Climate Vulnerability Assessment for the Islands of Rota & Tinian, CNMI

CNMI Bureau of Environmental and Coastal Quality

Division of Coastal Resources Management

2015

About this Document

This document presents the Climate Vulnerability Assessment for the Islands of Rota and Tinian, CNMI. The Assessment was conducted primarily in response to both observed and projected impacts from a changing climate, as well as an increasing focus in the CNMI on addressing locally significant effects from climate variability and extreme events. The following pages highlight the Assessment design, process, findings, and recommendations for future action. The Assessment was conducted from May 2014 to March 2015, and represents a concerted effort to weave local narratives about historic climate extremes with best available climate projections. The intention is to provide a baseline of information that will spur further technical investigations concerning specific vulnerabilities, while being relatable to a broad swath of the community. It is our hope that the Assessment serves to establish a foundation for initial climate adaptation planning on Rota and Tinian.

The Vulnerability Assessment for Rota and Tinian was conducted by the CNMI Division of Coastal Resources Management, in partnership with the collaborating agencies and organizations of the CNMI Climate Change Working Group, and the residents of Rota and Tinian. Ongoing support for the Vulnerability Assessment and financial assistance was provided by the Coastal Zone Management Act of 1972, as amended, administered by the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration (NOAA). Information for the assessment was derived from a wide range of federal and CNMI government agencies, non-governmental organizations, academic institutions, and community members.

Suggested Citation:

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Access and Limitations

This is an open-access document, and is available online through the CNMI Climate Working Group website at www.ClimateCNMI.net. The document may be distributed freely. Hard copies of the report are available at the CNMI Division of Coastal Resources Management Office on Saipan, and spatial data related to vulnerable features on Rota and Tinian can be viewed, queried, and downloaded online at the Division of Coastal Resources Management's Open Data Portal: http://data.dcrm.opendata.arcgis.com/.

The Vulnerability Assessment for Rota and Tinian is intended for broad planning and policy purposes, and serves as a scoping document to inform future climate adaptation planning, as well as future research directions in the CNMI. This document may also be used for educational endeavors, should any educational institution or pedagogue be adventurous enough to use it for such purposes. The Assessment is *not* intended for site-specific engineering or parcel-scale design purposes, nor should it be used in relation to litigation.

Acknowledgements

The Vulnerability Assessment for Rota and Tinian would not have been possible without the time, resources, and contributions of many individuals and organizations.

The staff of the CNMI Division of Coastal Resources Management (DCRM) and the National Oceanic and Atmospheric Administration (NOAA) CNMI Field Office were gracious with their time and generous with their knowledge. Robbie Greene, Rebecca Skeele, Dana Okano, and Megan Jungwi played pivotal roles in facilitating community workshops and providing planning support. Lyza Johnston, Steven Johnson, Ryan Okano, and Steve McKagan filled significant knowledge gaps with their expertise in CNMI coral health and marine ecosystems.

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In addition to workshop coordination, the participants of the Rota and Tinian workshops cannot be thanked enough for their in-depth knowledge and fascinating stories related to historic climate events and extremes. One of the goals of any project of this nature should be to capture local knowledge, allowing for community input and subsequent ownership. The residents of Rota and Tinian provided the means of accomplishing this goal, and instilled the nuances and flare that will ideally keep this document alive.

Funding for the VA was provided by NOAA, and NOAA's Office for Coastal Management offered valuable input and guidance on the methods employed within this study, while making tools available to better understand and visualize historic climate phenomena. NOAA's National Climatic Data Center is also acknowledged as one of the primary data providers in assessing and summarizing both historic climate extremes and current conditions.

This project also leveraged useful input and studies from the University of Guam's Water and Environmental Research Institute of the Western Pacific (WERI), the United States Geological Survey (USGS), and the United States Department of Agriculture.

Additional acknowledgement of data sources for historic conditions and future scenarios is detailed in Appendix B.

