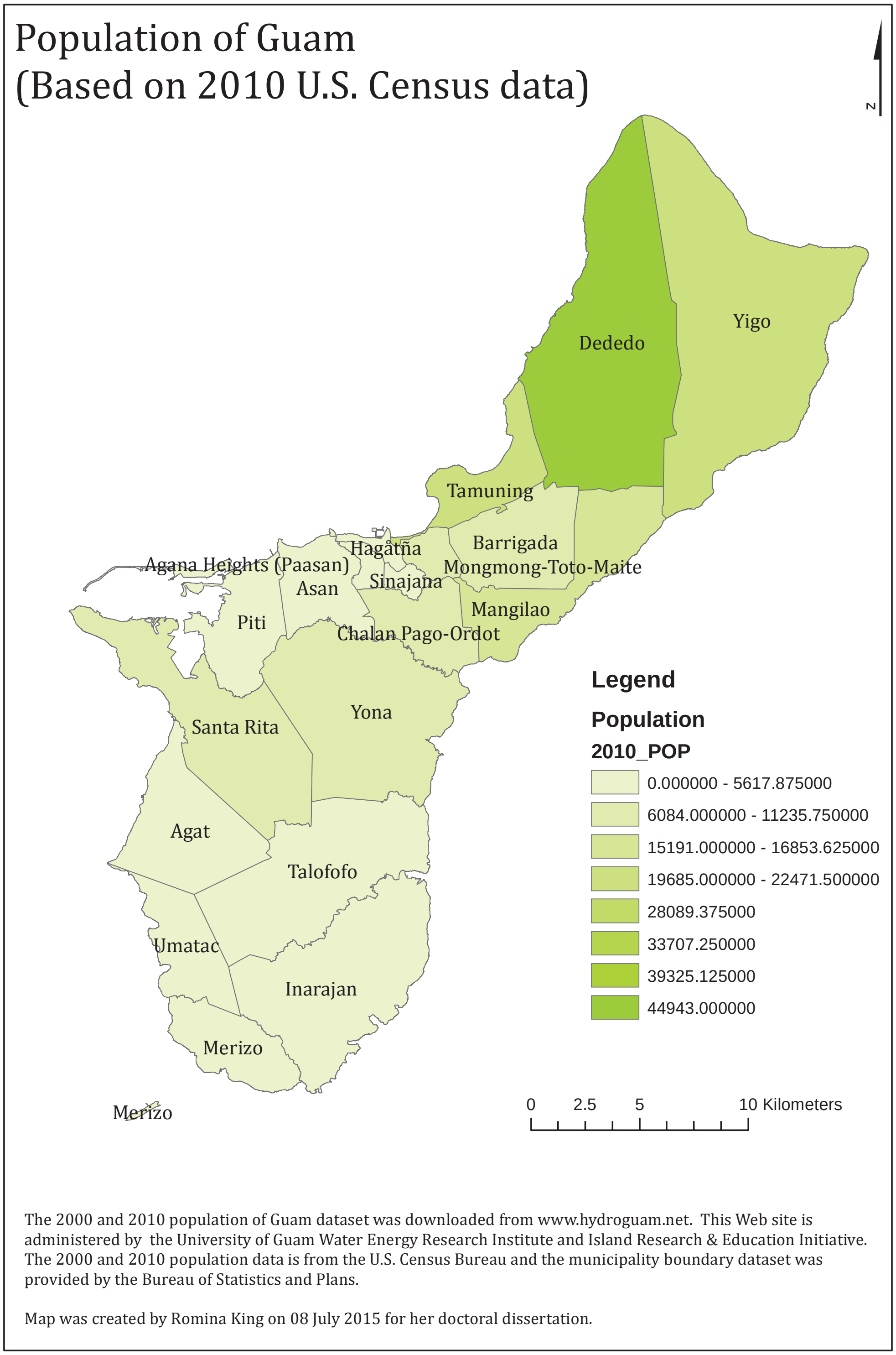

Figure 4: Chloropleth map showing the geographical distribution of the 2010 population of Guam according to municipality.

Figure 5: Digital elevation model of bare-Earth derived from 2007 LIDAR data. The relief shows the flat limestone plateau that characterizes Northern Guam and the volcanic mountainous region that characterizes Southern Guam.

Climate Change and Small Islands

Climate change is often regarded as the issue of this generation, especially for small island states. Small islands are the most vulnerable to the impacts of climate change[7] (e.g., SLR) (Briguglio, 1995; Carter et

[7] **Climate change** refers to a 'change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC 2019).

al., 2001; Engelen et al., 1993; Hay et al., 2001; Hay and Mimura, 2005; Heffernan, 2009; IPCC, 2007a; McCarthy, 2001; Mimura, 1999; Mimura et al., 2007; Nicholls and Mimura, 1998; Nurse et al., 2001; Pelling and Uitto, 2001; Tol et al., 2004; Vellinga and Klein, 1993). According to the IPCC (2019), IPCC (2014) and IPCC (2007a), some of the primary impacts of global climate change that may threaten small islands include:

1. The projected SLR for the next hundred years would cause enhanced soil erosion, loss of land, poverty, dislocation of people, increased risk from storm surges, reduced resilience of coastal ecosystems, saltwater intrusion into the freshwater aquifer, and high resource costs needed in responding and adapting to changes.
2. Coral reefs would be negatively affected by warming sea surface temperatures and decreases in ocean pH. There would be an increased number of bleaching events and reduced calcification rates. Other coastal ecosystems (e.g., mangroves, wetlands, seagrass beds) and the associated biodiversity would be adversely affected by rising temperatures and accelerated SLR.
3. Anticipated erosion of beaches and increased number coral bleaching events (leading to lower resilience of coral to disease which may increase coral mortality), is expected to affect sectors of the local economy such as fisheries and tourism.
4. SLR is expected to exacerbate inundation, storm surge, erosion, and other coastal hazards, thus threatening vital infrastructure (e.g., homes, water lines, hotels).
5. Higher-than-average temperatures are expected to contribute to an increase in the number of invasive, non-native species particularly on mid- and high latitude islands.
6. Water resources in many small islands in the Caribbean and the Pacific are expected to dwindle by mid-century, to the point of becoming insufficient to meet people's demand during periods of low precipitation.

In general, small islands tend to be regarded as vulnerable for a number of reasons (Adger et al., 2007). Small islands are usually fairly isolated, have relatively small populations, have limited land and freshwater resources (Barnett, 2001; Briguglio, 1995; Dahl, 1997; Hay et al., 2001; Mimura, 1999). These factors pose environmental and social challenges which will be further exacerbated by climate change (Barnett, 2001; Briguglio, 1995; Dahl, 1997; Hay et al., 2001; Mimura, 1999). Owing to factors of limited size, availability, geology, and topography, water resources in small islands are extremely vulnerable to changes and variations in climate, especially to rainfall (Adger et al., 2007). Islands also have to deal with other issues such as migration, the potential loss of languages and cultures through emigration, gender inequities, pollution, and illegal resource extraction (Kelman, 2006).

This vulnerability of small islands, especially atoll countries, to climate change coupled with low adaptive capacity may put their sovereignty at risk (Barnett and Adger, 2003). If a nation's physical land mass disappears, they are no longer a nation-state. Ironically, the loss of sovereignty is not an issue for Guam because Guam is a colonial possession. Despite these issues and factors, small islands can utilize some of their unique characteristics to improve their adaptive capacity and reduce their vulnerability to the adverse effects of climate change. Characteristics such as tight kinship networks, unique heritage, a strong sense of identity and community, creativity for sustainable livelihoods, remittances from off-island relatives, traditional knowledge, and experience of dealing with environmental and social changes, can work to the advantage of small islands.

Climate Models

In order to forecast future climate for adequate planning purposes, one tool that is used are climate models. Climate models are based on known physical earth processes to simulate the transfer of energy and materials through the climate and ocean systems. Climate models, also known as general circulation models (GCMs), use mathematical equations to calculate how matter and energy interact in different parts of the ocean, atmosphere, land. Creating and executing a climate model is a very complex process. It involves identifying and quantifying Earth system processes, representing them with mathematical equations, setting variables to represent initial conditions and subsequent changes in climate forcing, and repeatedly solving the equations using powerful supercomputers (NOAA, n.d.).

Climate models divide the Earth's surface into a three-dimensional grid of cells. The results of processes modeled in each cell are passed to neighboring cells to model the exchange of matter and energy over space and time. Grid cell size defines the resolution of the model: the smaller the size of the grid cells, the higher the level of detail in the model. More detailed models have more grid cells, so they need more computing power (NOAA, n.d.). See Figure 6 for a schematic of a GCM.

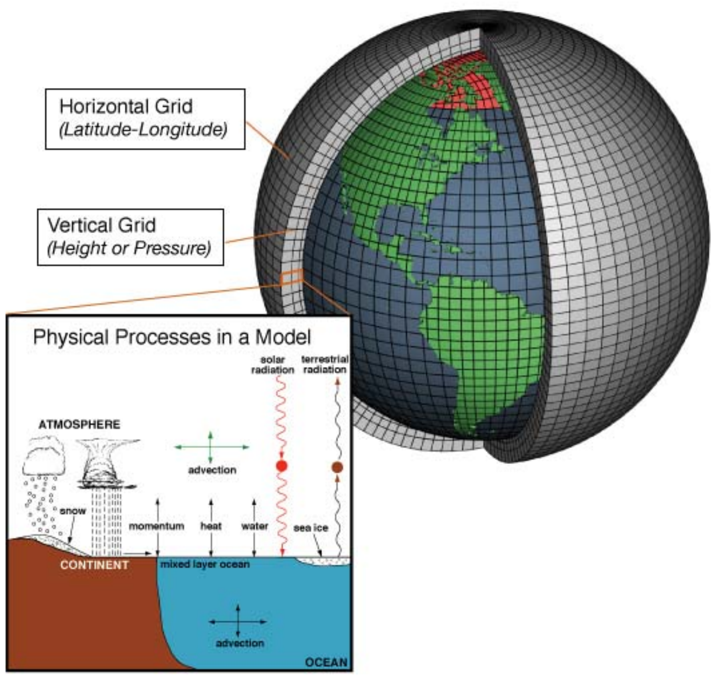

Figure 6: This schematic illustrates climate models. Each of the thousands of 3-dimensional grid cells can be represented by mathematical equations that describe the materials in it and the way energy moves through it. The advanced equations are based on the fundamental laws of physics, fluid motion, and chemistry. To "run" a model, scientists specify the climate forcing (for instance, setting variables to represent the amount of greenhouse gases in the atmosphere) and have powerful computers solve the equations in each cell. Results from each grid cell are passed to neighboring cells, and the equations are solved again. Repeating the process through many time steps represents the passage of time. Image source: NOAA.

Once a climate model has been established, its accuracy is 'tested' with a process known as "hind-casting." Hindcasting runs the model from the present time backwards into the past. The model results are then compared with observed climate and weather conditions to see how well they match. Depending on the results of the hindcast, climate model scientists can revise the equations, if necessary. GCMs' outputs are constantly compared to observations and results from other GCMs.

As soon as a climate model proves its accuracy in a hindcasting test, its results for simulating future climate are legitimized. To project climate into the future, the climate forcing is set to change according to a possible future scenario. Scenarios in climate change research, may be defined as 'plausible trajectories of climate conditions and other aspects of the future' (Moss et al., 2010). Basically, scenarios are possible stories about how quickly a human population may grow, how land use may change, how economies may evolve, and the atmospheric conditions (and therefore, climate forcing) that would result for each storyline.

The Intergovernmental Panel on Climate Change (IPCC) issued its Special Report on Emissions Scenarios (SRES), describing four scenario families to describe a range of possible future conditions (Nakicenovic et al., 2000). Referred to by letter-number combinations such as A1, A2, B1, B2, etc., each scenario was based on a complex relationship between the socioeconomic forces driving greenhouse gas and aerosol emissions and the levels to which those emissions would climb during the 21st century (Nakicenovic et al., 2000). Typical grid sizes for the SRES models are approximately 100 by 150 km (i.e., 60 by 90 miles) across at mid latitudes.

The SRES scenarios of Nakicenovic et al (2000) were updated in 2013. This new set of scenarios focused on the level of greenhouse gases in the atmosphere in 2100; they are referred to as Representative Concentration Pathways or RCPs (IPCC, 2013). Each RCP indicates the amount of climate forcing, expressed in Watts per square meter, that would result from greenhouse gases in the atmosphere in 2100. The rate and trajectory of the forcing is the pathway. Like their predecessors, these values are used in setting up climate models.

Representative concentration pathways (RCPs) are 'scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs), aerosols, and chemically active gases, as well as land use/land cover' (Moss et al., 2008). The word 'representative' signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term 'pathway' emphasizes the fact that in addition to long-term concentration levels, the trajectory taken over time to reach that outcome are of interest (Moss et al., 2010). RCPs were used to develop climate projections in Coupled Model Intercomparison Project CMIP5.

There were four RCPs used for the IPCC AR5 (2013) and they are as follows:

- RCP2.6: One pathway where radiative forcing peaks at approximately 3 W m–2 and then declines to be limited at 2.6 W m–2 in 2100 (the corresponding Extended Concentration Pathway (ECP) assuming constant emissions after 2100). This the 'ideal' or 'low-level' scenario that assumes that there is a significant reduction of greenhouse gases.
- RCP4.5 and RCP6.0: Two intermediate stabilization pathways in which radiative forcing is limited at approximately 4.5 W m–2 and 6.0 W m–2 in 2100 (the corresponding ECPs assuming constant concentrations after 2150). These are mid-level scenarios that assume that measures have been taken to reduce greenhouse gas emissions.
- RCP8.5: One high pathway which leads to >8.5 W m–2 in 2100 (the corresponding ECP assuming constant emissions after 2100 until 2150 and constant concentrations after 2250). This is often referred to as the 'business as usual' or 'high emissions' scenario.

The resolution or grid size for the RCPs are 0.5° × 0.5° (van Vuuren et al., 2011), which is approximately 34.5 miles x 34.5 miles at the equator. Thus, one cell of this grid would be 1190.25 mi^2, at the equator.

Unfortunately, due to Guam's small size (541 km^2 or 208.9 mi^2), the island would be register as water. Because of this, it is necessary to 'downscale' the RCPs for climate predictions for Guam.

Climate Predictions for Guam

There is only one downscaled model for Guam (Wang, 2016). Wang (2016) projected fine-resolution (.8 km horizontal model resolution) future climate changes for Guam for the late 21st century (2080-2099) with both a high emissions scenario (RCP 8.5) and a medium emission scenario (RCP 4.5). The .8 km horizontal resolution is the highest horizontal model resolution created for a downscaled climate model, to study regional climate change (Figure 7) (Wang, 2016). The downscaled model indicates that surface air temperature over Guam is likely to increase by 1.5 – 2.0 °C for RCP 4.5 and by 3.0 – 3.5 °C for RCP 8.5 (Wang, 2016). The projected annual mean future rainfall changes for Guam are not statistically significant in any location in either the RCP 4.5 or RCP 8.5 scenarios (Wang, 2016). The frequency of weak tropical cyclones (TCs) will significantly decrease within 500 km around Guam, while that of strong TCs will increase (Wang, 2016).

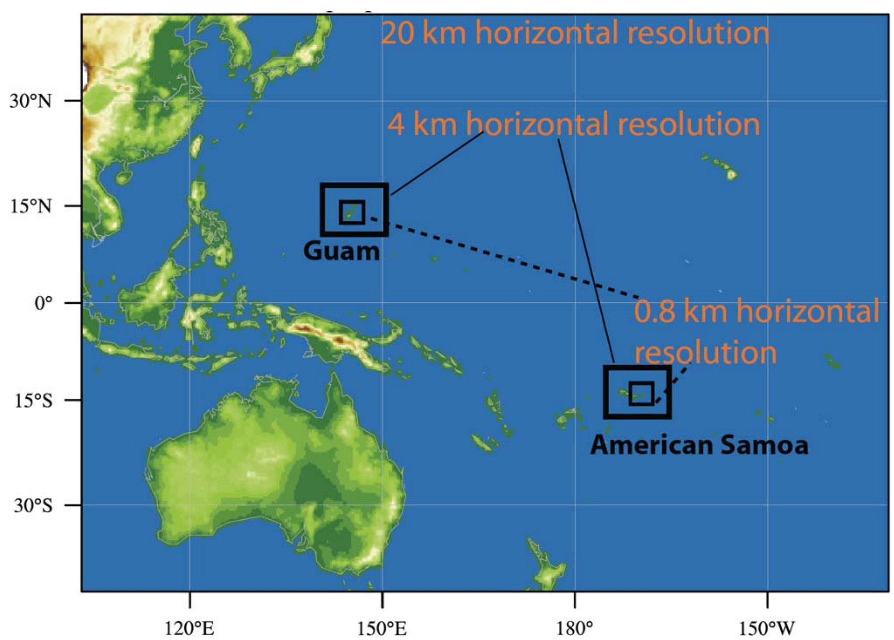

Figure 7: Visualization of the resolution of the only downscaled model for Guam. Reprinted from Wang (2016).

Sea Level Rise (SLR)

While there are many impacts of climate change, this study focuses on one particular impact - sea level rise and potential impacts to Guam's built infrastructure. Sea level rise (SLR) is the increase in the height of sea level. Local changes in sea level are referred to as relative sea level change and may occur at seasonal, annual, or longer time scales. Global SLR is primarily caused by:

1. a change in ocean volume as a result of an increase in the mass of water in the ocean (e.g., due to melt of glaciers and ice sheets)
2. changes in ocean volume as a result of changes in ocean water density (e.g., expansion under warmer conditions, or thermal expansion)

3. changes in the shape of the ocean basins and changes in the Earth's gravitational and rotational fields, and
4. local subsidence or uplift of the land (IPCC 2019).

See Figure 8 for a visualization of the various reasons why sea levels can change.

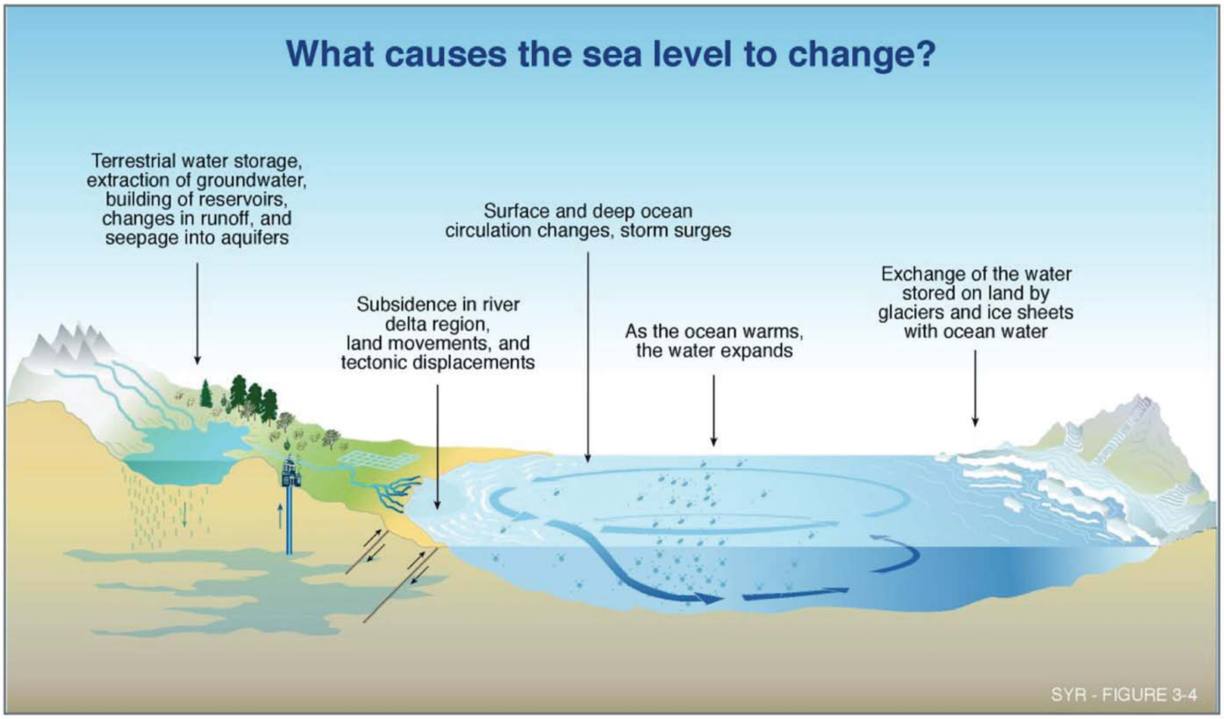

Figure 8: Infographic illustrating causes for relative sea level change. Figure is from climate.gov.

Global mean sea level (GMSL) is rising and accelerating (IPCC, 2019). Glacier and ice sheet melt is currently the dominant source contributing to GMSL rise (IPCC, 2019). GMSL from tide gauges and altimetry observations increased from 1901 – 2015 (Table 2).

Table 2: GMSL rise, according to altimetry observations and tide gauges. Data is from IPCC 2019.

Period	Increase (mm/yr)
1901 -1990	1.4
1970-2015	2.1
1993-2015	3.2
2006-2015	3.6

SLR and small Islands

According to Kelman and West, (2009), "…SLR is arguably the most certain and potentially devastating climate change impact [to small islands]." According to Meehl et al. (2007), it is anticipated that during the 21st century, sea level will rise at least 0.18 m and perhaps as much as 0.59 m. However, Meehl et al. (2007) explicitly do not provide an upper bound to the maximum possible SLR, stating that the final maximum rise by 2100 might exceed these projections, partly because of inputs from ice sheet break up in Greenland and Antarctica (events that were not included in the forecast). But, if the West Antarctic Ice Sheet collapses, global mean sea level is estimated to rise by approximately five meters (Mercer, 1978; Vaughn and Sponge, 2002), which would result in the total inundation of the coastal zones of most small islands. A recent study found that Greenland lost 3,800 ± 339 billion tons of ice between 1992 and 2018, causing mean sea level to rise by 10.6 ± 0.9 millimeters (Shepard et al., 2019). Alarmingly, total cumulative ice losses from Greenland as to date, have been close to the IPCC's predicted rates for their high-end climate warming scenario (the worst case scenario), which forecast an additional 50 to 120 millimeters of global sea-level rise by 2100 when compared to their central estimate (Shepard et al., 2019). Figure 9 provides a clear overview of the various SL estimates calculated by different groups (Church and White, 2011, 2006; Hay et al., 2015; Ray and Douglas, 2011; Wenzel and Schröter, 2014, 2010). While the details of each group's calculation vary, the overall trend indicates a rise in sea level (see Figure 9). Hay et al. (2015) found that rate of SLR is far greater than previously estimated, which may affect the accuracy of the projections.