Table of Contents

Executive Guide

The Vulnerability Assessments for Tinian and Rota are documented in the following pages in a very simple structure. The background and impetus for the assessments is briefly addressed, followed by summaries of both current trends in the CNMI's climate, as well as projections of future climate conditions and associated impacts. The design of the vulnerability assessment process and organization of information is then outlined, followed by two sections that discuss historic impacts and potential vulnerabilities separately for each island. These discussions of vulnerabilities and historic narratives are then followed by a broader conclusion section that suggests steps forward in addressing vulnerabilities and opportunities for Rota, Tinian, and the CNMI in general.

For policy makers with limited time, resource managers with limited jurisdictional interests, or scientists with limited subject interests, the following outline may assist in providing shortcuts to relevant sections of the document. This directory is a substitute for the more traditional *Executive Summary* and is intended to guide the reader to key information to support further inquiry and dialog.

- **Why were the vulnerability assessments conducted?**
- **How do they fit into the larger picture of climate adaptation in the CNMI?**

Page 3 offers insight into the broader context of climate adaptation initiatives in the CNMI, while pages 4-6 detail the general design and concept for the actual assessment process. Pages 21-22 also outline how the data and information collected during the assessment is organized.

- **How is the climate in Micronesia Changing?**
- **What might happen to the CNMI climate in the future?**

Pages 11-21 offer an overview of how individual climate components are shifting in the CNMI, and provide details on what climate scenarios might look like 50 and 75 years into the future.

- **What experiences and lessons do the communities of Rota and Tinian have to share?**
- **How can we learn from the past?**

The story of Rota's past climate impacts and vulnerabilities begins on page 23, and ends with a summary of lessons for adaptation, and the future in general using a synopsis table on page 39.

Likewise, Tinian's story begins on page 42 and culminates in a summary table of impacts and adaptive options on page 56.

- **What are our options for adapting?**

In addition to the summary tables for Rota (pg. 39) and Tinian (pg. 56), a combined table focusing only on *impacted systems* and *adaptive responses* is included on pages 60-62. Of course, there are many more options for adaptation; the samples provided in this table are intended to provide starting points by offering examples and suggestions for further discussions.

- **In general, how can Rota, Tinian, and the rest of the CNMI proceed in tackling the issues posed by climate change?**

This document ends with a brief discussion of broader approaches that may assist Rota, Tinian, and the CNMI in general in moving forward with adaptation implementation. See pages 58-70.

Introduction

Numerous changes in global, regional, and sub-regional climate have been observed and documented over the past century (IPCC 2001, 2007, 2012, 2013, 2014). These shifts suggest some persistent and worrisome alterations to a wide variety of atmospheric and oceanic phenomena. While communities and nations worldwide have built their economies, cultures, and relationships with the natural world based on these systems, the threat of an uncertain future is eliciting both concerns and some creative responses.

Paralleling these physical changes to our climate, a shift in the national and international climate change discussion has taken place. Accepting that some amount of change is inevitable, the climate conversation has moved beyond *mitigation* of greenhouse gases at a global level and established a more flexible and scalable emphasis on *adaptation*. Over the past three years the CNMI has pursued the development of processes that focus on the latter. Climate change adaptation refers to the adjustment of a human or natural system in response to current and/or future impacts from climate phenomena. The primary aim of adaptation is to identify impacts that may be unavoidable – regardless of greenhouse gas mitigation efforts – and temper harmful effects from climate change (IPCC 2007, NOAA 2010). By responding to expected changes, adaptation initiatives allow for more immediate outcomes in climate change work.

Climate change adaptation is most effective where a solid foundation of knowledge and information related to potential impacts and community vulnerabilities has been established (Snover et al. 2007; NOAA 2010). In the CNMI, this foundation is being built upon a baseline assessment of risk and vulnerability for the islands of Saipan, Tinian, and Rota. These vulnerability assessments (VAs) have adopted a variety of approaches and tools, attempting to synchronize local knowledge with any available data that might support impact analysis. Saipan's VA was completed in 2013, and released in early 2014, triggering some interest at both the local and federal level to support next steps in climate adaptation such as action plans and strategies. That VA, combined with this assessment for Rota and Tinian, constitutes the groundbreaking for a more sustained, effective climate adaptation initiative, and is intended to inform additional technical inquiries into climate impacts and eventually support the development and implementation of a long-term climate change adaptation strategy.