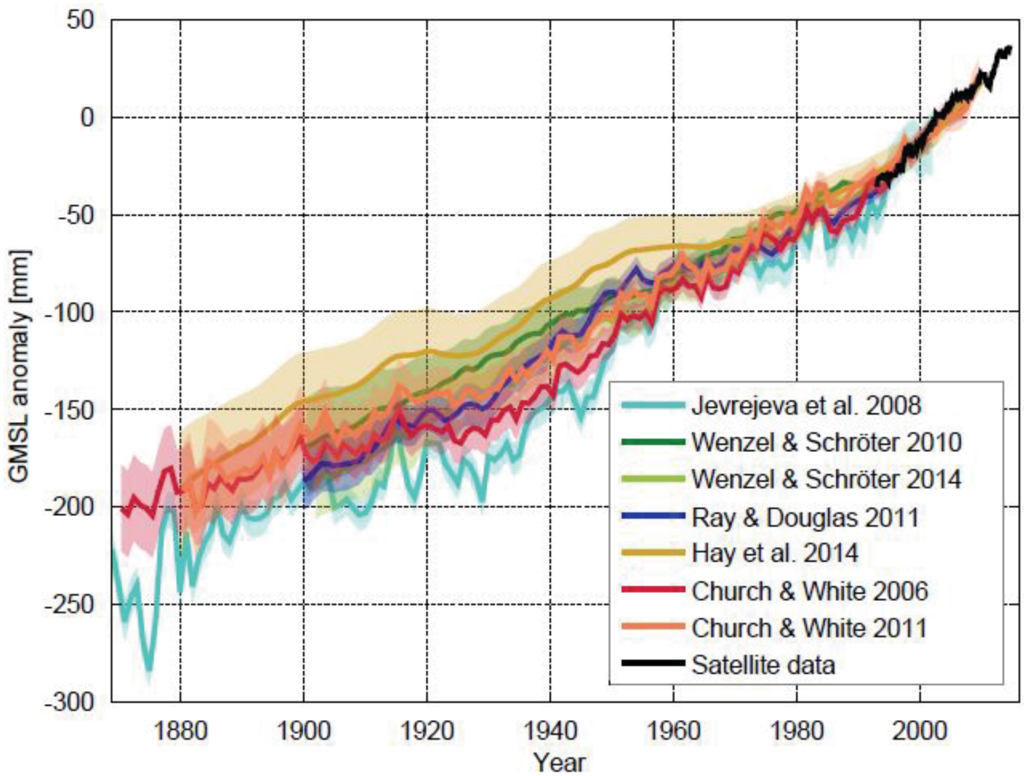

Figure 9: Sea level calculated by different research groups using various methods. Plots show sea level relative to satellite data (since 1992). Graph was created by Klaus Bittermann and reprinted from (Schmidt et al., 2015).

SLR is a substantial concern, not only for the low-lying atoll islands, but also for many high islands where settlements, infrastructure and facilities are concentrated in the coastal zone (Mimura et al., 2007), especially given the recent calculations of Greenland ice loss findings by Shepard et al. (2019). Again, projected globally averaged SLR at the end of the 21st century (2090 to 2099), relative to 1980 to 1999 for the six SRES scenarios, ranges from 0.19 to 0.58 m (Meehl et al., 2007) and the total Greenland ice loss (Shepard et al. 2019) will making 0.58 m more likely and potentially greater. Hay et al. (2015) argue that it could be far greater.

Climate models also indicate a geographical variation of SLR due to non-uniform distribution of temperature and salinity and changes in ocean circulation (Meehl et al., 2007). Furthermore, regional variations and local differences depend on several factors, including non-climate related factors such as island tectonic setting and postglacial isostatic adjustment (Meehl et al., 2007).

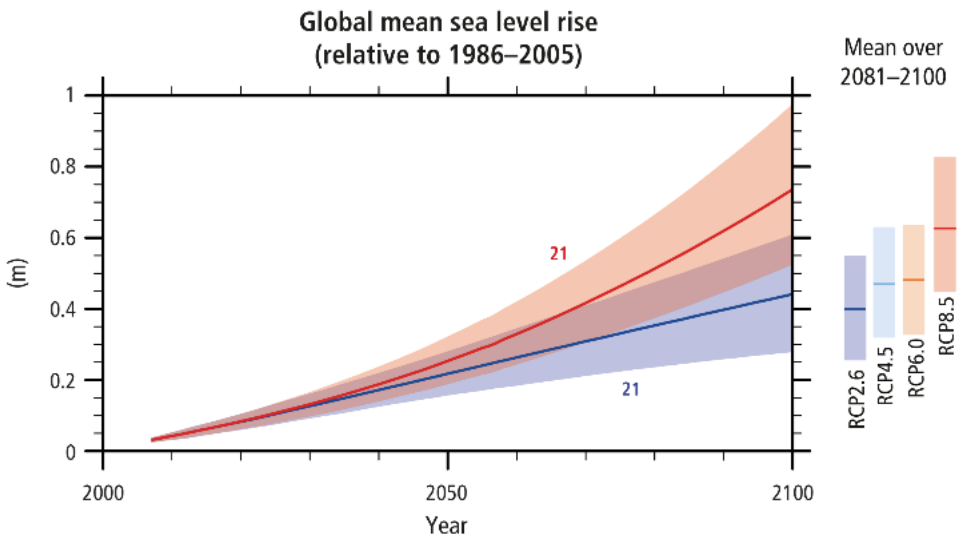

Figure 10: Change in global sea levels (mm) for the four IPCC AR5 Representative Concentration Pathways (RCPs) used for making projections (IPCC, 2019)

Between 1993-2010, global mean sea level rose, with the highest rise in the Western Pacific Ocean (Merrifield, 2011) (Figure 11). Increases in sea level in the western tropical Pacific Ocean, have been observed over the past two decades, with rates approximately three times the global average (Merrifield and Maltrud, 2011). Merrifield & Maltrud (2011) explain this anomaly by using a general circulation model to show that the high rates are caused by a gradual intensification of Pacific trade winds since the early 1990s. The modeled sea-level change captures the spatial trend pattern in satellite altimeter sea surface heights and the temporal trend shift in tide gauge observations. In addition to the sea level response, the model also shows how other aspects of the ocean circulation have increased appreciably in amplitude as a consequence of the trade wind intensification, including tropical surface currents, the shallow meridional over-turning circulation, the Equatorial Undercurrent, and the Indonesian Throughflow (Merrifield and Maltrud, 2011). These results highlight an ongoing shift in the state of the tropical Pacific Ocean that will continue as long as the trade wind trend persists” (Merrifield and Maltrud, 2011). Increased intensification and frequency of the Northeast trade winds are characteristic of La Nina.

It is important to note that SLR is not globally uniform and varies regionally**.** Thermal expansion, ocean dynamics, and land ice loss contributions will generate regional departures of about ±30% around the GMSL rise. Differences from the global mean can be greater than ±30% in areas of rapid vertical land movements, including those caused by local anthropogenic factors such as groundwater extraction (IPCC, 2019). Subsidence caused by human activities is currently the most important cause of RSL change especially in deltas. While climate-driven regional SLR will increase over time, it is critical to consider local processes, such as anthropogenic subsidence, for projections of sea level impacts at local scales (IPCC, 2019). Gravity for the Re-definition of the American Vertical Datum (GRAV-D) is a project initiated by NOAA's National Geodetic Survey to collect and monitor gravity data suitable for the re-definition of the vertical datum for the United States and territories. Field work was scheduled for Guam this past year.

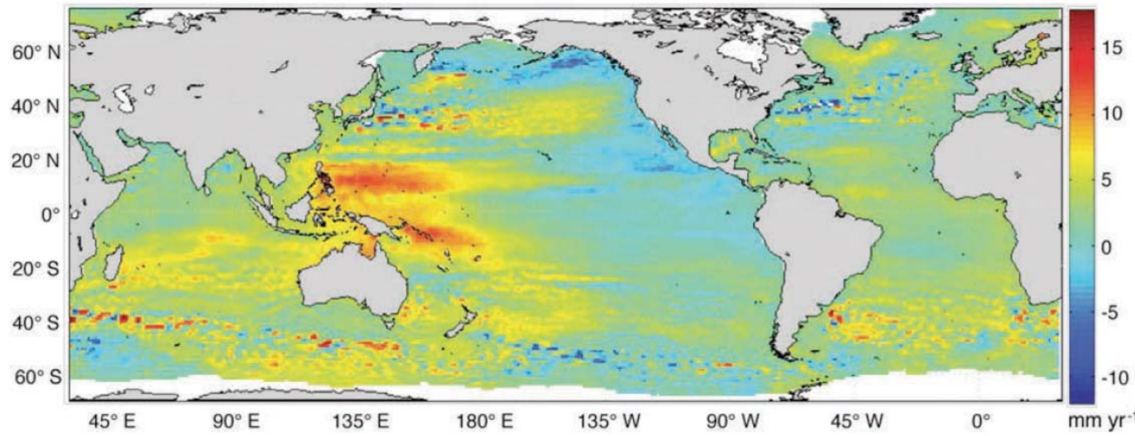

Figure 11: Sea-level trend for 1993–2010 from Aviso altimeter product, produced by Ssalto/Duacs with support from the Centre National d'Etudes Spatiales. (From Merrifield [2011] by permission of American Meteorological Society.) Reprinted with permission from Keener et al. (2013).

SLR coupled with seasonal high tides and storm surges can result in coastal inundation, a threat to coastal communities and infrastructure. SLR is a major factor contributing to recent and projected future reductions in coastal habitats, such as mangroves, tidal wetlands, coral reefs, beaches, and sea grass beds. This will ultimately affect ecosystem services, leading to an increased threat to resident wildlife and human populations. In a world without humans, the natural coastal ecosystem response to SLR would be a landward migration of tidal wetlands and beaches. However, this is not the case; humans are part of the coastal ecosystem and have impeded this natural response through the construction of seawalls, coastal roads, and various shoreline development. Enhancing natural ecosystems can increase resilience to climate change (Tompkins and Adger, 2004). Figure 12 illustrates how a higher sea level can increase inundation during tropical storms and typhoons.

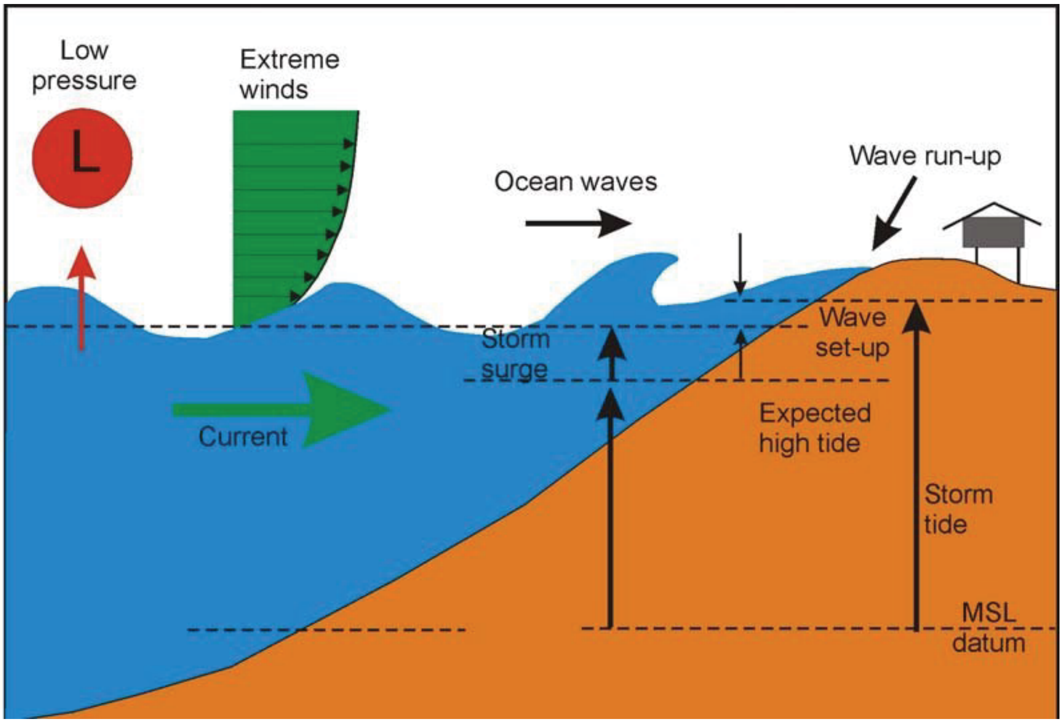

Figure 12: Schematic illustrating how SLR is an increase in the baseline. MHHW, Tides, Storm surge, wave runup, low-barometric pressure inducing rise all 'sit' on this baseline. Reprinted from (Mullan et al., 2019).

SLR and modelling

Global SLR is inevitable (even if GHG emissions were to completely stop today) and will continue past 2100, (Meehl et al., 2012; Mengel et al., 2018; Willis and Church, 2012). It is most likely to be irreversible on millennial timescales (Clark et al.2016; Levermann et al.2013; Solomon et al.2009), and surpass many planning and engineering timescales with regard to infrastructure and coastal flooding (Obeysekera and Salas, 2016; Sweet et al., 2017; Hall et al., 2019).

SLR is a major consequence of climate change that will continue long after emissions of greenhouse gases have stopped. The 2015 Paris Agreement attempted to minimize climate-related risks by reducing greenhouse gas emissions to net zero and limiting global-mean temperature increases. Hall et al. (2019) quantify the effect of these constraints on global sea-level rise until 2300, including Antarctic ice-sheet instabilities and estimated median sea-level rise between 0.7 and 1.2 m, if net-zero greenhouse gas emissions are sustained until 2300. Furthermore, temperature stabilization below 2 °C is insufficient to hold median sea-level rise until 2300 below 1.5 m (Hall et al., 2019). Hall et al. (2019) find that each five-year delay in near-term peaking of CO_2 emissions increases median year 2300 sea-level rise estimates by 0.2 m, and extreme sea-level rise estimates at the 95th percentile by up to one meter. This underlines the importance of near-term global mitigation action for limiting long-term sea-level rise risks.

Sweet et al., (2017) updated the scenarios of global mean sea level (GMSL) rise and integrated the global scenarios with regional factors contributing to sea level change for the entire U.S. coastline. The 0.3 m-2.5 m GMSL range for 2100 is discretized[8] by 0.5-m increments and aligned with emissions-based,

[8] represent or approximate (a quantity or series) using a discrete quantity or quantities.

conditional probabilistic storylines and global model projections into six GMSL rise scenarios: a Low, Intermediate-Low, Intermediate, Intermediate-High, High and Extreme, which correspond to GMSL rise of 0.3 m, 0.5 m, 1.0 m, 1.5 m, 2.0 m and 2.5 m, respectively (Sweet et al., 2017). These GMSL rise scenarios are used to derive regional RSL responses on a 1-degree grid covering the coastlines of the U.S. mainland, Alaska, Hawaii, the Caribbean, and the Pacific island territories, as well as at the precise locations of tide gauges along these coastlines. Global mean sea level (GMSL) has increased by about 21 cm to 24 cm (8–9 in) since 1880, with about 8 cm (3 in) occurring since 1993 (Church and White, 2011; Hay et al., 2015; Nerem et al., 2010). In addition, the rate of GMSL rise since 1900 has been faster than any comparable period over the last 2800 years (at least) (Kopp et al., 2016a). Sweet et al. (2017) further emphasize that GMSL will continue to rise throughout the 21st century and beyond, because of global warming that has already occurred and warming that is yet to occur due to the still-uncertain level of future emissions.

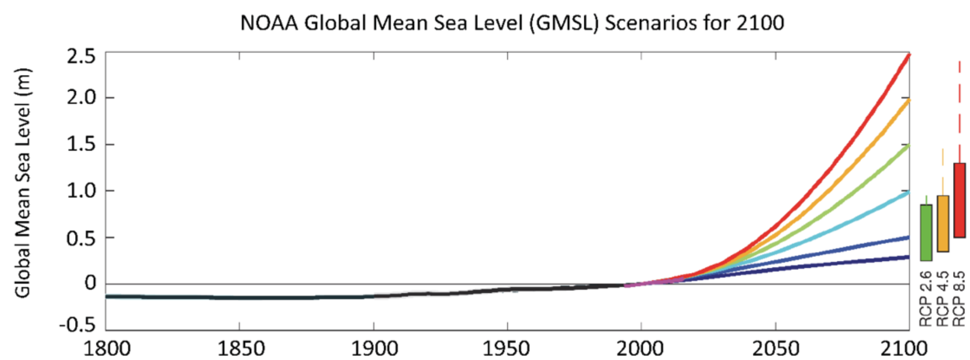

Figure 13: NOAA GMSL Scenarios for 2100. Reprinted from Sweet et al., 2017.

Coastal ecosystems are impacted by not only SLR, but also by adverse effects from human activities on ocean and land (IPCC, 2019). Non-climatic drivers such as infrastructure development and human-induced habitat degradation can reduce the natural resilience and coastal ecosystems can progressively lose their ability to adapt to climate-induced **changes** and provide ecosystem services, including acting as protective barriers (IPCC, 2019). This will increase the exposure and vulnerability of coastal communities to future SLR and extreme events (IPCC, 2019). Coastal ecosystems, including saltmarshes, mangroves, vegetated dunes and sandy beaches, can build vertically and expand laterally in response to SLR, though this capacity varies across sites. These ecosystems provide important services that include coastal protection and habitat for diverse biota.

SLR in Guam

For Guam, the mean sea level (MSL) trend is 8.60 millimeters/year with a 95% confidence interval of +/- 4.88 mm/yr (NOAA CO-OPS, 2014a), which is equivalent to a change of .88 meters (2.82 ft) in 100 years (See Figure 14). This trend is based on monthly MSL data from Apra Harbor, Guam from 1993 to 2013 (NOAA CO-OPS, 2014a). MSL is the highest in July (see Figure 15). Ninety year projections for Guam range from .13 m - .71 m , see Table 3.

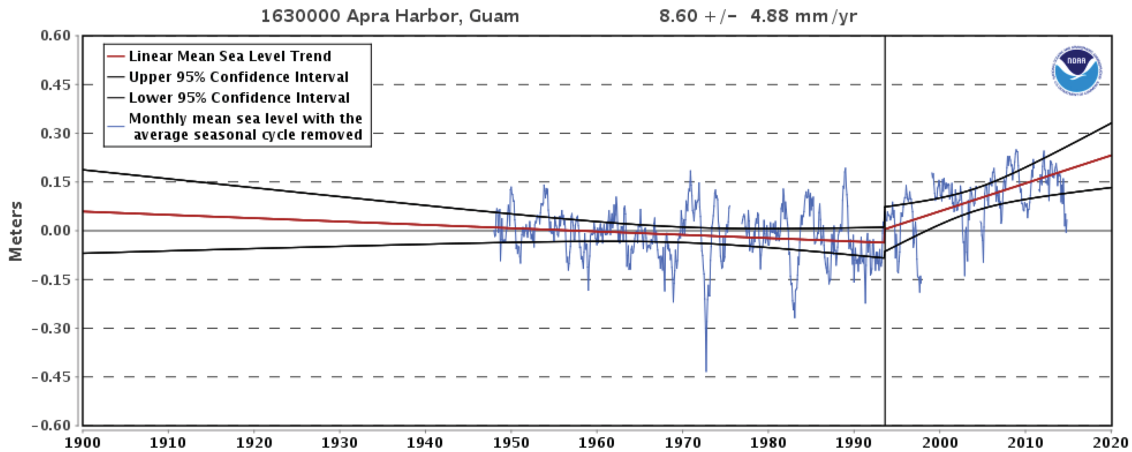

Figure 14: Plot showing the monthly mean sea level without the regular seasonal fluctuations caused by coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The long-term linear trend (in red) is shown, including its 95% confidence interval. The plotted values are relative to the most recent Mean Sea Level datum established by NOAA CO-OPS. Solid vertical lines indicate times of major earthquakes in the vicinity of the station. Plot is reprinted with permission from (NOAA CO-OPS, 2014a).

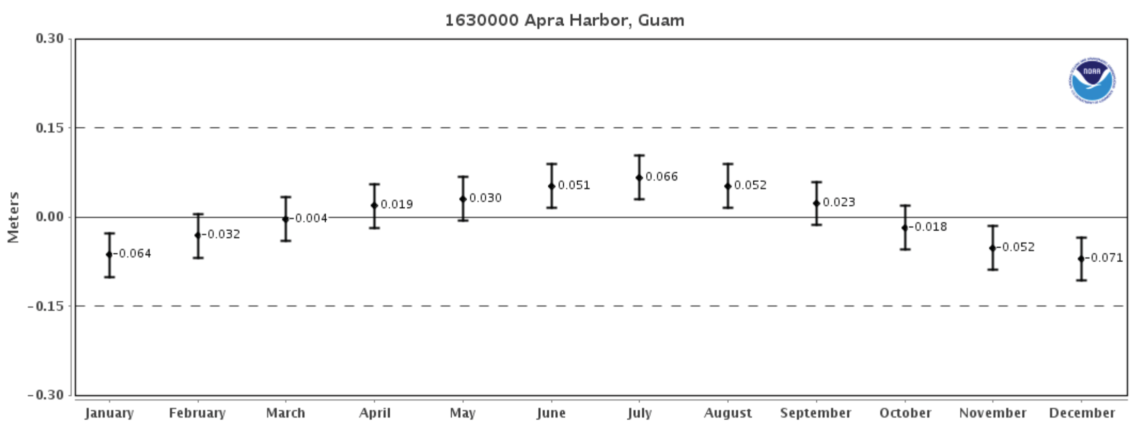

Figure 15: Plot showing the average seasonal cycle of mean sea level, caused by regular fluctuations in coastal temperatures, salinities, winds, atmospheric pressures, and ocean currents, for each calendar month's 95% confidence interval. Plot is reprinted with permission from (NOAA CO-OPS, 2014b).

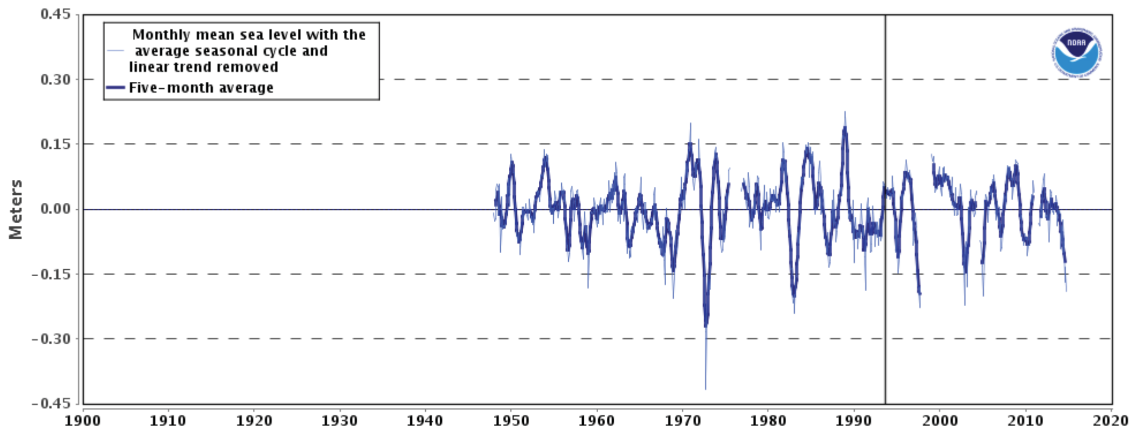

Figure 16: Plot showing the interannual variation of monthly mean sea level and the 5-month running average at Apra Harbor, Guam from 1948-2014. The average seasonal cycle and linear sea level trend have been removed. Inter-annual variation is caused by irregular fluctuations in coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The interannual variation for many Pacific stations is closely related to the ENSO. Plot is reprinted with permission from NOAA CO-OPS (2014).

Table 3: Ninety-year projections (2010-2100) of relative SLR for Guam, together with measurements of local vertical crustal motion (VM) and uncertainty ($\pm S_{vm}$) on crustal motion (meters/90 years). $B1_{min}$ and $A1FI_{max}$ are the minimum and maximum projections from the IPCC (2007) and $A1FI_{max}$+ is the upper limit for the A1FI SRES scenario augmented to account for accelerated drawdown of ice sheets (Meehl et al., 2007). RG_{max} and RG_{min} are the maximum and minimum values for a range of source attribution and fingerprinting scenarios for a semi-empirical projection of 1.15 m GMSL rise over 90 years. GMSL (90 years): $B1_{min}$ = 0.15 m; $A1FI_{max}$ = .51 m: $A1FI_{max}$+ = .69 m; RG = 1.15m. Data for table is reprinted from (Forbes et al., 2013).

Location	**$B1_{min}$** (m)	**$A1F1_{max}$** (m)	**$A1FI_{max}$+** (m)	**Rg_{max}** (m)	**Rg_{min}** (m)	**VM** (m)	**$\pm s_{vm}$** (m)
Guam	0.13	0.5	0.71	1.25	1.21	0.01	0.08

Impacts from SLR

The IPCC (2018) is highly confident that sea level rise will continue beyond 2100 even if global warming is limited to 1.5°C in the 21st century. Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-meter rise in sea level over hundreds to thousands of years; these instabilities could be triggered at around 1.5°C to 2°C of global warming (IPCC, 2018).

Due to projected GMSL rise, extreme events (e.g., hundred-year event) will become common by 2100 under all RCPs (IPCC, 2019). In the absence of adaptation, more intense and frequent extreme events, coupled with increased coastal development will increase expected annual flood damages by 2-3 orders of magnitude by 2100 (IPCC, 2019). However, well designed coastal protection can be very effective in reducing expected damages and cost efficient for urban and densely populated regions, but generally unaffordable for rural and poorer areas (IPCC, 2019). Effective protection requires investments on the order of tens to several hundreds of billions of USD/yr globally (IPCC, 2019). Small island states will be challenged to afford such investments, given their GDPs (IPCC, 2019). Even with well-designed hard protection, the risk of possibly disastrous consequences in the event of failure of defenses remains. (IPCC, 2019). Risk related to SLR (e.g., erosion, flooding and salinization) is expected to significantly increase by the end of this century along all low-lying coasts in the absence of major additional adaptation efforts (IPCC, 2019). Risks associated with sea level rise are higher at 2°C compared to 1.5°C (IPCC, 2018). The slower rate of SLR at global warming of 1.5°C reduces these risks, giving small islands a better chance to successfully manage and restore natural coastal ecosystems and reinforce or relocate critical infrastructure (IPCC, 2018).

While the impacts for SLR are not ideal, even under a 1.5°C or 2°C warming scenario for small islands, Kumar et al. (2018) used four physical variables (lithology, island shape, maximum elevation, and area) to calculate preliminary estimates of the potential for physical change of an island's coast in response to SLR. These four physical variables were used to determine an index for each of 1779 islands across 26 countries and 8 island types in the Pacific Ocean (Kumar et al., 2018). Most islands fell in the high (29%), moderate (23%) and low (23%) susceptibility classes, whilst the remainder were split between the extremes of very high (12%) and very low (13%) (Kumar et al., 2018). Guam was in the low susceptibility class (Kumar et al., 2018).

SLR Scenarios for Guam

Scenarios were initially utilized by the Shell Corporation in the 1960s and were intended to conceptualize multiple possible futures, in a structured and coherent way in order to facilitate decision-making in the present (Wack, 1985). Scenarios are not predictions, which describe what will happen, but rather "predicative judgments" which describe what could happen (Shearer, 2005). Hulme and Dessai, (2008) postulate that scenarios may be understood as processes or final products, which will in turn, determine the appropriate performance measures for evaluation.

Outputs of mathematical models are usually unattractive and unintuitive to the average person (Sorensen, 1997). Thus, scenarios should be "re-drawn" to illustrate their meaning at a non-scientific level, perhaps in the form of a narrative. Designing and managing the social processes of localized climate scenario generation and usage is as important and difficult as managing the technical aspects of climate scenario construction (Hulme and Dessai, 2008). It is important to remember that localized climate scenarios are relative to a specific time and context and will most likely be replaced with later scenarios due to the availability of better data, technology, and changes in people's understanding and relationship to climate change (Hulme and Dessai, 2008).

Narratives (see Reitsma 2010 for a definition of narrative) could be a starting point to gather attitudes, perceptions, and values of communities, policy makers, natural resource managers, and planners toward climate change for a tangible, plausible future scenario. Furthermore, narratives can help communities, policy makers, planners, and private developers by creating a mental image that depicts critical spatial environmental linkages within an area such as a watershed, and foster understanding how decisions (e.g., proposed developments or adaptation strategies) can environmentally and aesthetically impact a community especially with regard to an abstract concept, such as SLR or ecosystem-based management. Finally, narratives can assist in the conceptual development of ideas, the evaluation of a design or management option, the assessment of visual impacts, and the illustration ideas and alternatives for users and decision-makers.

For this project, three SLR scenarios were used (three, five, and ten-foot) and downloaded from the NOAA SLR Viewer – Digital Coast[9]. The process used to map sea level inundation in this viewer is a modified bathtub approach or linear superposition method (NOAA, 2017). Unlike the bathtub approach, the maps in this tool take into account local tidal variability and hydrologic connectivity. For Guam, historical data from the available tide stations were used to generate the tidal surface for the inundation maps (NOAA, 2017). Tidal surfaces were developed using the mean higher high water (MHHW) datum value from the respective tide stations (NOAA, 2017). Guam's LIDAR data is referenced to local mean sea level (LMSL), the difference between the MHHW elevation and the LMSL elevation became the value used for the starting tidal surface value (i.e., SLR = 0) (NOAA, 2017). The single-value approach using an adjusted tide station MHHW datum value was used, given the minimal amount of tidal variability and the lack of a hydrodynamic solution (e.g., VDatum) (NOAA, 2017). In addition, the maps take into account the hydroconnectivity of inundated areas, which distinguishes them from a simple bathtub approach. However, the maps also show low-lying areas, which are considered hydrologically "unconnected" areas that may flood. Both hydrologically connected and unconnected areas are determined solely by how well the elevation data capture the area's hydraulics (NOAA, 2017).

With regard to accuracy, the maps in the viewer are derived from source elevation data that meet or exceed the Federal Emergency Management Agency (FEMA) mapping specifications for the National Flood Insurance Program[10] (NOAA, 2017). Maps for the three SLR scenarios are located in APPENDIX B (ten-foot SLR scenarios), APPENDIX C (five-foot SLR scenarios), and APPENDIX D (three-foot SLR scenarios). These scenarios were used as the basis to for a GIS analysis to calculate the percentage of the built environment would be impacted by a three, five, and ten-foot SLR. The ten-foot SLR scenario was also used in a participatory GIS exercise.

Participatory GIS

Participatory GIS (PGIS), is an approach to mapping that is context- and issue-driven rather than technology-led; and it seeks to emphasize community involvement in the co-production of geographical information (Dunn, 2007). PGIS celebrates the multiplicity of geographical realities rather than the disembodied, objective and technical 'solutions' which have tended to characterize many conventional GIS applications (Dunn, 2007). Bitsura-Meszaros et al., (2019) utilize PGIS to engage stakeholders in a climate change risk assessment in order to capture and visualize locally relevant data and information. This integration of spatial data and technology with local knowledge, experiences, and expertise is an example of the co-production of science (Bitsura-Meszaros et al., 2019).

During the literature review on the use of PGIS in the development of climate change vulnerability assessments for small islands, there are several case studies that utilized PGIS (e.g., DeGraff and Ramlal, 2015; Levine and Feinholz, 2015; Williams, 2016). It is apparent that PGIS tended to be utilized with more developed island communities for a number of reasons. These more developed islands had

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[9] The Sea Level Rise Viewer is a helpful teaching and planning tool that enables users to visualize potential impacts from sea level rise. The viewer is a screening-level tool designed to provide interested users with a preliminary look at sea level rise and coastal flooding impacts. Users can select different sea level rise scenarios (0-6 ft), and the maps can be viewed at several different scales to help gauge trends and prioritize actions for different scenarios. The sea level rise scenarios are mapped on or above mean higher high water (MHHW). MHHW can be defined as the average of the highesthigh tide of each tidal d ay obser ved over a specific 19-year period (also referred to as the National Tidal Datum Epoch). So in the context of the viewer, 0 ft of sea level rise represents the current MHHW level. The data and maps in the viewer illustrate the scale of potential flooding, but not the exact location of where the flooding might occur. In addition, the viewer not does account for changes such as erosion, subsidence, or future construction. The maps and data are not designed to be used for permitting or any other legal purpose. (NOAA, 2017).

[10] 0.6 ft (18.5 centimeters) root mean square error (RMSE) f or low relief terrain; 1.2 ft (37.0 centimeters) RMSE for high relief terrain Areas that do not have elevation data that meet this criteria are shown as "Areas not mapped" in the viewer (NOAA, 2017).

- established technologically savvy pools of local expertise in climate change,
- access to high speed internet,
- moderate to high GIS and mapping capacity,
- external funding for public workshops for PGIS;
- dedicated project coordinators able to commit time and effort for preparation, promotion, organization of PGIS workshops, as well as the digitization and analysis of results.

In addition to a traditional GIS analysis of the impacts of SLR on Guam's built environment with regard to SLR scenarios, it is also valuable to obtain stakeholder input and local knowledge. Since Guam is a more developed island, utilizing PGIS at the All Planners Climate Change Workshop was a method in engaging the local community over a specific topic (SLR) for this vulnerability assessment.

Social Vulnerability Index

According to Flanagan et al. (2011), "Social vulnerability refers to the resilience of socioeconomic and demographic factors that affect the resilience of communities". Assessing social vulnerability became a recent aspect of disaster management as researchers recognized that socioeconomics and demographics affect community resilience (Juntunen, 2006). One part of this project assesses the social vulnerability of Guam on the village level using the Center for Disease Control Social Vulnerability Index (CDC SVI).

Local Early Action Planning (LEAP)

Local Early Action Planning (LEAP) (Wongbusarakum et al., 2015) is a tool developed by the Community Conservation Network (CCN) for the Pacific Islands Managed and Protected Area Community (PIMPAC). LEAP's purpose is to assist local communities in climate change adaption planning. Wongbusarakum et al. (2015) developed LEAP for The Nature Conservancy (TNC), by bringing together key stakeholders (e.g., farmers, fishermen, government employees, etc.) to collaborate and map out key historical climate events that have affected their community. This process creates a narrative which depicts participants' major climate concerns. The stakeholders' stories become the foundation to begin a meaningful dialogue between participants, local planners, and facilitators on how to alleviate impacts of climate change.

Community-Based Adaptation (CBA)

The LEAP tool is an example of community-based adaptation (CBA) to climate change. CBA emerged due to a disconnect between communities and experts regarding climate change education and planning. Traditionally, top-down methods were used. An outside expert would conduct a climate change vulnerability or adaptation assessment and submit it to the community or government for implementation. While these plans are academically sound, they had little to no community input. Without community buy-in, adaptation plans are less likely to be implemented (Naess, 2013).

McNamara and Buggy (2017) reviewed 128 publications on CBA and identified a series of key enablers for effective CBA such as the use participatory approaches; recognition that adaptation is a social process; and the need for financial and administrative support at multiple scales. McNamara & Buggy (2017) briefly touch on the future evolution of CBA which includes innovation and multi-sectoral approaches.

Wongbusarakum et al. (2015) notes that the first step of LEAP is to acknowledge the goal of a “healthy community” as part of the vision for a CBA plan—the ultimate result of using the LEAP tool. This recognition creates a common vision and initiates an honest and open dialogue with the community about the meaning of a “healthy community”, allowing participants to create their CBA plan with this perspective. For instance, some community members may value releasing female fish catch during breeding season, planting different crops together, or perhaps maintaining social connections. These can be incorporated into CBA plans. Essentially, the goal for the facilitators in a LEAP exercise is to guide the community in prioritizing their needs, as well as the resources they value, such as coral reefs, agroforestry, and culture, into their creation of CBA plans.

Case Studies

LEAP has been used in various locations worldwide, including Micronesia (Table 4). When it was first used in a 2010 TNC sponsored workshop in Guam, participants focused on climate change and addressed concerns about increased air temperature, rainfall, strong winds/high seas, droughts, and sea level rise (The Nature Conservancy, 2014). LEAP was most recently used in 08 April 2019, during an afternoon session led by TNC employees, as part of the All-Planner’s Climate Change Workshop. Results from this session have been included in the Results section of this report. Participants included natural resource managers, community members, university graduate students, and many non-government organizations (Appendix A).

Table 4: Summary table of LEAP case studies in Micronesia.

Location	Brief Description	Reference
Saipan (Commonwealth of the Northern Marianas Islands)	Community meetings to create a climate change timeline and to identify key resources. Due to timeline and attendance rates, the team leading faced complications	(Okano et al., 2015)
Yap (Federal States of Micronesia)	These workshops were done in two phases; Adapting to Climate and Planning guidance	(The Nature Conservancy, 2012)
Guam	Results for moderate sea level rise were shoreline erosion, flooding and inundation. Results showed that establishing community rules to protect native and upland zones	(The Nature Conservancy, 2014)

Methodology

Due to the limited amount of time, a mixed-methods approach was used. Four main approaches were used:

1. Participatory GIS
2. GIS Analysis of Guam's Built Environment with regard to three SLR Scenarios
3. Social Vulnerability Index
4. LEAP exercise

Participatory GIS

On Guam, a participatory mapping exercise was conducted on 08 April 2019 with approximately 110 planners, resource managers, researchers, and students, representing 48 various federal and local agencies, non-governmental organizations, and educational institutions in an All-Planners Climate Change Workshop, a pre-conference session at the 10th Center for Island Sustainability (CIS) Conference (APPENDIX A).

Climate change terminology and relevancy in the region was introduced through a morning presentation, with the mapping exercise conducted in the afternoon. Large-scale (1:5000 and 1:10000), municipal coastline maps printed on 35" x 49"poster paper, displaying a 10-ft SLR scenario, as well as power, water, and wastewater networks were printed and showcased on tables along with sticky notes and pens (e.g., Figure 17). All 10-ft SLR maps are located in APPENDIX B. A ten-ft SLR scenario was chosen because while the projected SLR is three ft by the end of the century (NOAA CO-OPS, 2014a), a ten-foot SLR scenario would display potential inundation caused by increased wave-run-up from a typhoon coupled with a high tide. It is important to visualize this, so that individuals can plan for the worse-case scenario. For this report, a GIS analysis on five-foot and three-foot SLR scenarios was also conducted. All five-foot SLR scenario maps are located in APPENDIX C; all three-foot SLR scenario maps are located in APPENDIX D.

Table groups were directed to rotate between maps and mark their concerns and solutions regarding sea level rise and inundation associated with storm events to infrastructure along Guam's coastline. Each map's marked concerns and solutions were presented to participants for validation. Maps were photographed and markings and notes were digitized into point shapefiles on *ArcMap 10.6*.

Results from the PGIS exercise may be found in the Results Section. A concerns frequency table and related solutions was compiled and organized on an *Excel* spreadsheet (Table 5).

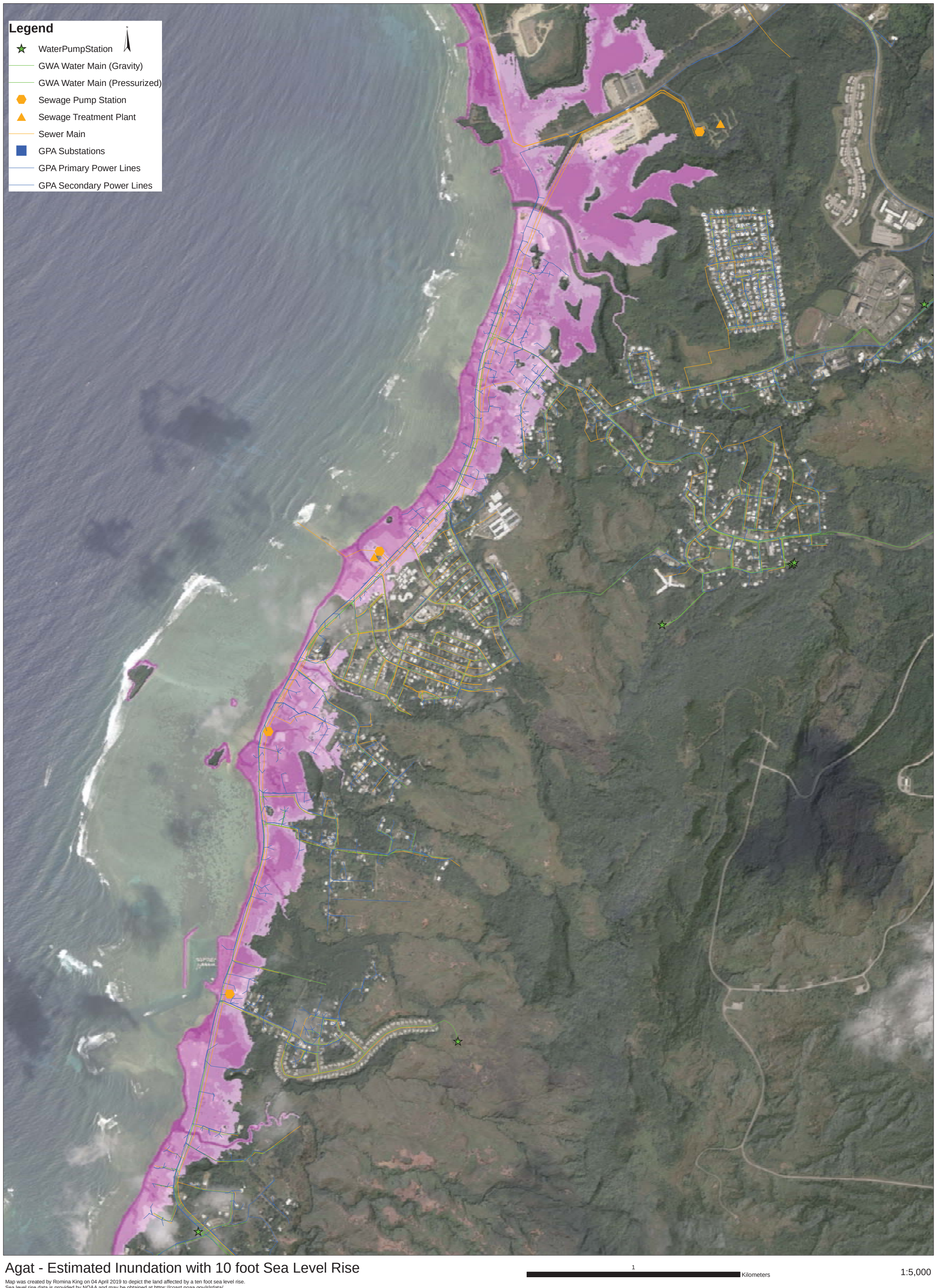


Figure 17: Map of estimated inundation of 10-ft sea level rise (purple shading) in Agat, Guam overlain by overhead power (Guam Power Authority, GPA) and underground water (Guam Waterworks Authority, GWA) and wastewater (sewer) networks. Scale is 1:5000

GIS Analysis of three, five, and ten-ft sea level rise scenarios

Geodatabases of line, point, and polygon GIS shapefiles of Guam municipalities, streets, highways, buildings, power, water, and sewer networks were received from Guam Waterworks Authority and Guam Power Authority, with acknowledgement from the Bureau of Statistics and Planning and Guam Coastal Management Program for use in this study. Shapefiles were uploaded into *ArcMap 10.6* and layered over a satellite imagery (Digital Globe World View 3) for Guam. Location symbols and colors were adjusted based on best visibility by infrastructure type:

1) streets – white lines, and highways – thick orange lines;
2) power network – light green lines, and power substations – light green squares;
3) water network – light blue lines, water pump stations – light blue squares, and wells – light blue circles;
4) sewer network – yellow lines, sewage pump stations – yellow hexagons, and sewage treatment plants – yellow triangles; and 5) buildings – light purple.

Three, five, and ten-ft SLR raster data files for Guam were downloaded from NOAA's Office for Coastal Management Sea Level Rise Viewer website (2019) and layered onto the working ArcMap. Each raster dataset was converted to a polygon shapefile and ArcMap files were created respective to SLR value ("3ftSLR.mxd," "5ftSLR.mxd," and "10ftSLR.mxd"). Impact analyses were conducted for each of the three, five, and ten-ft SLR scenarios.

New infrastructure shapefiles were created with the Intersect tool by respective three, five, or ten-ft SLR polygons (i.e. "streets_intersect3," "streets_intersect5," and "streets_intersect10") and will be termed "impacted infrastructure." Intersected shapefiles were added into corresponding ArcMap files. All line shapefiles were edited to convert length to ft. To validate successful conversion, the measurement tool was used by measuring straight lines within each line shapefile.