Vulnerability assessments are not a new concept. In the CNMI, VAs had been conducted prior to the initiation of assessments focused on climate change. Some of that work was concerned with natural disasters such as earthquakes and tsunamis (CNMI Standard State Mitigation Plan 2010 & 2014), and is conceptually aligned with the goals of this work: To inform the growth of a more resilient community.

Nationally and internationally VAs are conducted in the context of a variety of social, natural and physical threats, but much of the recent focus has been on climate change. These assessments are intended to identify levels of potential impact, investigate susceptibilities of human and natural systems, and explore any capacities for responding to identified impacts; however, they do not always result in immediate actions. Rather, they serve as a *basis* for action.

This role is especially important in the CNMI, where climate change is a fairly new concept to many audiences. The continued investment of time and resources in climate change adaptation will require a catalyst (such as a VA) to demonstrate the significance and relevance of climate change to policy makers, resource managers, community leaders, and educational institutions throughout the Commonwealth. It is with the need for this "catalyst" in mind that the CNMI designed its original climate adaptation initiative in 2012.

CNMI Climate Adaptation Context

The CNMI Division of Coastal Resources Management facilitated the convening of an inter-agency climate adaptation task force – the CNMI Climate Change Working Group (CCWG) – in the summer of 2012. In the CCWG's early meetings, a working group structure was developed, along with a vision and set of goals and objectives.

CCWG Vision Statement

- **The CNMI is ready and able to proactively adapt to climate change in order to maintain the integrity and resiliency of our communities and ecosystems. The community is aware of the threats posed by climate change, and is implementing a comprehensive adaptation plan to preserve our cultural, natural and economic resources for current and future use.**

Goals of the Climate Change Working Group

- **To develop a unified CNMI plan and approach to climate change adaptation**
- **To facilitate inter-agency coordination and capacity building to address climate change**
- **To identify gaps in knowledge and provide technical resources for climate change assessment and planning**
- **To identify the communities, livelihoods, and ecosystems in the CNMI that are most vulnerable to climate change through development of a vulnerability assessment**
- **To coordinate a CNMI-wide community education and outreach strategy**

The first actionable objective that was embarked upon was the development of a VA; however, this objective quickly became intertwined with the CCWG's progress toward overarching goals of agency collaboration and information sharing. Data collection and analysis occurred throughout 2013, a process that included assembling future sea level scenarios and general climate projections. This work synthesized local knowledge in participatory mapping workshops and adapted tools and methods that were used in other jurisdictions and at the national level.

As this process unfolded it became clear that Saipan's technical information and consequent opportunities for analysis and information comparison was far different than what was available on Tinian and Rota, so the Assessment was customized to focus on Saipan. The results allowed for clear visualization of vulnerabilities and spurred an Executive Directive from the Governor mandating participation in the CCWG by government representatives with decision making capacity. The resulting products also generated interest in completing a VA for Rota and Tinian. The latter islands are comparatively "data-poor" from a technical standpoint, lacking critical baseline information for analysis such as high-resolution elevation data, consistent climatology and time-series data related to climate phenomena, and accurate, updated GIS data.

The notion of being "data poor" does not necessarily translate into a lack of information or inability to conduct an assessment, but rather, creates a necessity to identify areas in which Rota and Tinian are "information rich". In the context of Rota and Tinian, the notion of being "information rich" is one born of optimism, an emphasis on the utility of collective, community knowledge over inconsistent data, and perhaps a de-emphasis on the traditional formats that fit into more mainstream structures of government decision- and policy-making.

Vulnerability Assessment Process and Design

This vulnerability assessment employed a fairly unique approach, attempting to draw relationships between historic climate events and future vulnerabilities. In this particular study, local knowledge and narrative about past climate events and their impacts was compared with projections for future climate scenarios. This comparison allows for a tentative estimate of how the impacts from these past events are likely to change in frequency and/or magnitude in the future. This type of comparison across time is herein referred to as a “climate analog”. The latter term is *not* part of accepted scientific nomenclature, but is being introduced here as a means of steering the climate adaption discussion in the Pacific Islands into more creative waters that may be more responsive to data gaps and more reflective of local knowledge.

This “climate analog” tactic was used as a result of two interrelated factors: (1) Rota and Tinian are characterized by a fragmented data landscape, and (2) the community as a whole does not have a preconceived grasp of future climate scenarios. Datasets pertaining to both climatic trends and the condition of stakeholder resources are inconsistent or incomplete around Rota and Tinian, making it difficult to take a more structured, index-based approach to measuring vulnerability. In the absence of consistent, accessible data, local knowledge takes on greater significance as a medium to fill information gaps.

Unfortunately local knowledge cannot automatically be placed in the context of future climate scenarios if those that retain this knowledge have not been exposed to the oft-confusing climate science. A recent study of public knowledge (n = 419) about climate change in the CNMI found that there is a general lack of understanding regarding changes in the Earth’s climate system and the resulting impacts (Skeele & Okano 2014). Given the conditions of limited existing data and low levels of familiarity with climate change, it was appropriate to glean information from stories, and later translate narratives to numbers.

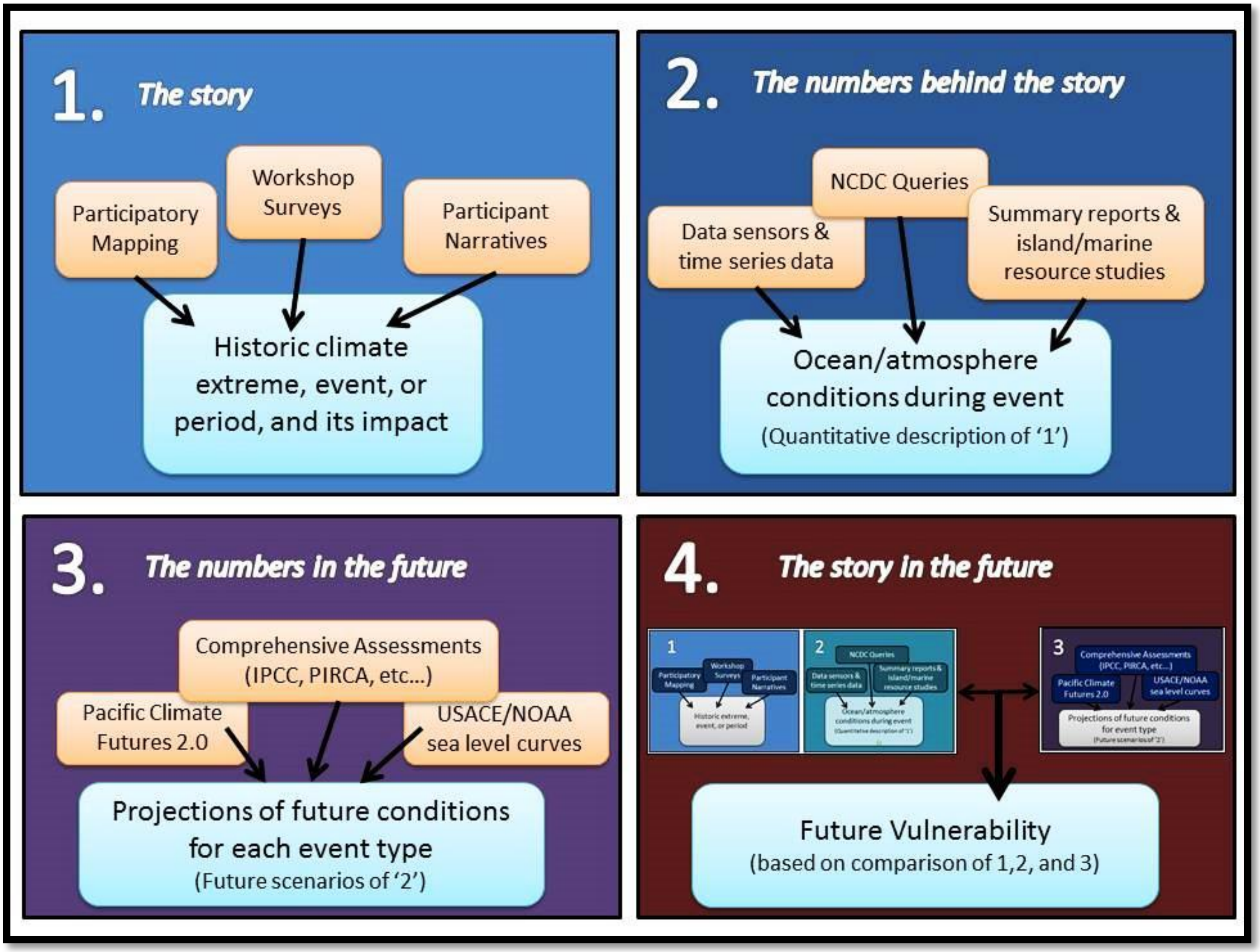
This translation leveraged any existing time-series data related to periods of historic climate extremes, and in the absence of official (e.g. National Climatic Data Center) data, isolated studies citing specifics about historic climate extremes were mined for numbers. Wherever possible, historic climate data records were used from the islands or specific locations referenced in community stories of historic extremes. Where this information was not available, data from increasingly broader scales or collection points in reasonable proximity (e.g. Guam) were used. Appendices B and C provide greater detail on these sources.