The "Select by Location" tool was utilized in two rounds to highlight infrastructure within (Clementini option) a single municipality for each SLR.mxd file. In the first round, total line shapefile lengths in individual municipalities were calculated with the "Summary Statistics" function. In the second round, only the intersected data was selected for within each municipality. Summary Statistics was utilized again to sum the impacted infrastructure lengths. Total and impacted point shapefiles (substations, pump stations, or buildings) were summed based on highlighted records in attribute tables. To ensure accuracy, selection processes were validated by panning within each village for highlighted infrastructure features. Excel spreadsheets were created to compile summation data and analyze percentage of SLR impact to 13 infrastructure categories by village: streets, highways, bridges, buildings, Government of Guam buildings, power lines, power substations, water lines, water pump stations, production wells, sewer lines, sewage pump stations, sewage treatment plants.

Results of the GIS analysis may be found in "Results and Discussion" - GIS Analysis of three, five, and ten-ft sea level rise scenarios

Social Vulnerability Index (SVI) - Methodology

The social vulnerability of Guam on the village level was assessed using the Center for Disease Control (CDC) SVI. The SVI uses data from 15 census variables to measure four themes: socioeconomic status;

household composition & disability; minority status & language; housing and transportation. These themes are summed into an overall index to assess social vulnerability. The data was gathered through the Guam census via American fact finder.

The CDC SVI is one of many tools to measure social vulnerability. The CDC SVI was developed by the CDC, National Center for Environmental Health (NCEH), Office of Terrorism Preparedness and Emergency Response (OTPER) in collaboration with the Agency for Toxic Substances and Disease Registry's Geospatial Research, Analysis, and Services Program in order to assist OTPER-funded state partners in all phases of the disaster cycle (Flanagan et al., 2011). It has been demonstrated to be a useful tool in assessing social vulnerability. While other methods of assessing social vulnerability such as the SoVI® are available, the CDC SVI was ultimately chosen due to its ease of interpretation (i.e., it uses percentile rank), availability of data (i.e., it uses census data available for download) and proven track record (i.e., it officially endorsed and used by the CDC & OTPER (Tarling, 2017).

The CDC SVI identifies vulnerable populations by combining and ranking 15 sociodemographic variables on the US tract level. However, this project identifies vulnerable populations at the village level. Data are from the 2010 Guam Census which may be searched via American FactFinder. The process of locating and obtaining the data is as follows:

1) go to the website;
2) go to advance search;
3) go to topics;
4) go to data set;
5) go to relevant Guam demographic data.

Fifteen sociodemographic datasets were downloaded and analyzed. These 15 sociodemographic variables may be grouped into four domains or themes. According to Flanagan et al. (2011), "The domains that form the basis of the SVI are

1) socioeconomic status,
2) household composition and disability,
3) minority status and language, and
4) housing and transportation" (p. 4).

Each domain is comprised of specific variables:

1) Socioeconomic Status (comprising income, poverty, employment, and education variables);
2) Household Composition/Disability (comprising age, single parenting, and disability variables);
3) Minority Status/Language (comprising race, ethnicity, and English language proficiency variables); and
4) Housing/Transportation (comprising housing structure, crowding, and vehicle access variables). (see Flanagan et al., 2011 for the rationale behind these chosen variables).

For this paper, there were changes in the original measurement for two variables:
1) disability population (≥5 years of age); 2) Speaking English well. Researchers substituted 1) total disability population and 2) Does not speak English, respectively. These substitutions were done because datasets for the original variables did not exist for Guam.

Each of sociodemographic variables are ranked using percentile rank with 0 being the lowest possible score and 1 being the highest possible score. This means that a higher percentile rank represents higher vulnerability. For example, if a village is ranked 0.95, this means that the village is more vulnerable than 95% of all the villages that are assessed. The percentile rank is calculated for each of the 15 variables, 4 themes, and the overall index. Villages with percentile rank of 0.90 or higher are flagged similar to Flanagan et al. (2011).

Results of the SVI are provided in Results Section.

Local Early Action Planning: Guam 2019

Overall, LEAP focuses on including key stakeholders in climate change adaptation and mapping out the planning process in a short document (Wongbusarakum et al., 2015).

LEAP is done in a four-step process:

1. getting organized for awareness and planning,
2. understanding climate change and your climate story,
3. field based threat and vulnerability assessment, and
4. finalizing your Local Early Action Plan.

LEAP was utilized by facilitators from The Nature Conservancy (TNC) on 08 April 2019, at the 2019 All-Planners Conference, held in Tumon, Guam. In attendance were community members, government officials, and natural resource managers, representing approximately 20 organizations (Appendix A). During the exercise, participants were randomly separated into four groups and given supplies such as clipboards, markers, pens, and sticky notes and tasked to create a community timeline for Guam and the CNMI territories.

The resulting timelines from the four groups were digitized and the three Guam-focused timelines were consolidated and analyzed to determine the primary concerns of the community (Figure 24). The fourth group created a CNMI-focused timeline and was omitted from this study. The Guam consolidated timeline was cross-referenced with actual, historical events from online databases in order to verify the information provided by the participants (Figure 24). The timeline was then updated to include “perceived” and “actual” sections (Figure 24).

Results and Discussion

This section provides the results of the participatory GIS (PGIS), the GIS analysis of the impacted infrastructure within each of the three SLR scenarios, the LEAP exercise, and the Social Vulnerability Index.

Participatory GIS - Results

Table 5 displays the ranking of concerns and solutions noted during the All-Planners Climate Change mapping exercise. Of 180 responses, frequency ranking by concern resulted as: 102 for infrastructure – *high concern*, 41 for natural – *moderate concern*, and 37 for culture – *low concern*. Concerns were organized into subcategories and ranked from highest to lowest frequency of responses: infrastructure – utilities (40), commercial building displacement (39), highway loss (19), and residential displacement (11); natural – marine ecosystem change or loss (15), freshwater ecosystem change or loss (12), beach or natural landmark loss (9), erosion or landslide (4), and unfavorable upland conditions (1); and cultural – historical site loss (15), cemetery displacement (8), tourism loss (5), aquaculture displacement (4), farmland loss (4), and fishing site loss (1).

Suggested solutions were relocation (includes 'land exchange'), hardening, and buffering. There were no proposed nature-based solutions. For example, to reduce shoreline erosion, one may consider using native vegetation to stabilize the beach.

Table 5: Frequency table of concerns and suggested solutions from the All-Planners' Climate Change Workshop PGIS mapping exercise on 08 April 2019, at the Hyatt Regency Hotel, Tumon, GU

Category	Concern	Frequency	Solution
Infrastructure	Utilities	40	Protect or relocate upland
	Commercial building displacement	39	Build seawall or relocate
	Highway loss	19	Build seawall or relocate
	Residential displacement	11	Relocate upland
Environmental	Marine ecosystem change, or loss	15	
	Freshwater ecosystem change, or loss	12	Buffer
	Beach or natural landmark loss	9	
	Erosion or landslide	4	
	Unfavorable upland conditions	1	
Cultural	Historical site loss	15	
	Cemetery displacement	8	Relocate upland
	Tourism loss	5	
	Aquaculture displacement	4	Relocate upland
	Farmland loss	4	Land exchange program
	Fishing site loss	1	

GIS Analysis of three, five, and ten-ft sea level rise scenarios

Percentages (presented from the greatest to least) for each of the 13 infrastructure categories for three, five, and ten-ft SLR scenarios within each of the 19 villages on Guam were calculated and mapped using ArcGIS (Appendix B, C, and D). Table 6 - Table 18 display percentages of one specific infrastructure category impacted within villages for each of the three, five, and ten-ft SLR scenarios. There are three sets of tables within each "Table" and each "Table" focuses on one of the thirteen categories of infrastructure. Villages are ranked from the highest to the lowest percentage of infrastructure impacted within the tables. Impact to overhead power are percentages of lines (not power poles) projected to have sea water ground coverage from SLR (Table 11). Since the power lines are overhead, they will not be submerged, but should the lines go down in a flooded area, that could be dangerous.

SLR scenario analyses resulted with 58% of total infrastructure impacted by a three ft SLR (Table 19), 74% impacted by a five-ft SLR (Table 20), and 84% impacted by a 10-ft SLR (Table 21). Of the villages, the greatest percentage of infrastructure impacted were southern villages: 3ft SLR – southern 73% and central 27% (Figure 18); 5-ft SLR – 64% southern, 29% central, and 7% northern (Figure 19); and 10 ft SLR – 56% southern 31% central, and 13% northern (Figure 20). The remaining villages with zero percent impact in the 13 infrastructure categories to all three SLR scenarios were Agana Heights, Barrigada, and Mangilao (Figure 18, Figure 19, and Figure 20).

Table 6: Comparison of the percentage of streets impacted within each municipality under a three, five, and ten foot SLR scenario. "Streets" includes highways, as designated by DPW, and village roads.

Percent (%) streets impacted within each village for a 3 feet sea level rise scenario.

Village	Streets
Merizo	1.6
Piti	1.2
Agat	0.4
Inarajan	0.4
Santa Rita	0.3
Yona	0.2
Asan	0.2
Umatac	0.1
Hagatna	0.1
Yigo	0.03
Tamuning	0.01
Chalan Pago Ordot	0.004
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Sinajana	0
Talofofo	0

Percent (%) streets impacted within each village for a 5 feet sea level rise scenario.

Village	Streets
Merizo	10.2
Inarajan	6.3
Piti	3.9
Hagatna	3.6
Santa Rita	2.9
Agat	1.1
Yona	0.3
Asan	0.3
Umatac	0.2
Tamuning	0.2
Chalan Pago Ordot	0.2
Yigo	0.1
Mongmong Toto Maite	0.1
Talofofo	0.01
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Sinajana	0

Percent (%) streets impacted within each village for a 10 feet sea level rise scenario.

Village	Streets
Agat	79.8
Hagatna	72.9
Piti	45.5
Inarajan	44.6
Merizo	37.4
Santa Rita	20.4
Tamuning	18.0
Sinajana	3.5
Yona	3.3
Chalan Pago Ordot	1.8
Umatac	1.7
Mongmong Toto Maite	0.7
Asan	0.6
Talofofo	0.4
Yigo	0.2
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0

Table 7: Comparison of the percentage of highways impacted within each municipality under a three, five, and ten-foot SLR scenario. Highways are part of 'streets' and are federally funded.

Percent (%) highways impacted within each village for a 3 feet sea level rise scenario.

Village	Highways
Merizo	3.4
Inarajan	0.4
Yona	0.3
Hagatna	0.3
Umatac	0.2
Asan	0.1
Agat	0.1
Agana Heights	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Yigo	0

Percent (%) highways impacted within each village for a 5 feet sea level rise scenario.

Village	Highways
Merizo	16.2
Inarajan	2.1
Yona	0.4
Mongmong Toto Maite	0.4
Hagatna	0.3
Umatac	0.2
Santa Rita	0.2
Asan	0.1
Agat	0.1
Agana Heights	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Mangilao	0
Piti	0
Sinajana	0
Talofofo	0
Tamuning	0
Yigo	0

Percent (%) highways impacted within each village for a 10 feet sea level rise scenario.

Village	Highways
Hagatna	60.8
Merizo	57.6
Agat	52.2
Piti	44.6
Inarajan	30.0
Tamuning	14.7
Chalan Pago Ordot	5.1
Yona	2.6
Santa Rita	2.4
Umatac	0.3
Mongmong Toto Maite	0.2
Asan	0.2
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Sinajana	0
Talofofo	0
Yigo	0

Table 8: Comparison of the percentage of bridges impacted within each municipality under a three, five, and ten-foot SLR scenario.

Percent (%) bridges impacted within each village for a 3 feet sea level rise scenario.

Village	Bridges
Merizo	100.0
Inarajan	75.0
Umatac	50.0
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Yigo	0
Yona	0

). Percent (%) bridges impacted within each village for a 5 feet sea level rise scenario.

Village	Bridges
Chalan Pago Ordot	100.0
Merizo	100.0
Inarajan	75.0
Umatac	50.0
Yona	50.0
Hagatna	25.0
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Yigo	0

. Percent (%) bridges impacted within each village for a 10 feet sea level rise scenario.

Village	Bridges
Chalan Pago Ordot	100.0
Merizo	100.0
Inarajan	75.0
Hagatna	50.0
Umatac	50.0
Yona	50.0
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Yigo	0

Table 9: Comparison of the percentage of buildings impacted within each municipality under a three, five, and ten-foot SLR scenario. This includes federal, local, and privately owned buildings.

Percent (%) buildings impacted within each village for in a 3 feet sea level rise scenario.

Village	Buildings
Merizo	3.4
Piti	3.0
Hagatna	1.1
Inarajan	0.8
Agat	0.6
Asan	0.4
Umatac	0.4
Santa Rita	0.3
Tamuning	0.1
Agana Heights	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Sinajana	0
Talofofo	0
Yigo	0
Yona	0

Percent (%) buildings impacted within each village for a 5 feet sea level rise scenario.

Village	Buildings
Merizo	18.5
Hagatna	8.7
Piti	8.2
Agat	3.9
Inarajan	3.1
Umatac	1.1
Santa Rita	1.1
Mongmong Toto Maite	0.8
Asan	0.4
Tamuning	0.4
Chalan Pago Ordot	0.3
Talofofo	0.1
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Sinajana	0
Yigo	0
Yona	0

Percent (%) buildings impacted within each village for a 10 feet sea level rise scenario.

Village	Buildings
Hagatna	85.3
Merizo	49.9
Piti	40.2
Agat	32.2
Inarajan	13.7
Santa Rita	8.8
Umatac	8.3
Tamuning	7.3
Asan	3.8
Mongmong Toto Maite	1.2
Chalan Pago Ordot	0.9
Talofofo	0.3
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Sinajana	0
Yigo	0
Yona	0

Table 10: Comparison of the percentage of GovGuam buildings impacted within each municipality under a three, five, and ten-foot SLR scenario.

Percent (%) GovGuam buildings impacted within villages for a 3 feet sea level rise scenario.

Village	GovGuam
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Percent (%) GovGuam buildings impacted within villages for a 5 feet sea level rise scenario.

Village	GovGuam
Agat	20.0
Agana Heights	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Percent (%) GovGuam buildings impacted within villages for a 10 feet sea level rise scenario.

Village	GovGuam
Agat	60.0
Piti	28.6
Hagatna	25.0
Agana Heights	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Table 11: Comparison of the percentage of powerlines impacted within each municipality under a three, five, and ten-foot SLR scenario. It should be noted that the majority of the powerlines along the coast are above ground.

Percent (%) power lines impacted within villages for a 3 feet sea level rise scenario.

Village	Power lines
Piti	2.3
Merizo	1.4
Agat	0.4
Hagatna	0.3
Inarajan	0.2
Chalan Pago Ordot	0.1
Umatac	0.1
Yona	0.03
Asan	0.03
Santa Rita	0.02
Tamuning	0.01
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Sinajana	0
Talofofo	0
Yigo	0

*Overhead power lines with projected sea water ground coverage from SLR.

Percent (%) power lines impacted within villages for a 5 feet sea level rise scenario.

Village	Power lines
Merizo	9.4
Piti	4.5
Agat	3.8
Hagatna	3.4
Inarajan	2.1
Santa Rita	0.6
Chalan Pago Ordot	0.4
Mongmong Toto Maite	0.1
Umatac	0.1
Tamuning	0.1
Talofofo	0.05
Yona	0.04
Asan	0.04
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Sinajana	0
Yigo	0

*Overhead power lines with projected sea water ground coverage from SLR.

Percent (%) power lines impacted within villages for a 10 feet sea level rise scenario.

Village	Power lines
Hagatna	82.7
Piti	63.9
Merizo	41.8
Agat	40.9
Inarajan	19.8
Tamuning	7.6
Santa Rita	3.3
Chalan Pago Ordot	2.3
Mongmong Toto Maite	2.3
Umatac	2.0
Asan	1.8
Sinajana	1.2
Talofofo	1.0
Yona	0.8
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Yigo	0

*Overhead power lines with projected sea water ground coverage from SLR.

Table 12: Comparison of the percentage of power substations impacted within each municipality under a three, five, and ten-foot SLR scenario.

Percent (%) power substations impacted within villages for a 3 feet sea level rise scenario.

Village	Power substations
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Percent (%) power substations impacted within villages for a 5 feet sea level rise scenario.

Village	Power substations
Santa Rita	25.0
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Percent (%) power substations impacted within villages for a 10 feet sea level rise scenario.

Village	Power substations
Santa Rita	50.0
Piti	37.5
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Table 13: Comparison of the percentage of water lines impacted within each municipality under a three, five, and ten-foot SLR scenario.

. **Percent (%) water lines impacted within villages for a 3 feet sea level rise scenario.**

Village	Water lines
Merizo	1.6
Piti	1.1
Hagatna	0.2
Inarajan	0.2
Umatac	0.2
Asan	0.1
Agat	0.1
Yona	0.03
Agana Heights	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Yigo	0

Percent (%) water lines impacted within villages for a 5 feet sea level rise scenario.

Village	Water lines
Merizo	8.1
Piti	2.6
Inarajan	1.7
Agat	0.7
Hagatna	0.4
Umatac	0.2
Asan	0.2
Yona	0.1
Chalan Pago Ordot	0.1
Mongmong Toto Maite	0.1
Talofofo	0.01
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Santa Rita	0
Sinajana	0
Tamuning	0
Yigo	0

Percent (%) water lines impacted within villages for a 10 feet sea level rise scenario.

Village	Water lines
Hagatna	86.7
Piti	66.0
Merizo	46.7
Agat	35.1
Inarajan	18.6
Tamuning	11.9
Yona	5.6
Chalan Pago Ordot	3.6
Asan	1.8
Umatac	1.4
Mongmong Toto Maite	0.6
Talofofo	0.04
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Santa Rita	0
Sinajana	0
Yigo	0

Table 14: Comparison of the percentage of water pump stations impacted within each municipality under a three, five, and ten-foot SLR scenario.

Percent (%) water pump stations impacted within villages for a 3 feet sea level rise scenario.

Village	Water pump station
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Percent (%) water pump stations impacted within villages for a 5 feet sea level rise scenario.

Village	Water pump station
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

. **Percent (%) water pump stations impacted within villages for a 10 feet sea level rise scenario.**

Village	Water pump station
Inarajan	7.7
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Table 15: Comparison of the percentage of production wells impacted within each municipality under a three, five, and ten-foot SLR scenario.

Percent (%) production wells impacted within villages for a 3 feet sea level rise scenario.

Village	Production wells
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Percent (%) production wells impacted within villages for a 5 feet sea level rise scenario.

Village	Production wells
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

. Percent (%) production wells impacted within villages for a 10 feet sea level rise scenario.

Village	Production wells
Tamuning	16.7
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Umatac	0
Yigo	0
Yona	0

Table 16: Comparison of the percentage of sewer lines impacted within each municipality under a three, five, and ten-foot SLR scenario.

Percent (%) sewer lines impacted within villages for a 3 feet sea level rise scenario.

Village	Sewer lines
Chalan Pago Ordot	0.9
Umatac	0.6
Merizo	0.5
Inarajan	0.3
Hagatna	0.3
Tamuning	0.3
Asan	0.2
Agat	0.1
Santa Rita	0.1
Dededo	0.02
Agana Heights	0
Barrigada	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Sinajana	0
Talofofo	0
Yigo	0
Yona	0

Percent (%) sewer lines impacted within villages for a 5 feet sea level rise scenario.

Village	Sewer lines
Merizo	5.6
Inarajan	5.1
Santa Rita	1.8
Chalan Pago Ordot	1.1
Umatac	0.8
Tamuning	0.8
Agat	0.8
Asan	0.6
Hagatna	0.4
Piti	0.2
Mongmong Toto Maite	0.1
Dededo	0.03
Agana Heights	0
Barrigada	0
Mangilao	0
Sinajana	0
Talofofo	0
Yigo	0
Yona	0

Percent (%) sewer lines impacted within villages for a 10 feet sea level rise scenario.

Village	Sewer lines
Hagatna	89.4
Piti	66.4
Santa Rita	59.2
Agat	45.3
Merizo	42.1
Inarajan	33.1
Umatac	19.3
Tamuning	16.2
Asan	11.4
Chalan Pago Ordot	5.9
Dededo	1.0
Yona	0.7
Mongmong Toto Maite	0.2
Agana Heights	0
Barrigada	0
Mangilao	0
Sinajana	0
Talofofo	0
Yigo	0

Table 17: Comparison of the percentage of sewage pumps impacted within each municipality under a three, five, and ten-foot SLR scenario.

Percent (%) sewage treatment plants impacted within villages for a 3 feet sea level rise scenario.

Village	Sewage treatment plant
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Percent (%) sewage treatment plants impacted within villages for a 5 feet sea level rise scenario.

Village	Sewage treatment plant
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Percent (%) sewage treatment plants impacted within villages for a 10 feet sea level rise scenario.

Village	Sewage treatment plant
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Table 18: Comparison of the percentage of sewage treatment plants impacted within each municipality under a three, five, and ten-foot SLR scenario.

Percent (%) sewage pump stations impacted within villages for a 3 feet sea level rise scenario.

Village	Sewage pump stations
Merizo	8.3
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Percent (%) sewage pump stations impacted within villages for a 5 feet sea level rise scenario.

Village	Sewage pump stations
Merizo	16.7
Tamuning	8.3
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Umatac	0
Yigo	0
Yona	0

Percent (%) sewage pump stations impacted within villages for a 10 feet sea level rise scenario.

Village	Sewage pump stations
Agat	100.0
Hagatna	100.0
Merizo	66.7
Piti	66.7
Inarajan	50.0
Umatac	20.0
Chalan Pago Ordot	11.1
Tamuning	8.3
Agana Heights	0
Asan	0
Barrigada	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Santa Rita	0
Sinajana	0
Talofofo	0
Yigo	0
Yona	0

Table 19: Percentage of infrastructure impacted within each municipality under a three -foot SLR scenario.

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**

Table 20: Percentage of infrastructure impacted within each municipality under a five -foot SLR scenario.