Similarly, climate change projections have not been down-scaled to a resolution specific to sections of the Marianas Archipelago, so information concerning future climate scenarios was extrapolated from numerous sources focused on regional and sub-regional (e.g. “Western Micronesia”) projections. The use of disparate historic climate data and projections at multiple scales represents this project’s endeavor to compile “best available data”. Comparing the historic data to future projections, and using this comparison to infer shifts in magnitude of related impacts is acknowledged as stretching the limitations of data utility, but nevertheless, the collection of data sources at the very least achieves an assemblage of useful information for reference (see Appendices B and C).

Despite complications within the congregation of historic and future climate data, the process adhered to in conducting the VA was fairly straightforward:

- In the summer and fall of 2014, NOAA and DCRM staff facilitated information-gathering activities on Rota and Tinian. These included:
    - Basic surveys inquiring about historic climate extremes and impacts (Appendix A);
    - Structured story-telling and group discussions related to past climate impacts; and
    - Participatory mapping workshops to geo-reference and visualize the impacted areas and features from participants' stories.
- A database was assembled to organize participant stories, and mine each narrative about impacted features into categorical information related to *historic time period and/or dates*, *impacted features,* and *level of impact.*
- The database was expanded to include quantitative climate data related to the historic time period/dates, future projections, associated changes in the magnitude and level of impact, and consequent vulnerability of impacted systems.

The climate analog concept and design for the VA is summarized in the figure below.



The remainder of this document is formatted to accomplish the following:

- Summarize the current climate and potential future climate scenarios for the CNMI.
- Discuss the individual stories and climate analogs resulting from the VA process.
- Offer general adaptation options for impacted systems.
- Conclude with a broader discussion of paths forward for climate adaptation on Rota and Tinian, and in the CNMI in general.*

*While the scope of this project does not include the development of an adaptation plan or proposal for actions, general responses to the 2014 Saipan VA suggested that intermittent discussions of options would helpful to frame future planning efforts.

Rota and Tinian Climate Background

A few notable phenomena that dominate climate and pattern in the Western North Pacific (WNP) are worth mentioning prior to a discussion of individual climate components and stressors. One of the most important drivers of climate in the region is the large-scale east-west tropical circulation and overturning of air known as the Walker circulation. This circulation is one of the primary drivers for seasonal winds and associated movement of weather systems across the equatorial Pacific. The Walker Circulation is one of the main reasons for the CNMI's comfortable conditions from ~December – February. Observed Pacific sea level pressure over the last century suggests that this circulation is weakening a bit, and some climate models indicate that the consequent weakened surface winds have altered the thermal structure and circulation of the tropical Pacific Ocean (Vecchi et al. 2006). Because this circulation affects all the various components that make up the CNMI's seasonal climate, the potential for further weakening of circulation in the WNP during the 21st century presents some interesting implications regarding more specific climate variables.