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	2.0	0.52	0	14	100	18	0	8.2	0	0	10	0	0
Asan	0.40	0.67	0	0.76	0	0.11	0	1.3	0	0	1.7	0	0
Barrigada	0	0	0	0	0	0	0	0	0	0	0	0	0
Chalan Pago Ordot	1.0	0	11	1.5	0	4.1	0	1.4	0	0	7.7	0	0
Dededo	0	0	0	0	0	0	0	0	0	0	1.3	0	0
Hagatna	8.8	1.5	11	14	0	9.4	0	2.3	0	0	1.6	0	0
Inarajan	13	14	33	8.1	0	14	0	22	0	0	18	0	0
Mangilao	0	0	0	0	0	0	0	0	0	0	0	0	0
Merizo	30	77	11	32	0	33	0	45	0	0	28	67	0
Mongmong Toto Maite	0.25	1.0	0	2.8	0	0.60	0	0.64	0	0	0.50	0	0
Piti	14	0	0	16	0	16	0	16	0	0	0.72	0	0
Santa Rita	26	1.5	0	7.1	0	3.3	100	0	0	0	11	0	0
Sinajana	0	0	0	0	0	0	0	0	0	0	0	0	0
Talofofo	0	0	11	0.25	0	0.27	0	0.13	0	0	0	0	0
Tamuning	1.2	0	0	3.3	0	1.0	0	0	0	0	19	33	0
Umatac	0.29	0.84	11	0.76	0	0.21	0	0.58	0	0	1.4	0	0
Yigo	1.1	0	0	0	0	0	0	0	0	0	0	0	0
Yona	1.1	3.5	11	0	0	0.40	0	2.2	0	0	0	0	0
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**0**	**0**	**100**	**100**	**0**

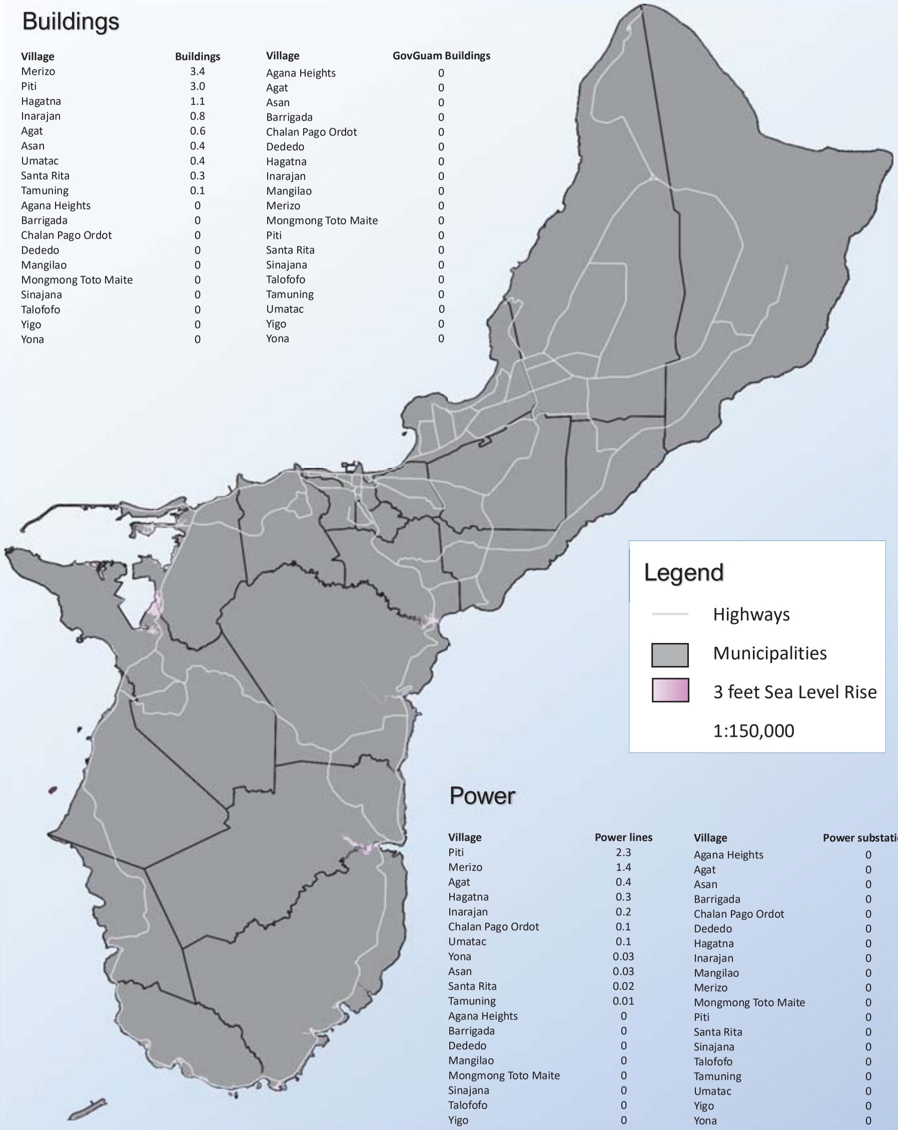
Table 21: Percentage of infrastructure impacted within each municipality under a ten -foot SLR scenario.

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	14	16	0	19	38	18	0	17	0	0	24	16	0
Asan	0.071	0.066	0	1.2	0	0.48	0	0.58	0	0	1.3	0	0
Barrigada	0	0	0	0	0	0	0	0	0	0	0	0	0
Chalan Pago Ordot	1.1	1.4	0	0.68	0	2.0	0	2.0	0	0	1.7	5.3	0
Dededo	0	0	0	0	0	0	0	0	0	0	1.7	0	0
Hagatna	18	18	22	23	38	21	0	22	0	0	16	5.3	0
Inarajan	9.3	13	33	6.0	0	12	0	11	100	0	4.9	11	0
Mangilao	0	0	0	0	0	0	0	0	0	0	0	0	0
Merizo	11	18	11	14.3	0	13	0	11	0	0	8.8	42	0
Mongmong Toto Maite	0.27	0	0	0.68	0	1.1	0	0.26	0	0	0.051	0	0
Piti	16	20	0	14	25	21	60	18	0	0	9.4	11	0
Santa Rita	18	1.2	0	10	0	1.8	40	0	0	0	14.7	0	0
Sinajana	0.27	0	0	0	0	0.13	0	0	0	0	0	0	0
Talofofo	0.18	0	0	0.13	0	0.53	0	0	0	0	0	0	0
Tamuning	10	12	0	11	0	9.1	0	14	0	100	15.4	5.3	0
Umatac	0.21	0.066	11	0.94	0	0.36	0	0.18	0	0	1.4	5.3	0
Yigo	0.24	0	0	0	0	0	0	0	0	0	0	0	0
Yona	1.0	1.4	11	0	0	0.64	0	4.5	0	0	0.25	0	0
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**0**

Three-ft SLR

Summary information for infrastructure affected by a 3-ft SLR may be viewed in Figure 18. Built infrastructure impacted by a 3-ft SLR were eight of 13 categories (62%). Merizo had the highest percentages of impacted transportation network: streets, highways, and bridges – 1.6%, 3.4%, and 100%, respectively. From greatest to least in impact percentage, the most impact occurred along the southern and central coastline and river outlets for bridges (75% Inarajan and 50% Umatac), streets (1.2% Piti and 0.4% Agat), then highways (0.4% Inarajan and 0.3% Yona). Buildings in Merizo had the highest impact – 3.4%, followed Piti (3%), then Hagatna (1.1%). No GovGuam buildings were impacted in this scenario. The highest impact to power lines were observed in Piti (2.3%), Merizo (1.4%), then Agat (0.4%). No power substations were impacted in this scenario. Water distribution lines were most impacted in Merizo (1.6%), then Piti (1.1%), and Hagatna (0.2%). Water pump stations and production wells were not impacted. Sewer lines were most impacted along bridges in Chalan Pago Ordot (0.9%) and Umatac (0.6%), and along the coast in Merizo (0.5%). Sewage pump stations along the coastline, as found in Merizo, were the most impacted – 8.3%. No sewage treatment plants were impacted in this SLR scenario. Merizo had the largest count of highest percentages of *within village* infrastructure categories impacted, six out of eight. *Between villages,* Merizo also had the largest count of highest percentages in four out of eight categories of impacted infrastructure.

3 feet Sea Level Rise Impact on Guam Built Infrastructure



Buildings

Village	Buildings
Merizo	3.4
Piti	3.0
Hagatna	1.1
Inarajan	0.8
Agat	0.6
Asan	0.4
Umatac	0.4
Santa Rita	0.3
Tamuning	0.1
Agana Heights	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Sinajana	0
Talofofo	0
Yigo	0
Yona	0

Village	GovGuam Buildings
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Transportation

Village	Streets
Merizo	1.6
Piti	1.2
Agat	0.4
Inarajan	0.4
Santa Rita	0.3
Yona	0.2
Asan	0.2
Umatac	0.1
Hagatna	0.1
Yigo	0.03
Tamuning	0.01
Chalan Pago Ordot	0.004
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Sinajana	0
Talofofo	0

Village	Highways
Merizo	3.4
Inarajan	0.4
Yona	0.3
Hagatna	0.3
Umatac	0.2
Asan	0.1
Agat	0.1
Agana Heights	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Yigo	0

Village	Bridges
Merizo	100
Inarajan	75
Umatac	50
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Yigo	0
Yona	0

Water

Village	Water lines
Merizo	1.6
Piti	1.1
Hagatna	0.2
Inarajan	0.2
Umatac	0.2
Asan	0.1
Agat	0.1
Yona	0.03
Agana Heights	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Yigo	0

Village	Water pump station
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Village	Production wells
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Power

Village	Power lines
Piti	2.3
Merizo	1.4
Agat	0.4
Hagatna	0.3
Inarajan	0.2
Chalan Pago Ordot	0.1
Umatac	0.1
Yona	0.03
Asan	0.03
Santa Rita	0.02
Tamuning	0.01
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Sinajana	0
Talofofo	0
Yigo	0

Village	Power substations
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Sewer

Village	Sewer lines
Chalan Pago Ordot	0.9
Umatac	0.6
Merizo	0.5
Inarajan	0.3
Hagatna	0.3
Tamuning	0.3
Asan	0.2
Agat	0.1
Santa Rita	0.1
Dededo	0.02
Agana Heights	0
Barrigada	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Sinajana	0
Talofofo	0
Yigo	0
Yona	0

Village	Sewage treatment plant
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Village	Sewage pump stations
Merizo	8.3
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Figure 18: Summary Information Graphic displaying percentage of buildings, roads, power, water, and sewer affected by a three-foot SLR. Geospatial databases were provided by GWA, GPA, and the Bureau of Statistics and Plans.

Five-ft SLR

Summary information for infrastructure affected by a 5-ft SLR may be viewed in Figure 19. The highest percentages of impacted streets for a 5 ft SLR scenario were located in Merizo (10.2%), Inarajan (6.3%), and Piti (3.9%). In Merizo and Inarajan, 16.2% and 2.1% of those streets were highways. The third largest percent of impacted highways was observed in Yona (0.4%). Bridges over rivers close to the coast were impacted the most: Chalan Pago and Merizo - 100%, and Inarajan - 75%. Greatest impact percentages for buildings were Merizo (18.5%), Hagatna (8.7%), and Piti (8.2%). Agat was the only village with impact to GovGuam buildings (20%). Merizo, Piti, and Agat had the most impacted power lines 0 9.4%, 4.5%, and 3.8%, respectively. The only village with impacted power substations was Santa Rita (25%). Water lines in Merizo, Piti, and Inarajan had the most impact - 8.1%, 2.6%, and 1.7%, respectively. Sewer lines had most impact in Merizo (5.6%), Inarajan (5.1%), and Santa Rita (1.8%). Impacted sewage pump stations were in two villages - Merizo (16.7%) and Tamuning (8.3%). There was no impact to water pump stations, production wells, or sewage treatment plants for this SLR scenario. Merizo had the largest percentages of *within village* infrastructure categories impacted, seven out of 10. *Between villages,* Merizo also had the largest count of highest percentages, seven out of ten categories of impacted infrastructure.

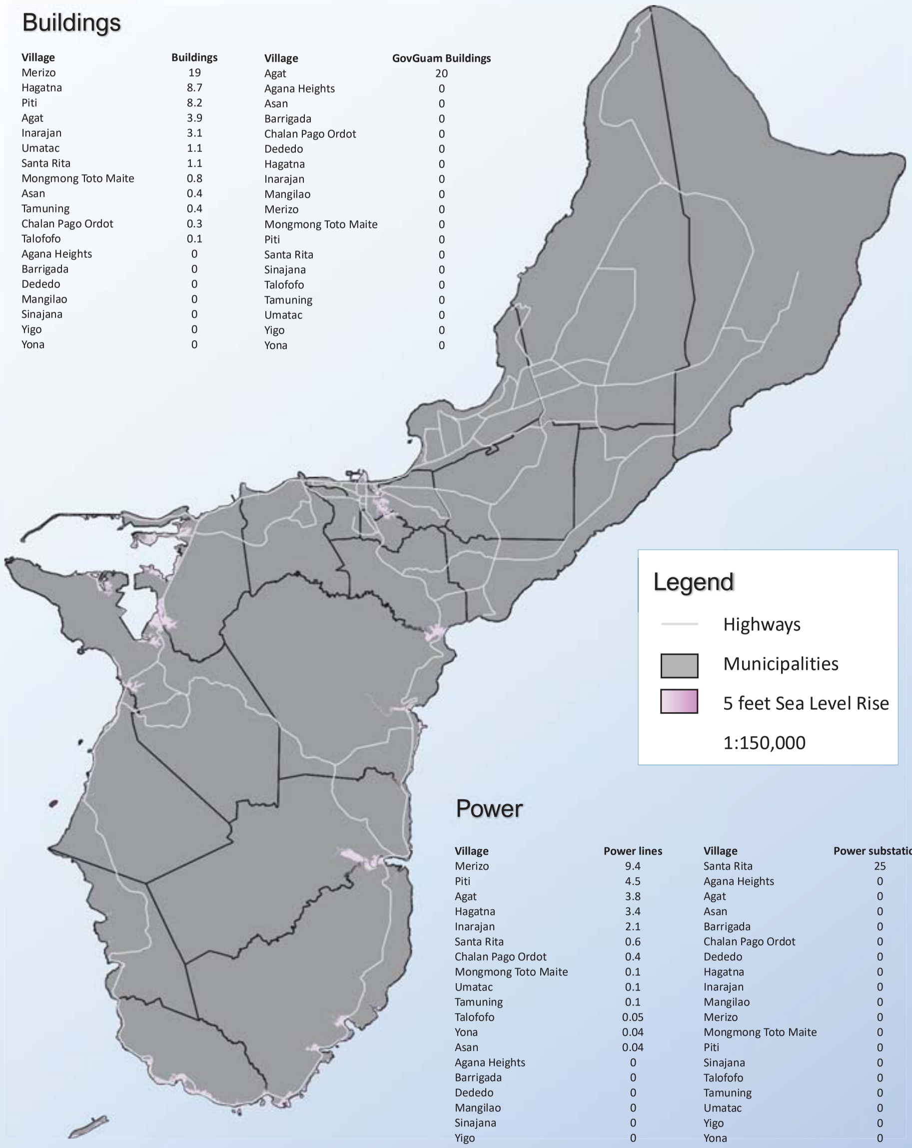
Ten-ft SLR

Summary information for percentage of infrastructure affected may be viewed in Figure 20. The largest percentages of impacted streets were observed in Agat (79.8%), Hagatna (72.9%), and Piti (45.5%). Of the impacted streets in Hagatna and Agat, 60.8% and 52.2% were highways. The third was Merizo with 57.6% impacted highways. The largest percentages of impacted bridges were in Chalan Pago-Ordot (100%), Merizo (100%), and Inarajan (75%), unchanged from results in the 5-ft SLR scenario. Percentages of buildings drastically increased from the previous SLR scenarios and the three largest were in Hagatna (85.3%), Merizo (49.9%), and Piti (40.2%). Sixty percent of GovGuam buildings in Agat were affected, while 28.6% were in Piti and 25% in Hagatna. An increase in impact to power lines was also observed: Hagatna - 82.7%, Piti - 63.9%, and Merizo - 41.8%. Affected power substations were located in two villages, 50% in Santa Rita and 37.5% in Piti. Villages with the highest impacted water lines were Hagatna (86.7%), Piti (66%), and Merizo (46.7%). Other impacted water infrastructure was one water pump station, Ugum, in Inarajan (7.7%) and one production well, UWA-1, in Tamuning (16.7%). Sewer systems were mostly affected in central and southern villages. Hagatna (89.4%), Piti (66.4%), and Santa Rita (59.2%) had the highest percentages of impacted sewer lines. 100% of sewage pump stations were affected in Agat and Hagatna, and 66.7% in Merizo and Piti. No sewage treatment plants were impacted in the 10-ft SLR scenario. Hagatna had the largest percentages of *within village* infrastructure categories impacted, 5 out of 12. *Between villages,* Hagatna also had the largest count of highest percentages, 5 out of 12 categories of impacted infrastructure.

5 feet Sea Level Rise Impact on Guam Built Infrastructure

Buildings

Village	Buildings	Village	GovGuam Buildings
Merizo	19	Agat	20
Hagatna	8.7	Agana Heights	0
Piti	8.2	Asan	0
Agat	3.9	Barrigada	0
Inarajan	3.1	Chalan Pago Ordot	0
Umatac	1.1	Dededo	0
Santa Rita	1.1	Hagatna	0
Mongmong Toto Maite	0.8	Inarajan	0
Asan	0.4	Mangilao	0
Tamuning	0.4	Merizo	0
Chalan Pago Ordot	0.3	Mongmong Toto Maite	0
Talofofo	0.1	Piti	0
Agana Heights	0	Santa Rita	0
Barrigada	0	Sinajana	0
Dededo	0	Talofofo	0
Mangilao	0	Tamuning	0
Sinajana	0	Umatac	0
Yigo	0	Yigo	0
Yona	0	Yona	0



Transportation

Village	Streets	Village	Highways	Village	Bridges
Merizo	10	Merizo	16	Chalan Pago Ordot	100
Inarajan	6.3	Inarajan	2.1	Merizo	100
Piti	3.9	Yona	0.4	Inarajan	75
Hagatna	3.6	Mongmong Toto Maite	0.4	Umatac	50
Santa Rita	2.9	Hagatna	0.3	Yona	50
Agat	1.1	Umatac	0.2	Hagatna	25
Yona	0.3	Santa Rita	0.2	Agana Heights	0
Asan	0.3	Asan	0.1	Agat	0
Umatac	0.2	Agat	0.1	Asan	0
Tamuning	0.2	Agana Heights	0	Barrigada	0
Chalan Pago Ordot	0.2	Barrigada	0	Dededo	0
Yigo	0.1	Chalan Pago Ordot	0	Mangilao	0
Mongmong Toto Maite	0.1	Dededo	0	Mongmong Toto Maite	0
Talofofo	0.01	Mangilao	0	Piti	0
Agana Heights	0	Piti	0	Santa Rita	0
Barrigada	0	Sinajana	0	Sinajana	0
Dededo	0	Talofofo	0	Talofofo	0
Mangilao	0	Tamuning	0	Tamuning	0
Sinajana	0	Yigo	0	Yigo	0

Water

Village	Water lines	Village	Water pump stations	Village	Production wells
Merizo	8.1	Agana Heights	0	Agana Heights	0
Piti	2.6	Agat	0	Agat	0
Inarajan	1.7	Asan	0	Asan	0
Agat	0.7	Barrigada	0	Barrigada	0
Hagatna	0.4	Chalan Pago Ordot	0	Chalan Pago Ordot	0
Umatac	0.2	Dededo	0	Dededo	0
Asan	0.2	Hagatna	0	Hagatna	0
Yona	0.1	Inarajan	0	Inarajan	0
Chalan Pago Ordot	0.1	Mangilao	0	Mangilao	0
Mongmong Toto Maite	0.1	Merizo	0	Merizo	0
Talofofo	0.01	Mongmong Toto Maite	0	Mongmong Toto Maite	0
Agana Heights	0	Piti	0	Piti	0
Barrigada	0	Santa Rita	0	Santa Rita	0
Dededo	0	Sinajana	0	Sinajana	0
Mangilao	0	Talofofo	0	Talofofo	0
Santa Rita	0	Tamuning	0	Tamuning	0
Sinajana	0	Umatac	0	Umatac	0
Tamuning	0	Yigo	0	Yigo	0
Yigo	0	Yona	0	Yona	0

Power

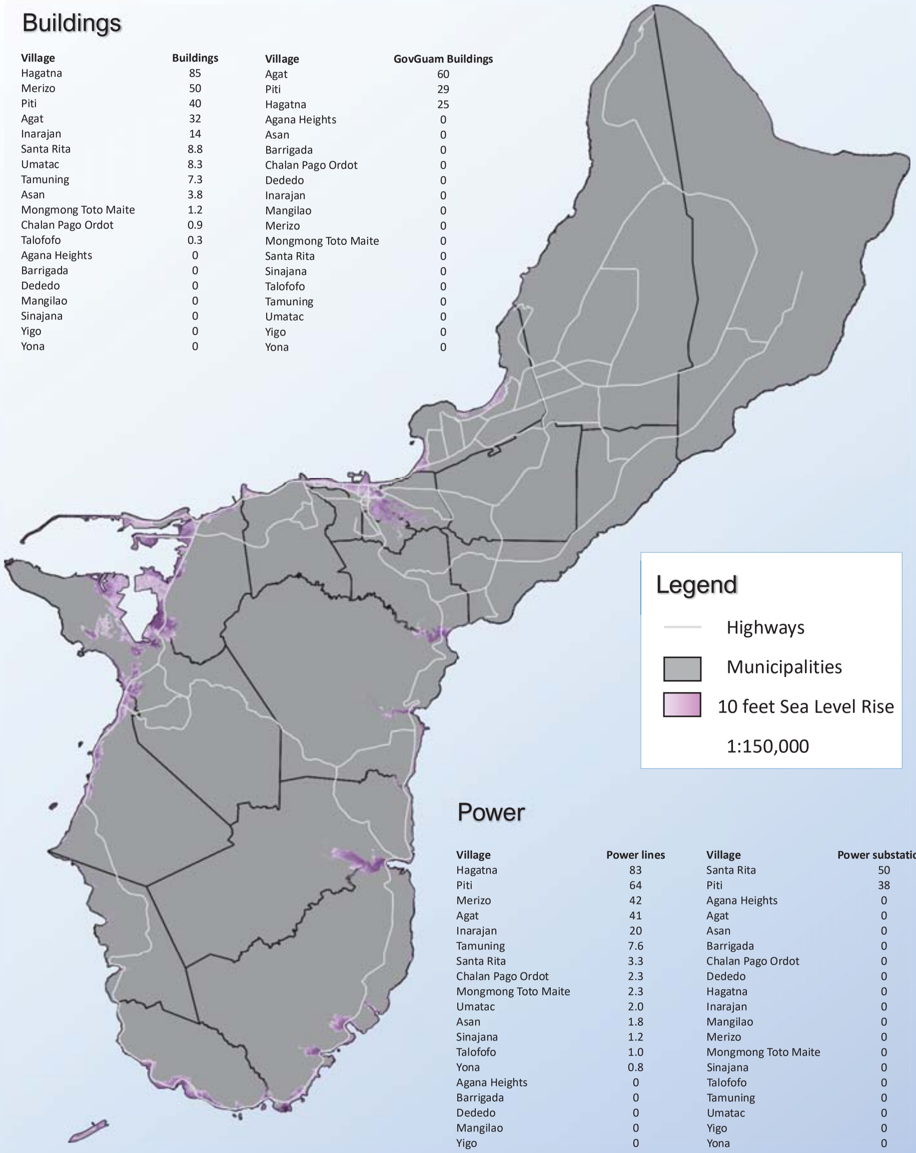
Village	Power lines	Village	Power substations
Merizo	9.4	Santa Rita	25
Piti	4.5	Agana Heights	0
Agat	3.8	Agat	0
Hagatna	3.4	Asan	0
Inarajan	2.1	Barrigada	0
Santa Rita	0.6	Chalan Pago Ordot	0
Chalan Pago Ordot	0.4	Dededo	0
Mongmong Toto Maite	0.1	Hagatna	0
Umatac	0.1	Inarajan	0
Tamuning	0.1	Mangilao	0
Talofofo	0.05	Merizo	0
Yona	0.04	Mongmong Toto Maite	0
Asan	0.04	Piti	0
Agana Heights	0	Sinajana	0
Barrigada	0	Talofofo	0
Dededo	0	Tamuning	0
Mangilao	0	Umatac	0
Sinajana	0	Yigo	0
Yigo	0	Yona	0