On a shorter time scale the El Nino-Southern Oscillation (ENSO) introduces some of the most extreme variability to WNP climate patterns. During El Nino events the east-west circulation and trade winds that bring the CNMI its normal seasonal variation (cooler temperatures, regular rainfall and consistent winds) weaken, and the CNMI faces greater potential for drought and typhoons. The opposite phase of El Nino, La Nina, is characterized by a strengthening of the trade winds and east – west flow across the tropical Pacific. These events can increase rainfall in the region, and bring higher sea levels as the enhanced east-west flow pushes surface water from the eastern Pacific toward the WNP.

Because of the extreme changes that ENSO can cause, any assertions concerning short-term impacts to regional climate come with uncertainty; however, long-term projections appear to place the average climate conditions of the future outside the range of current observed variability (Mora et al. 2013). For example, the mean high temperature experienced now in the CNMI will be similar to, if not less than, the *average* temperature in the CNMI in 2080. Keeping this concept in mind, a closer look at long-term climate change in the WNP is warranted, despite significant short-term variability.

For our baseline of summarizing current climate, we can focus on a few key components that have impacted Rota and Tinian throughout history. Changes to these systems will play a role in the impacts of future climate scenarios.

Temperature & Precipitation

Temperature and precipitation amounts in the CNMI are largely determined by regional-scale atmospheric patterns that are subject to great annual and decadal variability. Regardless, some general trends can be estimated with a reasonable amount of confidence.

Annual normals, as well as annual summaries for individual years for many weather stations can be viewed and accessed interactively through NOAA NCDC's Climate Data Online website and map (CDO Map). Data records for Rota and Tinian, however, are incomplete, and discrepancies have discouraged computation, and subsequent NCDC publication, of annual normals in some locations. In the case of the VA, calculations from locally-focused studies may sometimes provide a more nuanced understanding of annual normals, extreme periods, and local variations in the Islands' water budgets.

It should also be noted variations in annual rainfall can be quite extreme in the event that the passage of one or more typhoons impacts one island more than another. Lander (2004) notes differences of up to 15% among annual precipitation measurements in the Marianas due to a *single* tropical cyclone event.

Rota Annual Normal: 94.70 inches/year based on complete records from Rota International Airport (Lander and Guard 2003)

While Rota receives more rainfall than Tinian, nearly 100% of the drinking water supply on Rota is pumped from a single water pooling cave, which sits just below the cliff line of the Sabana, within the Talakhaya/Sabana watershed (CNMI Office of the Governor 2012). This is an important consideration in the context of climate adaptation, as a lack of multiple sources for drinking water supply concentrates a strong reliance on a single feature. As a general principle, placement of all provision for a single service on a single feature creates an inherent vulnerability, and a lower level of adaptive capacity in terms of current assets.

The caves and springs at Matan Hanom and As Onaan are presently supplying all domestic water on Rota via pipeline. The stream flows are perennial and intermittent with flows diminished during the dry season. Flows have been substantially curtailed and possibly eliminated at times by increased use of the water for community water supply (CNMI Office of the Governor 2012).

Tinian Annual Normal: 82 inches/year for the period 1988 – 1996 (USGS 2002), or 83.4 inches/year through combined records over a longer span of time (Lander and Guard 2003).

Tinian's emphasis on agricultural resources, as well as its reliance on a basal lens for groundwater resources, has spurred some thorough analyses of water resources in the past. Estimates of water-budget components for Tinian are 82 inches per year of rainfall, about 6 inches per year of runoff, 46 inches per year of evapotranspiration, and 30 inches per year of recharge. As with any water budget, this leaves a finite amount for careful partitioning among infrastructure and general community use, and any changes to precipitation amounts and frequency should be monitored closely for influence on future availability.

From 1990–97, ground-water withdrawal from the Municipal well, the major source of water, averaged about 780 gallons per minute (USGS 2002). While more recent withdrawal rates were not available from a consistent source, the withdrawal rate from the Municipal well should be a focal indicator of ongoing discussions related to development and consequent future pressure on water supply. As with Rota, reliance on one primary source of water creates an inherent vulnerability. This vulnerability, combined with historic impacts from drought place precipitation scenarios and water systems on Tinian in the forefront of climate adaptation priorities.