Sewer

Village	Sewer lines	Village	Sewage treatment plant	Village	Sewage pump stations
Merizo	5.6	Agana Heights	0	Merizo	17
Inarajan	5.1	Agat	0	Tamuning	8.3
Santa Rita	1.8	Asan	0	Agana Heights	0
Chalan Pago Ordot	1.1	Barrigada	0	Agat	0
Umatac	0.8	Chalan Pago Ordot	0	Asan	0
Tamuning	0.8	Dededo	0	Barrigada	0
Agat	0.8	Hagatna	0	Chalan Pago Ordot	0
Asan	0.6	Inarajan	0	Dededo	0
Hagatna	0.4	Mangilao	0	Hagatna	0
Piti	0.2	Merizo	0	Inarajan	0
Mongmong Toto Maite	0.1	Mongmong Toto Maite	0	Mangilao	0
Dededo	0.03	Piti	0	Mongmong Toto Maite	0
Agana Heights	0	Santa Rita	0	Piti	0
Barrigada	0	Sinajana	0	Santa Rita	0
Mangilao	0	Talofofo	0	Sinajana	0
Sinajana	0	Tamuning	0	Talofofo	0
Talofofo	0	Umatac	0	Umatac	0
Yigo	0	Yigo	0	Yigo	0
Yona	0	Yona	0	Yona	0

Figure 19: Summary Information Graphic displaying percentage of buildings, roads, power, water, and sewer affected by a five-foot SLR. Geospatial databases were provided by GWA, GPA, and the Bureau of Statistics and Plans.

10 feet Sea Level Rise Impact on Guam Built Infrastructure



Buildings

Village	Buildings
Hagatna	85
Merizo	50
Piti	40
Agat	32
Inarajan	14
Santa Rita	8.8
Umatac	8.3
Tamuning	7.3
Asan	3.8
Mongmong Toto Maite	1.2
Chalan Pago Ordot	0.9
Talofofo	0.3
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Sinajana	0
Yigo	0
Yona	0

Village	GovGuam Buildings
Agat	60
Piti	29
Hagatna	25
Agana Heights	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Transportation

Village	Streets
Agat	80
Hagatna	73
Piti	46
Inarajan	45
Merizo	37
Santa Rita	20
Tamuning	18
Sinajana	3.5
Yona	3.3
Chalan Pago Ordot	1.8
Umatac	1.7
Mongmong Toto Maite	0.7
Asan	0.6
Talofofo	0.4
Yigo	0.2
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0

Village	Highways
Hagatna	61
Merizo	58
Agat	52
Piti	45
Inarajan	30
Tamuning	15
Chalan Pago Ordot	5.1
Yona	2.6
Santa Rita	2.4
Umatac	0.3
Mongmong Toto Maite	0.2
Asan	0.2
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Sinajana	0
Talofofo	0
Yigo	0

Village	Bridges
Chalan Pago Ordot	100
Merizo	100
Inarajan	75
Hagatna	50
Umatac	50
Yona	50
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Yigo	0

Water

Village	Water lines
Hagatna	87
Piti	66
Merizo	47
Agat	35
Inarajan	19
Tamuning	12
Yona	5.6
Chalan Pago Ordot	3.6
Asan	1.8
Umatac	1.4
Mongmong Toto Maite	0.6
Talofofo	0.04
Barrigada	0
Dededo	0
Mangilao	0
Santa Rita	0
Sinajana	0
Tamuning	0
Yigo	0

Village	Water pump stations
Inarajan	7.7
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Village	Production wells
Tamuning	17
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Umatac	0
Yigo	0
Yona	0

Power

Village	Power lines
Hagatna	83
Piti	64
Merizo	42
Agat	41
Inarajan	20
Tamuning	7.6
Santa Rita	3.3
Chalan Pago Ordot	2.3
Mongmong Toto Maite	2.3
Umatac	2.0
Asan	1.8
Sinajana	1.2
Talofofo	1.0
Yona	0.8
Agana Heights	0
Barrigada	0
Dededo	0
Mangilao	0
Yigo	0

Village	Power substations
Santa Rita	50
Piti	38
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Sewer

Village	Sewer lines
Hagatna	90
Piti	66
Santa Rita	59
Agat	45
Merizo	42
Inarajan	33
Umatac	19
Tamuning	16
Asan	11
Chalan Pago Ordot	6
Dededo	1.0
Yona	0.7
Mongmong Toto Maite	0.2
Agana Heights	0
Barrigada	0
Mangilao	0
Sinajana	0
Talofofo	0
Yigo	0

Village	Sewage treatment plant
Agana Heights	0
Agat	0
Asan	0
Barrigada	0
Chalan Pago Ordot	0
Dededo	0
Hagatna	0
Inarajan	0
Mangilao	0
Merizo	0
Mongmong Toto Maite	0
Piti	0
Santa Rita	0
Sinajana	0
Talofofo	0
Tamuning	0
Umatac	0
Yigo	0
Yona	0

Village	Sewage pump stations
Agat	100
Hagatna	100
Merizo	67
Piti	67
Inarajan	50
Umatac	20
Chalan Pago Ordot	11
Tamuning	8.3
Agana Heights	0
Asan	0
Barrigada	0
Dededo	0
Mangilao	0
Mongmong Toto Maite	0
Santa Rita	0
Sinajana	0
Talofofo	0
Yigo	0
Yona	0

Figure 20: Summary Information Graphic displaying percentage of buildings, roads, power, water, and sewer affected by a ten-foot SLR. Geospatial databases were provided by GWA, GPA, and the Bureau of Statistics and Plans.

Social Vulnerability Index (SVI) - Results

This section presents the results of the SVI in tabular form. It provides the following:

1) a discussion of the SVI; and
2) limitations of the SVI.
3) a summary of the most vulnerable villages according to theme;
4) percentile rankings of each village for all the census variables used;
5) percentile rankings of each village for each of the four themes;
6) a key table showing the specific variables, their acronyms, a brief description of each variable, and the theme they fall under;
7) the final Social Vulnerability Index for Guam and associated map;
8) correlations;

SVI Discussion

The CDC SVI ranked Guam's municipalities based on the overall sum of fifteen indicators of social vulnerabilities (Table 23). The three most vulnerable villages are Agat, Mongmong-Toto-Maite (MTM) and Hagatna and the three least vulnerable villages are Piti, Santa Rita, and Asan-Maina (Table 43).

Villages of concern for each of the four themes are as follows:

1) socioeconomic status [Agat (89 percentile), Merizo (95 percentile), Umatac (100 percentile)](Table 39);
2) household composition & disability (Agana Heights (89 percentile), Agat (95 percentile), Merizo (100 percentile)] (Table 40);
3) minority status & language (Tamuning (89 percentile), Dededo (95 percentile), Hagatna (100 percentile)] (Table 41);
4) household & transportation (Mangilao (89 percentile), Hagatna (95 percentile), Agat (100 percentile)] (Table 42).

These results for the themes may be summarized in Table 22.

Table 22: Summary Table showing the three most vulnerable villages according to each theme (Socioeconomic Status, Household Composition and Disability, Minority Status/Language, Housing and Transportation) of the SVI

Theme	Most Vulnerable	Second Most Vulnerable	Third Most Vulnerable
A5 - Socioeconomic Status	Umatac	Merizo	Agat
B5 - Household Composition & Disability	Merizo	Agat	Agana Heights
C3 - Minority Status/Language	Hagatna	Dededo	Tamuning
D6 - Housing and Transportation	Agat	Hagatna	Mangilao

In order to further shed light on why Agat, MTM and Hagatna were the most vulnerable, a correlation matrix was calculated using SPSS (Table 44). According to Table 44, the variable minority (C1) may explain much of the overall variation in the SVI ranking. "Minority" for this paper is calculated as the non-white population, the same fotrmula used by the CDC. The non-white populations are referenced in Table 23. It appears that the higher the non-white population, the higher the social vulnerability. Minority is discussed in the inverse, whereas the higher the white population the lower the social vulnerability, because it is more intuitive to understood rather than the former.

The variable minority (C1) is strongly correlated with overall social vulnerability (E1) ($r = .805$, $p < .001$) (Table 44). The relationship between minority (C1) and social vulnerability (E1) may be visualized in a scatterplot and linear regression (Figure 23). The least vulnerable villages Piti, Santa Rita, and Asan-Maina have the lowest populations of minorities (non-whites) and the greatest populations of Caucasians. Agat, MTM, and Hagatna are the most vulnerable and have substantially higher populations of minorities (non-whites). The slope (R^2) of the linear regression is .648, meaning that approximately 65% of the variance in the SDI (E1) is due to the variance in the minority variable (C1). R^2 provides an indication of how well the data 'fit' the linear regression model.

Again, there is strong relationship between minority (C1) and the social vulnerability index (E1) (Table 44). However it should be noted that this relationship between minority (C1) and social vulnerability (E1) is applicable only to the group level data of all 19 villages rather than being an all-encompassing explanation for each village as the level of social vulnerability of some villages may be more influenced by other variables than size of its Caucasian population.

Perhaps, these villages with higher populations of Caucasians have lower social vulnerability as Caucasians tend to be generally wealthier than non-white individuals in the United States (Dettling et al., 2017) (Figure 21). According to a U.S. Federal Reserve survey in 2016, white families had the highest level of both median and mean family wealth: $171,000 and $933,700, respectively (Dettling et al., 2017) (Figure 21). 'Other' families (a diverse group that includes those identifying as Asian, American Indian, Alaska Native, Native Hawaiian, Pacific Islander, other race, and all respondents reporting more than one racial identification) have lower net worth than white families but higher net worth than black and Hispanic families (Dettling et al., 2017) (Figure 21).

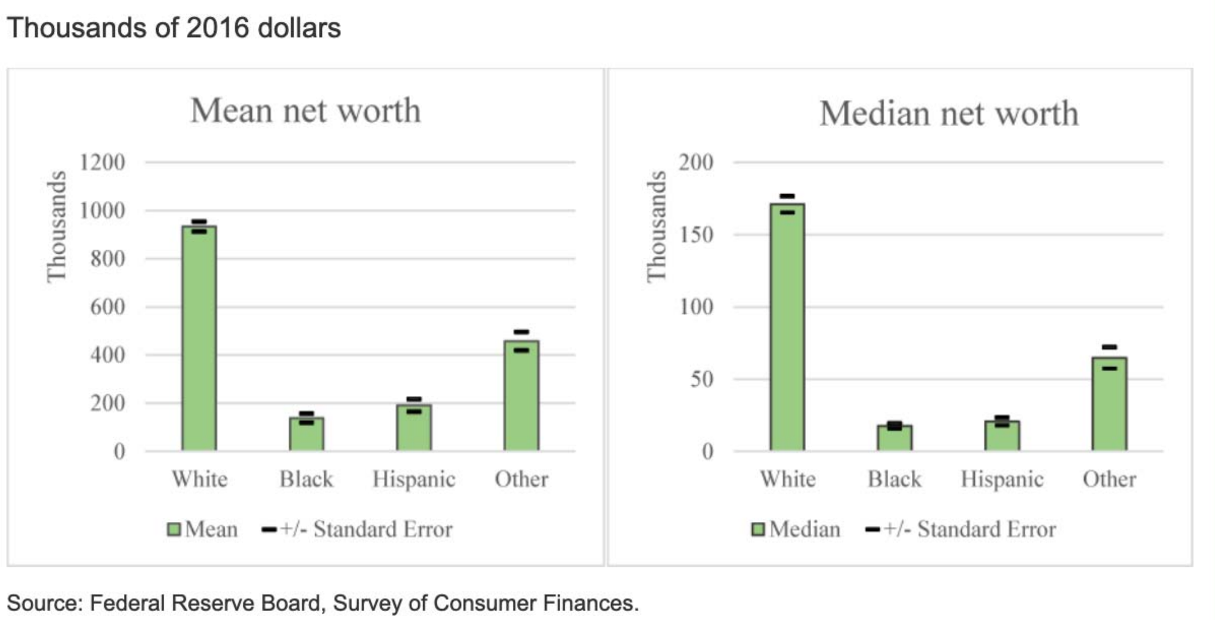


Figure 21: Graph showing results from a survey conducted by the U.S. Federal reserve. Reprinted from (Dettling et al., 2017).

The correlation coefficient (r) further support this claim as the variable minority (C1) ($r = .836$, $p < .001$)] is strongly correlated with the socioeconomic theme (A5), as well as mean income (A3) ($r = .758$, $p < .001$) (Table 42).

Another possible explanation of higher populations of Caucasians in Piti, Santa Rita, and Asan-Maina may be the presence of military housing, as the US Naval base is located in Santa Rita and is in close proximity with Piti and Asan-Maina, which would indicate more military families. In 2015, 44% of all Americans in the U.S. military, ages 18 to 44 were racial or ethnic minorities; or 56% were Caucasian (Parker et al., 2017). This is in contrast with the neighboring village of Agat, the most socially vulnerable village which has the second lowest population of white people (Table 32), and has fewer, if any, military housing than Santa Rita, Piti, and Asan-Maina. The presence of military housing is that they are occupied by military personnel who are of general higher economic status than non-military households, and the majority of whom are most likely Caucasian. Thus, it is probable that Caucasians inflate the social vulnerability ranking towards less vulnerability.

Other individual variables such as Percentage of individuals below poverty (A1), Per Capita Income (A3), Percentage of persons (>25 years) without a high school diploma (A4), and Lack of Vehicle Availability (D4), show strong correlations with the overall social vulnerability ranking (Table 44). However, when taken within the context of the significant relationship between minority and social vulnerability, these variables may be better understood in terms of socioeconomics. Caucasians are generally of higher social economic status than non-whites (Figure 21).

SVI Limitations

While each of the municipalities are ranked according to each of the fifteen social indicators (Table 24 - Table 38), it outside the scope of work of this project to find explanations or test hypotheses for particular geographic distributions of each indicator. For example, Agat is in the 95 percentile for the variable total disability (B5) (Table 30) and MTM is in the 58 percentile for that category (Table 30), yet overall, according to Guam's SVI (Table 43), they are the top two most socially vulnerable villages. It is also outside the scope of work to conduct linear regression models for all significant values of R in the correlation matrix.

As with all tools measuring social vulnerability, there are limitations. For example, the tools place greater emphasis on certain variables over others, making it difficult to assess all aspects of social vulnerability. Specifically, the CDC SVI assesses the disabled population, housing, and vehicle access, but does not look at the homeless population (Tarling, 2017). Another limitation is that the CDC SVI was developed in the context of the United States, so the domains and sociodemographic variables may not entirely reflect the island environment of Guam. For example, type of material for household composition may be an important variable to include as non-concrete households are particularly vulnerable to typhoons.

Fifteen census variables to calculate the four themes used in the SVI – Percentile Ranks

The SVI uses data from 15 census variables to measure four domains/themes: socioeconomic status; household composition & disability; minority status & language; housing and transportation. These themes are summed into an overall index to assess social vulnerability. The data was gathered through the Guam census via American fact finder. Table 23 displays each of the variables used, their corresponding acronym, a brief description, and the specific domain/theme they fall under.

Table 23: Acronyms, Variables, Descriptions, Themes. Note B3 & C2 were modified as the data was not unavailable. Adapted from Flanagan et al (2011).

Acronym	Variable	Description	Domain/Theme
A1	Percent individuals below poverty	Individuals below poverty="under .50" + ".50 to .74" + ".75 to .99." Percent of persons below federally defined poverty line, a threshold that varies by the size and age composition of the household. Denominator is total population where poverty status is checked.	Socioeconomic Status
A2	Percent civilian unemployed	Based on total population 16+. Civilian persons unemployed divided by total civilian population. Unemployed persons actively seeking work.	Socioeconomic Status
A3	Per capita Income	The mean income computed for every person in the census tract.	Socioeconomic Status
A4	Percent persons with no high school diploma	Percent of persons 25 years of age and older, with less than a 12th grade education (including individuals with 12 grades but no diploma).	Socioeconomic Status
A5	Socioeconomic Status	The ranking sum of the variables within the theme="A1" + "A2" + "A3" + "A4."	Socioeconomic Status
B1	Percent persons 65 years of age or older		Household Composition/Disability
B2	Percent persons 17 years of age or younger		Household Composition/Disability
B3	Total persons with a disability (Note. Originally persons more than 5 years old a with disability)		Household Composition/Disability
B4	Percent male or female householder, no spouse present, with children under 18	"Other family: male householder, no wife present, with own children under 18 years" + "Other family: female householder, no husband present, with own children under 18 years"	Household Composition/Disability
B5	Household Composition/Disability	The ranking sum of the variables within the theme="B1" + "B2" + "B3" + "B4."	Household Composition/Disability
C1	Percent minority	Total of the following: "black or African American alone" + "American Indian and Alaska Native alone" + "Asian alone" + "Native Hawaiian and other Pacific Islander alone" + "some other race alone" + "two or more races" + "Hispanic or Latino – white alone."	Minority Status/Language
C2	Percent persons who speak no English (Note. Originally persons who speak English less than "well")	For all age groups and all languages— the total of persons who speak no English	Minority Status/Language
C3	Minority Status/Language	The ranking sum of the variables within the theme="C1" + "C2."	Minority Status/Language
D1	Percent multi-unit structure	Percent housing units with 10 or more units in structure.	Housing/Transportation
D2	Percent mobile homes	Percent housing units that are mobile homes.	Housing/Transportation
D3	Crowding	At household level, more people than rooms. Percent total occupied housing units (i.e., households) with more than one person per room.	Housing/Transportation
D4	No vehicle available	Percent households with no vehicle available.	Housing/Transportation
D5	Percent of persons in group quarters	Percent of persons who are in institutionalized group quarters (e.g., correctional institutions, nursing homes) and non-institutionalized group quarters (e.g., college dormitories, military quarters).	Housing/Transportation
D6	Housing/Transportation	The ranking sum of the variables within the theme="D1" + "D2" + "D3" + "D4" + D5."	Housing/Transportations
E1	Social Vulnerability Index	The ranking sum of all the themes="A5" + "B5" + "C3" + "D6"	Social Vulnerability Index

Table 24: A1 - Percentage of individuals below poverty within each village. Higher percentile rank represents higher vulnerability. Source U.S. Census 2010, Guam.

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Santa Rita	12.85	1	5.26
Piti	16.57	2	10.53
Inarajan	17.77	3	15.79
Agana Heights	17.94	4	21.05
Chalan Pago-Ordot	17.94	5	26.32
Asan-Maina	18.72	6	31.58
Sinajana	19.37	7	36.84
Talofofo	19.67	8	42.11
Barrigada	20.14	9	47.37
Yona	21.08	10	52.63
Yigo	21.52	11	57.89
Tamuning	22.69	12	63.16
Mangilao	23.67	13	68.42
Merizo	24.43	14	73.68
Dededo	24.66	15	78.95
Agat	26.54	16	84.21
Hagatna	27.21	17	89.47
Umatac	28.77	18	94.74
Mongmong-Toto-Maite	29.7	19	100

Table 25: A2 - Percentage of civilians unemployed per municipality (A2). Higher percentile rank represents higher vulnerability. Source U.S. Census 2010, Guam.

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Tamuning	5.7	1	5.26
Piti	6.2	2	10.53
Barrigada	6.6	3	15.79
Agana Heights	7	4	21.05
Chalan Pago-Ordot	7.6	5	26.32
Asan-Maina	7.8	6	31.58
Inarajan	7.9	7.5	39.47
Talofofo	7.9	7.5	39.47
Santa Rita	8.1	9	47.37
Yigo	8.4	10.5	55.26
Dededo	8.4	10.5	55.26
Sinajana	9	12	63.16
Mangilao	9.3	13	68.42
Hagatna	9.6	14	73.68
Mongmong-Toto-Maite	9.8	15	78.95
Yona	10	16	84.21
Agat	13.7	17	89.47
Merizo	14.1	18	94.74
Umatac	15.6	19	100

Table 26: A3 - Per capita income in each municipality. Higher percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	Per Capita Income (USD)	Non-Percentile Rank	Percentile Rank
Piti	26303	1	5.26
Tamuning	22182	2	10.53
Asan-Maina	21626	3	15.79
Santa Rita	20298	4	21.05
Talofofo	19304	5	26.32
Barrigada	19279	6	31.58
Agana Heights	19276	7	36.84
Sinajana	18492	8	42.11
Yona	18270	9	47.37
Chalan Pago-Ordot	17882	10	52.63
Hagatna	16093	11	57.89
Inarajan	15816	12	63.16
Mongmong-Toto-Maite	15675	13	68.42
Mangilao	15580	14	73.68
Agat	14749	15	78.95
Merizo	13962	16	84.21
Yigo	13949	17	89.47
Dededo	13550	18	94.74
Umatac	13546	19	100

Table 27: A4 - Percentage of individuals (25 years and older) with no high school diploma. Higher percentile rank represents higher vulnerability. Source U.S. Census 2010, Guam.

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Piti	12.5	1	5.26
Santa Rita	13.5	2	10.53
Tamuning	16.3	3	15.79
Asan-Maina	16.7	4	21.05
Agana Heights	17.1	5	26.32
Barrigada	17.8	6	31.58
Chalan Pago-Ordot	18.2	7	36.84
Talofofo	18.7	8	42.11
Sinajana	19.5	9	47.37
Yona	19.7	10	52.63
Umatac	20.1	11	57.89
Mangilao	20.6	12	63.16
Inarajan	21.5	13	68.42
Mongmong-Toto-Maite	21.9	14.5	76.32
Yigo	21.9	14.5	76.32
Agat	23	16	84.21
Merizo	24	17	89.47
Dededo	24.1	18	94.74
Hagatna	28.6	19	100

Table 28: B1 - Percentage of individuals 65 years of age or older. Higher percentile rank represents higher vulnerability. Source: US Census 2010

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Hagatna	1.43	1	5.26
Yigo	1.77	2	10.53
Mangilao	2.04	3	15.79
Tamuning	2.36	4	21.05
Yona	2.5	5	26.32
Dededo	2.51	6	31.58
Santa Rita	2.51	7	36.84
Chalan Pago-Ordot	2.61	8	42.11
Mongmong-Toto-Maite	2.73	9	47.37
Talofofo	2.89	10	52.63
Barrigada	3	11	57.89
Inarajan	3.04	12	63.16
Umatac	3.07	13	68.42
Piti	3.09	14	73.68
Agana Heights	3.39	15	78.95
Asan-Maina	3.74	16	84.21
Merizo	4.05	17	89.47
Agat	4.07	18	94.74
Sinajana	4.36	19	100

Table 29: B2 - Percentage of individuals 17 years of age or younger. Higher percentile rank indicates higher vulnerability. Source: US Census 2010.

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Umatac	0.38	1	5.26
Asan-Maina	0.56	2	10.53
Tamuning	0.6	3	15.79
Inarajan	0.62	4	21.05
Piti	0.69	5	26.32
Talofofo	0.69	6	31.58
Sinajana	0.69	7	36.84
Dededo	0.71	8	42.11
Yigo	0.73	9	47.37
Barrigada	0.78	10	52.63
Mongmong-Toto-Maite	0.85	11	57.89
Santa Rita	0.85	12	63.16
Chalan Pago-Ordot	0.86	13	68.42
Mangilao	0.87	14	73.68
Yona	0.93	15	78.95
Hagatna	0.95	16	84.21
Agat	1	17	89.47
Agana Heights	1.23	18	94.74
Merizo	1.24	19	100

Table 30: B3 - Percentage of population with a disability. Higher percentile rank represents higher vulnerability. Source: US Census 2010. This variable replaces "Persons five years and older with a disability".

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Yigo	5.92	1	5.26
Santa Rita	6.38	2	10.53
Tamuning	6.47	3	15.79
Piti	7.36	4	21.05
Dededo	7.41	5	26.32
Talofofo	7.51	6	31.58
Mangilao	7.79	7	36.84
Barrigada	7.86	8	42.11
Yona	8.04	9	47.37
Chalan Pago-Ordot	8.08	10	52.63
Mongmong-Toto-Maite	8.28	11	57.89
Asan-Maina	8.47	12	63.16
Hagatna	9.23	13	68.42
Inarajan	9.59	14	73.68
Agana Heights	9.64	15	78.95
Umatac	9.72	16	84.21
Sinajana	10.96	17	89.47
Agat	11.71	18	94.74
Merizo	12.27	19	100

Table 31: B4 - Percentage of single head of household (male or female with no spouse present), with children under 18. Higher percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	**Percentage**	**Non-Percentile Rank**	**Percentile Rank**
Tamuning	7.48	1	5.26
Piti	7.71	2	10.53
Santa Rita	10.23	3	15.79
Yigo	11.67	4	21.05
Asan-Maina	11.98	5	26.32
Talofofo	12	6	31.58
Hagatna	12.37	7	36.84
Sinajana	12.65	8	42.11
Agana Heights	12.85	9	47.37
Barrigada	13.06	10	52.63
Dededo	13.12	11	57.89
Agat	14.12	12	63.16
Yona	14.54	13	68.42
Chalan Pago-Ordot	14.68	14	73.68
Mangilao	15.14	15	78.95
Inarajan	15.65	16	84.21
Merizo	15.98	17	89.47
Mongmong-Toto-Maite	17.28	18	94.74
Umatac	19.37	19	100

Table 32: C1 - Percentage of the population that are minorities, according to municipality. Higher percentile rank represents higher vulnerability. Source: US Census 2010. Minorities, as defined by the U.S. Census are "black or African American alone", "American Indian and Alaska Native; "Asian", "Native Hawaiian and other Pacific Islander", "some other race than Caucasian alone", "two or more races", "Hispanic + Latino".

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Santa Rita	71.55	1	5.26
Piti	83.91	2	10.53
Asan-Maina	88.35	3	15.79
Yigo	88.86	4	21.05
Talofofo	90.16	5	26.32
Tamuning	90.65	6	31.58
Yona	92.82	7	36.84
Agana Heights	93.17	8	42.11
Chalan Pago-Ordot	93.7	9	47.37
Barrigada	93.96	10	52.63
Mangilao	94.86	11	57.89
Sinajana	95.6	12	63.16
Mongmong-Toto-Maite	95.91	13	68.42
Inarajan	96.17	14	73.68
Hagatna	96.19	15	78.95
Dededo	96.72	16	84.21
Merizo	97.08	17	89.47
Agat	97.13	18	94.74
Umatac	97.83	19	100

Table 33: C2 - Percentage of the population who do not speak English. Higher percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Piti	0	1.5	7.89
Umatac	0	1.5	7.89
Agat	0.04	3	15.79
Inarajan	0.04	4	21.05
Merizo	0.05	5	26.32
Yona	0.08	6	31.58
Agana Heights	0.13	7	36.84
Chalan Pago-Ordot	0.15	8	42.11
Sinajana	0.15	9	47.37
Asan-Maina	0.19	10	52.63
Mongmong-Toto-Maite	0.19	11	57.89
Santa Rita	0.23	12	63.16
Mangilao	0.32	13	68.42
Dededo	0.32	14	73.68
Yigo	0.47	15	78.95
Barrigada	0.48	16	84.21
Talofofo	1.05	17	89.47
Tamuning	1.14	18	94.74
Hagatna	1.9	19	100

Table 34: D1 - Percentage of the population that reside in a multi-unit structure according to municipality. Higher percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Inarajan	0	1.5	7.89
Umatac	0	1.5	7.89
Talofofo	0.11	3	15.79
Santa Rita	0.28	4	21.05
Asan-Maina	0.8	5	26.32
Merizo	1.3	6	31.58
Yigo	3.18	7	36.84
Dededo	5.7	8	42.11
Yona	5.8	9	47.37
Barrigada	5.96	10	52.63
Agat	7.23	11	57.89
Chalan Pago-Ordot	11.18	12	63.16
Agana Heights	14.67	13	68.42
Sinajana	15.59	14	73.68
Mangilao	20.35	15	78.95
Piti	25.57	16	84.21
Mongmong-Toto-Maite	26.95	17	89.47
Hagatna	29.55	18	94.74
Tamuning	54.44	19	100

Table 35: D2 - Percentage of the population who reside in mobile homes according to municipality. Higher percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Umatac	0	1	5.26
Mongmong-Toto-Maite	0.17	2	10.53
Sinajana	0.22	3	15.79
Hagatna	0.25	4	21.05
Piti	0.35	5	26.32
Tamuning	0.39	6	31.58
Asan-Maina	0.4	7	36.84
Merizo	0.43	8	42.11
Santa Rita	0.44	9	47.37
Agana Heights	0.48	10	52.63
Yona	0.67	11	57.89
Chalan Pago-Ordot	0.85	12	63.16
Mangilao	0.94	13	68.42
Inarajan	0.99	14	73.68
Dededo	1	15	78.95
Talofofo	1	16	84.21
Yigo	1.22	17	89.47
Barrigada	1.4	18	94.74
Agat	1.86	19	100

Table 36: D3- Percentage of household units that have more than one occupant per room (i.e., Crowding). Higher percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Talofofo	1.56	1	5.26
Piti	10.16	2	10.53
Santa Rita	10.51	3	15.79
Tamuning	12.17	4	21.05
Asan-Maina	12.65	5	26.32
Sinajana	13.52	6	31.58
Agana Heights	14.51	7	36.84
Chalan Pago-Ordot	16.3	8	42.11
Hagatna	16.41	9	47.37
Barrigada	16.45	10	52.63
Mongmong-Toto-Maite	17.41	11	57.89
Yona	18.69	12	63.16
Agat	21.22	13	68.42
Mangilao	21.34	14	73.68
Yigo	22.86	15	78.95
Dededo	24.41	16	84.21
Merizo	25.27	17	89.47
Inarajan	27.68	18	94.74
Umatac	29.32	19	100

Table 37: D4 - Percentage of households with no vehicle. Higher percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Piti	0.88	1	5.26
Talofofo	3.22	2	10.53
Inarajan	3.29	3	15.79
Santa Rita	3.93	4	21.05
Yigo	4.01	5	26.32
Barrigada	4.11	6	31.58
Asan-Maina	4.13	7	36.84
Chalan Pago-Ordot	4.5	8	42.11
Yona	5.28	9	47.37
Mangilao	5.42	10	52.63
Dededo	5.97	11	57.89
Merizo	6.05	12	63.16
Agana Heights	6.11	13	68.42
Tamuning	6.11	14	73.68
Sinajana	7.42	15	78.95
Agat	7.43	16	84.21
Umatac	7.85	17	89.47
Mongmong-Toto-Maite	9.23	18	94.74
Hagatna	9.34	19	100

Table 38: D5 - Percentage of persons who reside in group quarters. Higher percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	Percentage	Non-Percentile Rank	Percentile Rank
Inarajan	0	2	10.53
Sinajana	0	2	10.53
Umatac	0	2	10.53
Asan-Maina	0.05	4	21.05
Yona	0.62	5	26.32
Piti	1.03	6	31.58
Chalan Pago-Ordot	1.06	7	36.84
Dededo	1.19	8	42.11
Merizo	1.41	9	47.37
Agana Heights	1.52	10	52.63
Mongmong-Toto-Maite	1.58	11	57.89
Talofofo	1.84	12	63.16
Agat	2.12	13	68.42
Yigo	3.47	14	73.68
Barrigada	3.59	15	78.95
Mangilao	5.17	16	84.21
Tamuning	6.72	17	89.47
Santa Rita	15.02	18	94.74
Hagatna	21.98	19	100

Themes of the SVI – Percentile Ranks

Table 39: A5 - Theme 1: Socioeconomic Status is the ranking sum of the variables of the theme (A1+A2+A3+A4). Higher percentile represents higher vulnerability. Source: US Census 2010.

Municipality	Percentile Rank	Non-Percentile Rank
Piti	5.26	1
Santa Rita	10.53	2
Tamuning	15.79	3
Asan-Maina	21.05	4
Agana Heights	26.32	5
Barrigada	31.58	6
Chalan Pago-Ordot	36.84	7
Talofofo	42.11	8
Inarajan	47.37	9
Sinajana	52.63	10
Yona	57.89	11
Mangilao	63.16	12
Yigo	68.42	13
Hagatna	73.68	14
Mongmong-Toto-Maite	81.58	15.5
Dededo	81.58	15.5
Agat	89.47	17
Merizo	94.74	18
Umatac	100	19

Table 40: B5 – Theme 2-Household Composition Disability is the ranking sum of the variables within the theme (B1+B2+B3+B4). Higher Percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	Non-Percentile Rank	Percentile Rank
Tamuning	1	5.26
Yigo	2	10.53
Santa Rita	3	15.79
Piti	4	21.05
Talofofo	5	26.32
Dededo	6	31.58
Asan-Maina	7	36.84
Hagatna	8	42.11
Barrigada	9.5	50
Mangilao	9.5	50
Yona	11	57.89
Chalan Pago-Ordot	12	63.16
Inarajan	13	68.42
Mongmong-Toto-Maite	14.5	76.32
Umatac	14.5	76.32
Sinajana	16	84.21
Agana Heights	17	89.47
Agat	18	94.74
Merizo	19	100

Table 41: C3 - Theme 3 - Minority Status and Language is the ranking sum of the variables within this theme (C1+C2). Higher percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	Non-Percentile Rank	Non-Percentile Rank
Piti	1	5.26
Asan-Maina	2	10.53
Santa Rita	3	15.79
Inarajan	4.5	23.68
Yona	4.5	23.68
Umatac	6	31.58
Agana Heights	7	36.84
Chalan Pago-Ordot	8	42.11
Sinajana	9.5	50
Talofofo	9.5	50
Merizo	11	57.89
Agat	12	63.16
Yigo	13	68.42
Mangilao	14	73.68
Barrigada	15.5	81.58
Mongmong-Toto-Maite	15.5	81.58
Tamuning	17	89.47
Dededo	18	94.74
Hagatna	19	100

Table 42: D6 - Theme 4 -Household and Transportation is the ranking sum of variables within this theme (D1+D2+D3+D4+D5). Higher percentile rank represents higher vulnerability. Source: US Census 2010.

Municipality	Percentage	Non-Percentile Rank
Asan-Maina	1	5.26
Piti	2	10.53
Talofofo	3	15.79
Santa Rita	4	21.05
Inarajan	5	26.32
Sinajana	6	31.58
Umatac	7	36.84
Yona	8	42.11
Chalan Pago-Ordot	9	47.37
Merizo	10	52.63
Agana Heights	11	57.89
Dededo	12.5	65.79
Yigo	12.5	65.79
Barrigada	14.5	76.32
Mongmong-Toto-Maite	14.5	76.32
Tamuning	16	84.21
Mangilao	17	89.47
Hagatna	18	94.74
Agat	19	100

SVI – Summary Table and Map

Table 43: E1 - Social Vulnerability Index - Guam. Higher percentile rank represents higher vulnerability. Calculated using methodology outlined by CDC for SVI. Source: US Census 2010.

Municipality	Non-Percentile Rank	Percentile Rank	
Piti	1	5.26	Least Vulnerable
Santa Rita	2	10.53	
Asan-Maina	3	15.79	
Talofofo	4	21.05	
Inarajan	5	26.32	
Yona	6	31.58	
Chalan Pago-Ordot	7	36.84	
Tamuning	8	42.11	
Agana Heights	9	47.37	
Yigo	10	52.63	
Sinajana	11	57.89	
Barrigada	12	63.16	
Umatac	13	68.42	
Dededo	14	73.68	
Mangilao	15	78.95	
Merizo	16	84.21	
Hagatna	17	89.47	
Mongmong-Toto-Maite	18	94.74	
Agat	19	100	Most Vulnerable

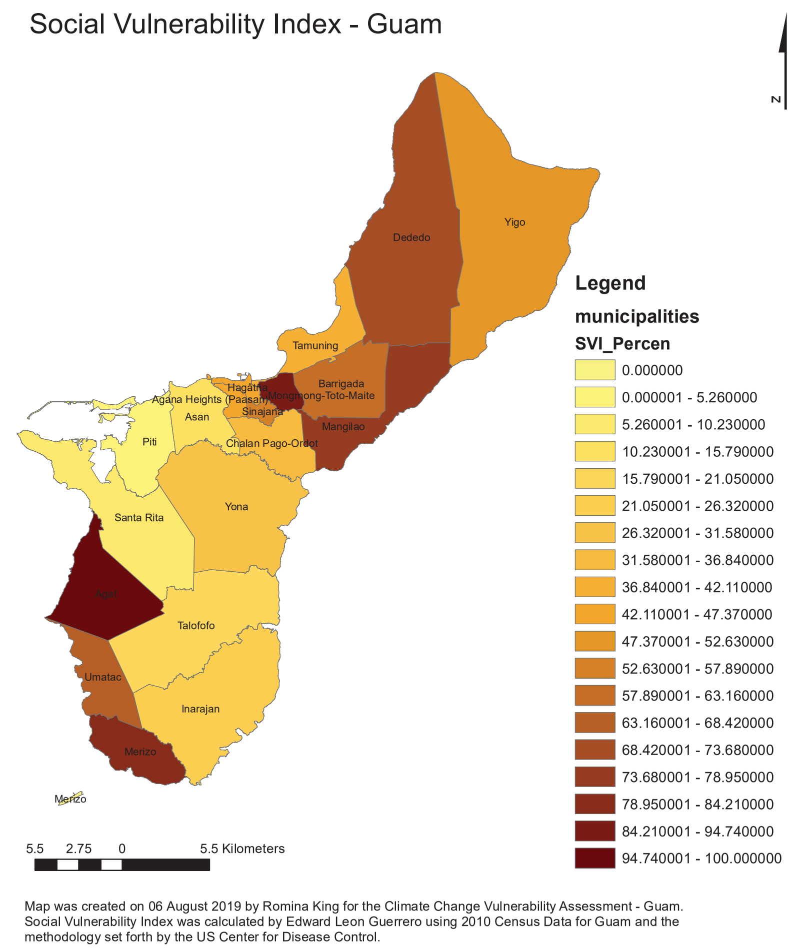


Figure 22: Map of Guam - SVI

Correlations

Table 44: Correlation Matrix showing the correlation coefficients between all the variables. See Table 23 for the name and descriptions of each of the variables.

	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	D1	D2	D3	D4	D5	D6	E1
A1	1.000																			
A2	.679*	1.000																		
A3	.668*	.745**	1.000																	
A4	.728**	.726**	.848**	1.000																
A5	.832**	.881**	.917**	.896**	1.000															
B1	-.218	.049	-.104	-.175	.003	1.000														
B2	.165	.349	.246	.372	.280	-.065	1.000													
B3	.260	.502*	.335	.374	.491*	.672*	.284	1.000												
B4	.463*	.629*	.696**	.548*	.701**	.174	.253	.598*	1.000											
B5	.248	.524*	.428	.375	.524*	.625*	.451	.917**	.748**	1.000										
C1	.693*	.656*	.758**	.763**	.836**	.209	.230	.696**	.753**	.689*	1.000									
C2	.167	-.280	-.186	.054	-.161	-.649*	-.021	-.528*	-.443	-.591*	-.255	1.000								
C3	.696**	.150	-.377	.573*	.438	-.453	.247	-.078	.085	-.054	.438	663*	1.000							

D1	.211	-.197	-.240	-.039	-.140	-.236	.275	-.086	-.211	-.042	-.027	.271	.473*	1.000						
D2	-146	-.163	.151	.152	-.003	-.125	.239	-.240	-.039	-.114	-.058	.174	.155	-.303	1.000					
D3	.533*	.625*	.898**	.732**	.787**	-.053	.149	.370	.751**	.450	.735**	-.308	.239	-,317	.170	1.000				
D4	.749*	.545*	.423	.484*	.596*	.037	.286	.551*	.379	.505*	.670*	.016	.523*	.466	-.465*	.296	1.000			
D5	.207	-.114	-.116	.054	-.101	-.571*	.401	-.441	-.373	-.412	-.181	.696**	.578*	.383	.250	-.239	.091	1.000		
D6	.674*	.252	.425	.533*	.451	-.388	.502*	.071	.206	.156	.482*	.361	.840**	.559*	.214	.353	.615*	.612*	1.000	
E1	.858**	.635*	.705**	.778**	.811**	-.033	.465*	.460*	.542*	518*	805**	.091	.741**	.321	-.007	.574*	.784**	.262	.811**	1.000

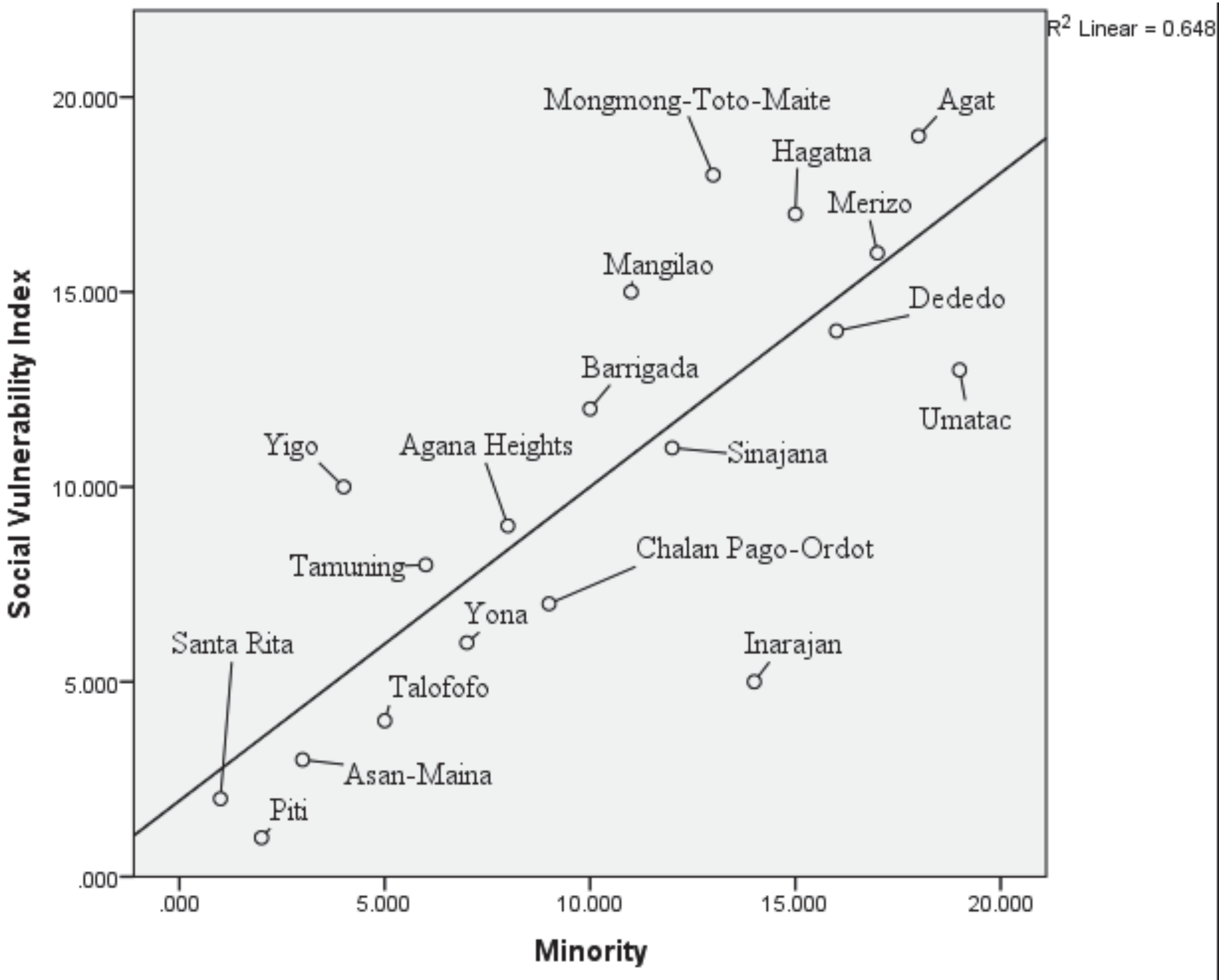


Figure 23: Scatterplot and linear regression line showing SVI and minority. The least vulnerable villages Piti, Santa Rita, and Asan-Maina have the lowest populations of minorities (non-whites) and the greatest populations of Caucasians. Agat, MTM, and Hagatna are the most vulnerable and have substantially higher populations of minorities (non-whites). The slope (R^2) of the linear regression is .648, meaning that approximately 65% of the variation in the SDI (E1) is due to the variation the minority variable (C1).

LEAP Results and Discussion

The 2019 LEAP exercise indicates that the community of Guam mark their climate history with major weather events, specifically typhoons that cause significant damage to infrastructure and have a high monetary cost of recovery (Figure 24). Of the 49 typhoons that passed over Guam from 1970 – 2018, the consolidated timeline for Guam shows only 12 "perceived" typhoons from 1970 to the present day (Figure 24). Participants did not include the additional 37 typhoons which had affected Guam during the same timeframe (Figure 24). Although there were minor errors associated with specific dates, costs, and damages from the typhoons, the consolidated timeline suggests that major typhoons that have caused the most disruption to daily living and its high financial impacts have psychologically scarred the community psyche (Figure 24). Thus, future climate change adaptation planning should address minimizing damage from typhoons, speedy post-typhoon recovery, and increased community resilience.

While major typhoons were a substantial part of the consolidated community timeline, other impacts of anthropogenic and natural climate change, such as change in vegetation, increased wildfires, change in fruit seasons, drought, changes in precipitation patterns, and increased temperatures were not mentioned. Also omitted from the timelines, were the El Niño-Southern Oscillation (ENSO) cycle. ENSO may be predicted six months in advance and incredibly useful to predict drought and typhoon activity for the region. During the initial phase of an El Nino, there is increased cyclonic storm activity for Micronesia and during the latter phase, there is drought. Drought does not seem to be an issue for the Guam community because of the large Northern Guam Lens Aquifer, the island's abundant main source of freshwater. While ecological drought may be characterized by increased wildfires, it does not affect everyday life. There are no water conservation measures to reduce personal, agricultural, and industrial usage.

Group 3 primarily focused on typhoons.

In addition to typhoons, Group 1's timeline focused on major impacts to Guam's economy and concerns about the island's infrastructure. For example, unlike the Group 2 & 3, Group 1 mentioned the opening of Micronesia Mall in 1979, the Yigo Amusement Park in 1974,[11] and the new Dededo famer's market also known as the "flea market" completed in November 2016. This indicates that this particular group values the economic growth and benefits of retail malls and tourist attractions, thus suggesting that improving Guam's economy may make the island more resilient to typhoons. Group 1 also noted infrastructure improvements, such as the building of the Guam Regional Medical City (GRMC), the first private hospital in Micronesia and Guam. Group 1 included the 2009 'military build-up', which refers to the transfer of US Marine troops from Okinawa to Guam, impacting natural resources and existing infrastructure. It is clear that Group 1 is sensitive about factors that may cause additional strain to the island's aging infrastructure and they value the economy.

In comparison to Group 1 and Group 3, Group 2 placed an emphasis on environmental events. For example, Group 2 was the only group to include the 8.0 earthquake which affected Guam on 08 August 1993 (Swan and Harris 1993), the devastating, mass coral bleaching events that occurred from 2013 to 2017 (Raymundo et al., 2019), wildfires, and polychlorinated biphenyl (PCBs) spills (Eugenio, 2019).

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[11] Martha Ruth, *Amusement Park to Reopen?,* (March 29, 1977) Pacific Daily News, MARC Vertical Files: Yigo.

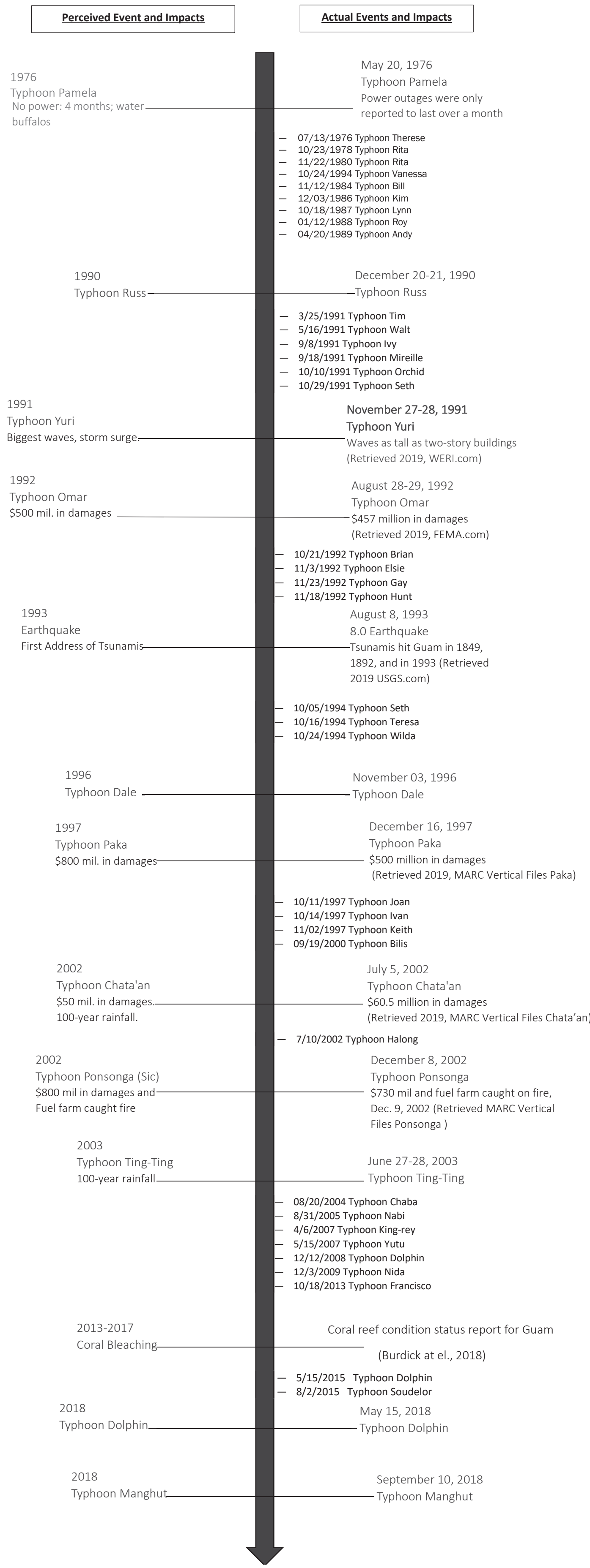

Figure 24: Consolidated community timeline from the All Planners Climate Change Workshop, held on 08 April 2019. The community timeline is labeled as 'perceived'. The timeline also includes 'actual' events.

Recommendations and Future Research

Sea level rise is a certain impact of climate change; the questions are when, and how much, rather than if. Even if society sharply reduces emissions in the coming decades, sea level will most likely continue to rise for centuries (Golledge et al., 2015; DeConto and Pollard, 2016). SLR increases the threat of erosion and flooding along coastlines, making small islands particularly susceptible. Given the number of tropical storms and typhoons that affect Guam, SLR can increase damages to infrastructure from these events. Engineering solutions (e.g. seawalls and breakwaters) in response to protecting coastal communities and associated infrastructure are increasingly becoming economically and ecologically unsustainable. Yet during the PGIS exercise, many planners and developers proposed solutions that involved shoreline hardening.

Nature-Based Solutions

One of the recommendations of this study is to further examine nature-based solutions (NBS) as viable options for coastal protection on Guam. Examples of NBS include creating or restoring natural habitats, such as sand dunes, saltmarsh, mangroves, seagrass and kelp beds, and coral and shellfish reefs, to provide coastal protection in place of (or to complement) artificial structures (Morris et al., 2018). Coastal managers are frequently faced with the problem of an eroding coastline, which will only increase with SLR. Morris et al. (2018) assess the current evidence for the efficacy of nature-based versus artificial coastal protection and discuss future research needs. Future research should evaluate habitats created or restored for coastal protection for cost-effectiveness in comparison to an artificial structure under the same environmental conditions and include a cost-benefit analysis (Morris et al., 2018). Interdisciplinary research among scientists, coastal managers and engineers is required to facilitate the experimental trials needed to test the value of these NBS shoreline protection schemes, in order to support their use as alternatives to artificial structures (Morris et al., 2018). One study in North Carolina found that that bulkheads are not meeting waterfront property-owner expectations despite continued use, and that nature-based coastal protection schemes may be able to more effectively align with homeowner needs (Smith et al., 2017).

NBS seem promising, because ideally, they can help to protect coastal communities from climate change impacts while simultaneously sequester carbon dioxide, support biodiversity, and improve ecosystem services (Seddon et al., 2019). However, the potential of NBS to provide the intended benefits has not been rigorously assessed and there are concerns over their reliability and cost-effectiveness compared to engineered alternatives (Seddon et al., 2019). Furthermore, an NBS can prove to be environmentally disastrous if climate mitigation policy encourages NBS with low biodiversity value, such as reforestation with non-native species. This can result in maladaptation, a negative outcome, especially in a rapidly changing world where biodiversity-based resilience and multifunctional landscapes are key (Seddon et al., 2019). Seldon et al. (2019) highlight the rise of NBS in climate policy—focusing on their potential for climate change adaptation as well as mitigation—but caution on the lack of peer-reviewed studies supporting their efficacy. Seldon et al. (2019) also outline the major financial and governance challenges to implementing NBS at various scales.

Reducing poverty and elevating average socioeconomic status

The CDC SVI is a useful tool that pinpoints individual villages' social vulnerabilities. Larger Caucasian populations strongly influence the overall SVI at the group level, most likely because they are probably of higher socioeconomic status relative to non-white populations. Agat, MTM and Hagatna are the top three most socially vulnerable villages and must be prioritized in any action plan for reducing social vulnerability. Future research should adapt the CDC SVI methodology to Guam, as well as further explore strong relationships between particular individual variables and the SVI identified in Table 44. In addition to adapting the tool and using it to monitor social vulnerability over time, it is also an opportunity for policy-makers to prioritize the first United Nations sustainable development goal (SDG) – reducing poverty. It appears that the least vulnerable villages on Guam are indirectly related to higher socioeconomic status via larger Caucasian populations. By elevating the socioeconomic status of the general population, it will most likely reduce overall vulnerability. Successfully reducing social vulnerability to climate change and variability requires action and commitment at multiple levels. Cinner et al., (2018) argue that one way of increasing community resilience to climate change is to increase individuals' 'assets', which may be defined as financial, technological, and service (e.g., health care) resources, so that individuals may use them in times of need (e.g., post-typhoon recovery, flooding event). Poor people face a double burden of inequality — from uneven development and climate change (Pelling and Garschagen, 2019). Filho et al. (2019) found a promising positive relationship between cities' income level and adaptation capacity.

This past September, the United Nations set out an ambitious global agenda for helping communities adapt to climate change through the framework of the Sustainable Development Goals (SDGs). The first SDG seeks to reduce poverty. Stronger coordination between the SDGs and climate change adaptation in Guam may offer opportunities for economic development and help minimize vulnerability to climate change but it is important to proceed cautiously.

Coastal Development

The final recommendation is to create a climate change adaptation plan that addresses these vulnerabilities identified in this technical report. It is suggested that the adaptation plan incorporate the following goals for the coastal zone:

1) Maintain functioning and healthy coastal ecosystems
2) Reduce exposure and vulnerability of the built environment
3) Strengthen governance frameworks for coastal adaptation
4) Maintain livelihood opportunities and diversify options
5) Reduce risks to human health and safety

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APPENDIX A

List of Attendees at the All Planners Climate Change Conference held on 08 April 2019 at the Hyatt Resort and Hotel, Tumon Guam

No.	Last name	First name	Organization
1	Acosta	Mark	University of Guam
2	Adanzo	Eugene	UOG OIT EPSCOR
3	Aquzor	Celestino	
4	Aranza	Ed	Guam Department of Education
5	Arellano	Justine	
6	Artero	Kenny	Guam Homeland Security/ Office of Civil Defense
7	Artuz	Josh	
8	Atalig	Brenda Ann	Port Authority of Guam
9	Atena Joel	University of Guam	
10	Aterta	Joel	University of Guam
11	Babauta	Collin	
12	Bacsafra	Joseph	Guam Power Authority
13	Ballendorf	Heidi	Guam Water Authority
14	Bautista	Kaylyn	WERI- University of Guam
15	Bearden	Brian	Guam Environmental Protection Agency
16	Benitez	Christian	Bureau of Statistics and Plans
17	Brown	Val	NOAA Fisheries
18	Brown	Larla	US Coast Guard
19	Cadag	KC	
20	Calvo	Denille	Guam Homeland Security/ Office of Civil Defense
21	Camacho	Esther	Bureau of Statistics and Plans
22	Carlson	Edward	National Geodetic
23	Castro	Fran	UOG- Sea Grant
24	Charalaubous	Nayia	University of Guam
25	Comia	Jan	University of Guam
26	Concepcion	Teddy Lee	UOG- Sea Grant
27	Conde	Enrique	Port Authority of Guam
28	Crame	Alannah	University of Guam
29	Cristobal	Hope A.	NGSWCD/Kumision I Fino' Chamoru
30	Cruz	Jesse	Guam Environmental Protection Agency
31	Cruz	Rosemarie	Guam Department of Education
32	Cushing	Janet	Pacific Islands Climate Adaptation Science Center
33	de Lemos-Loyola	Ruth	Guam Department of Education
34	Dela Paz	Maurine	
35	Delos Santos	Simeon	Port Authority of Guam
36	Denton	Uriah	University of Guam
37	Derrington	Erin	CNMI Office of Planning and Development
38	Detera	Cherlene	
39	Di Ramos	Lowella	University of Guam
40	Dungca	Raymond	Guam State Clearinghouse

41	Enriquez	Noel	Stanley Consultations Inc.
42	Erguiza	Millie	Bureau of Statistics and Plans
43	Espia	Leo Rustum	Guam Homeland Security/ Office of Civil Defense
44	Evangelista	Josephine	Guam Water Authority
45	Flores	Jacqueline	US Fish and Wildlife Service
46	Flores	Thomas	Guam Department of Agriculture
47	Franquez	Renee	Guam Department of Agriculture
48	Gawel	Mike	US National Park Service
49	Gill	Olina	Hyatt Regency Guam
50	Gorong	Berna	The Nature Conservancy
51	Greene	Robbie	NOAA
52	Guerrero	Marilyn	Bureau of Statistics and Planning GCMP
53	Guerrero	Roberta	Micronesia Islands Nature Alliance
54	Gutierrez	Iremar	Port Authority of Guam
55	Hamilton	Sara	UnderWater World
56	Hill	Cielo	Guam Power Authority
57	Hood	Eileen	University of Guam
58	Imperial	Janlane	University of Guam
59	Jones II	Elaine	
60	Juruor	Randy	
61	Kerking	Heather	USGS & Pacific Islands Climate Adaptation Science Center
62	King	Romina	University of Guam
63	Lau	Rabriel	National Security Agency
64	Leberer	Trina	The Nature Conservancy
65	Leon Guerrero	Lola	Bureau of Statistics and Plans
66	Leon Guerrero	Rachael	University of Guam ORSP
67	Lerner	Darren	USGS & Pacific Islands Climate Adaptation Science Center
68	Lujan	Vangie	Guam Water Authority
69	Mafnas	Joseph	Guam Forestry
70	Magnuson	Hannah	Micronesia Climate Change Alliance
71	Manibusan	Joey	Guam Fire Department
72	Mario	Patty	Guam Power Authority
73	Martin	Nathaniel	Guam Department of Agriculture
74	Mercado	Khristia	Guam Power Authority
75	Mesa	Taryn	Guam Environmental Protection Agency
76	Mizerek	Toni	US Fish and Wildlife Service
77	Mojas	Jana	
78	Morgan	Mallory	Bureau of Statistics and Plans
79	Morrison	Bethany	County of Hawaii Planning Department
80	Nelson	Nicole	Office of Technology, GovGuam
81	Olah	Molly	SJS

82	Perez	Bart	Guam Power Authority
83	Perez	Davilynn	University of Guam
84	Quinata	Marybelle	Friends of Reefs Guam
85	Quitugua	Jeffrey	Guam DAWR
86	Raymundo	Laurie	University of Guam Marine Lab
87	Romine	Bradley	Hawaii Sea Grant, PI-CASC
88	San Miguel	Chris	University of Guam
89	Santiago	Jose	UOG OIT EPSCOR
90	Savercool	Dan	EA Engineering, Science, and Technology, Inc. PBC
91	Schober	Katie	USDA WS
92	Shinohira	Raymond	UOG CIS
93	Silang	Sonia	Bureau of Statistics and Plans
94	Soto	Elijah	Duenas, Camacho, & Associates, Inc.
95	Swavely	Dan	Office of the Governor
96	Taijeron	Farron	The Nature Conservancy
97	Taitano	Claudia	Youth Educational Services
98	Taitano	Conchita SN	Guam Environmental Protection Agency
99	Tison	Maria Paz	Guam Power Authority
100	Torres	Victor Robert	
101	Ulloa	Joseph	DPW CIP Building Inspection and Permit Section
103	Rustig	Holly	
104	Leon Guerrero	Christina	
105	Barcinas	Tyler	

Total number of participants = 110

Total number of organizations = 48

APPENDIX B

Ten-foot SLR Scenario Maps

APPENDIX C

Five-foot SLR Scenario Maps

APPENDIX D

Three-foot SLR Maps

APPENDIX E

Key Terms

Adaptation may be defined (in human systems), as 'the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities' (IPCC, 2019). For natural systems, adaptation may be defined as 'the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects' (IPCC, 2019).

Adaptive capacity may be defined as 'the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences (IPCC, 2014).

Climate may be generally defined 'as the average weather—or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities—over a period of time ranging from months to thousands or millions of years.' The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change refers to a 'change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC 2019).

El Niño-Southern Oscillation (ENSO) is a coupled atmosphere-ocean phenomenon occurring at preferred time scales of approximately two to seven years. It is often measured by the surface pressure anomaly difference between Tahiti and Darwin and/or the sea surface temperatures (SST) in the central and eastern equatorial Pacific. During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the SSTs warm, further weakening the trade winds. This phenomenon has a great impact on the wind, SST and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world, through global teleconnections. The cold phase of ENSO is called La Niña. The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation (IPCC, 2019).

Exposure may be defined as 'the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected' (IPCC 2019).

Hazard may be defined as 'the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources' (IPCC 2019).

Regional sea level change is a rise or fall in sea level relative to a datum (e.g., present-day mean sea level) at spatial scales of about 100 km.

Relative sea level is sea level measured by a tide gauge with respect to the land upon which it is situated.

Representative concentration pathways (RCPs) are 'scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs), aerosols, and chemically active gases, as well as land use/land cover (Moss et al., 2008). The word 'representative' signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term 'pathway' emphasizes the fact that not only the long-term concentration levels, but also the trajectory taken over time to reach that outcome are of interest (Moss et al., 2010). RCPs were used to develop climate projections in Coupled Model Intercomparison Project CMIP5.

There were four RCPs used for the IPCC AR5 and they are as follows:

> RCP2.6: One pathway where radiative forcing peaks at approximately 3 W m–2 and then declines to be limited at 2.6 W m–2 in 2100 (the corresponding Extended Concentration Pathway (ECP) assuming constant emissions after 2100). This the 'ideal' or 'low-level' scenario that assumes that there is a significant reduction of greenhouse gases.
> RCP4.5 and RCP6.0: Two intermediate stabilization pathways in which radiative forcing is limited at approximately 4.5 W m–2 and 6.0 W m–2 in 2100 (the corresponding ECPs assuming constant concentrations after 2150). These are mid-level scenarios that assume that measures have been taken to reduce greenhouse gas emissions.
> RCP8.5: One high pathway which leads to >8.5 W m–2 in 2100 (the corresponding ECP assuming constant emissions after 2100 until 2150 and constant concentrations after 2250). This is often referred to as the 'business as usual' or 'high emissions' scenario.

Resilience may be defined as 'the capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure (Arctic Council, 2016).
Sea level change may be defined as the rise or fall of the height of sea level, both globally and locally (relative sea level change) at seasonal, annual, or longer time scales due to

> (1) a change in ocean volume as a result of a change in the mass of water in the ocean (e.g., due to melt of glaciers and ice sheets)
> (2) changes in ocean volume as a result of changes in ocean water density (e.g., expansion under warmer conditions, or thermal expansion)
> (3) changes in the shape of the ocean basins and changes in the Earth's gravitational and rotational fields, and
> (4) local subsidence or uplift of the land (IPCC 2019).

Global mean sea level change resulting from change in the mass of the ocean is called barystatic. The amount of barystatic sea level change due to the addition or removal of a mass of water is called its sea level equivalent (SLE). Sea level changes, both globally and locally, resulting from changes in water density are called steric. Density changes induced by temperature changes only are called thermosteric, while density changes induced by salinity changes are called halosteric. Barystatic and steric sea level changes do not include the effect of changes in the shape of ocean basins induced by the change in the ocean mass and its distribution (IPCC 2019).

Scenarios in climate change research, may be defined as 'plausible trajectories of climate conditions and other aspects of the future' (Moss et al., 2010).

Vulnerability may be defined as the 'propensity or predisposition to be adversely affected and the term encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt' (IPCC, 2019).