Sea Levels, Winds, and Waves

Long-term sea level rise (SLR) and short-term sea level change (SLC) are the focus of numerous climate vulnerability inquiries throughout the Pacific Islands. Rota and Tinian are categorized as “high islands”, with elevated limestone terraces that serve to protect the vast majority of each island from modest amounts of SLR. However, these islands have still experienced significant impacts from historic high and low sea levels, as well as wind and wave systems that can occasionally pose hazardous conditions.

Between 1993 and 2010 sea levels in the WNP rose at a rate of over 10 mm per year. This is over three times the rate of the global mean sea level (GMSL) average during that time (Keener et al. 2012). While this extreme rate of rise is not expected to continue, and has been attributed to natural variation (e.g. Pacific Decadal Oscillation), it is an example of how sea levels in the region can change relatively rapidly.

The El Niño Southern Oscillation has a similarly drastic and immediate impact on sea levels. During an El Niño year, the mean sea level drops across most of Micronesia. In general, the sea level around Rota and Tinian falls to its lowest level in December of the El Niño year, and then returns to normal levels by the spring of the following year. During La Niña, enhanced trade winds push the sea level to higher values than normal. During the major El Niño event of 1997, the sea level fell about 6 inches below its baseline average, and during the La Niña years that followed (1998-2001), the sea level rose to levels nearly 1 foot above its average. This effectively created a SLC event of approximately 1.5 feet in the span of a few years (Lander 2004).

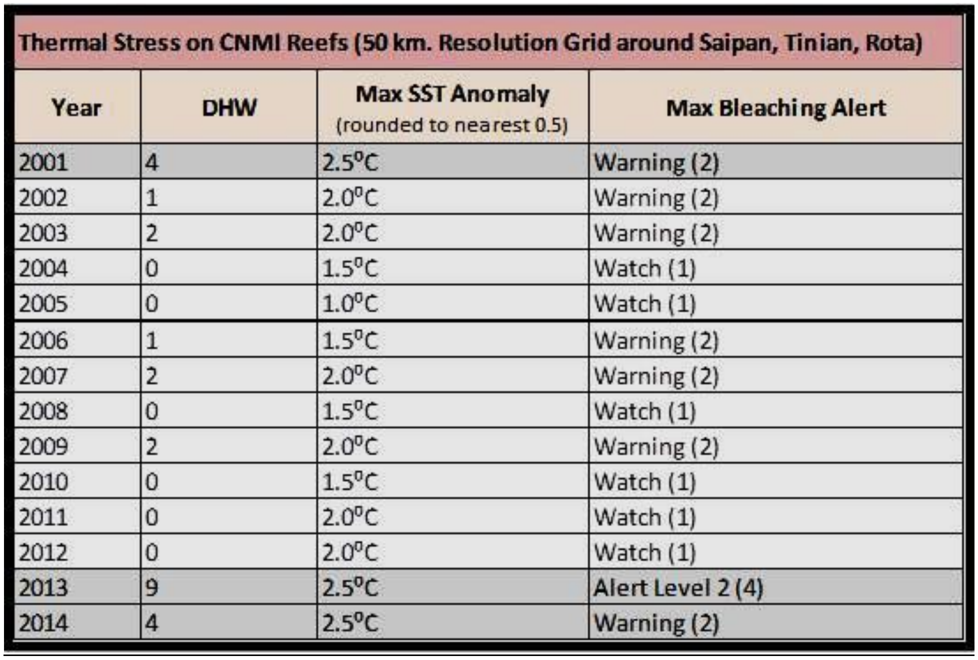
With this variability super-imposed on regular storm activity and associated surge, as well as moderate to large seasonal ocean swells generated by fresh ENE trade winds, both Rota and Tinian are situated in an ocean environment capable of generating significant threats on a consistent basis. SLC in response to short-term variability has impacted salinity levels in the CNMI’s basal lenses (Carruth 2003; USGS 2002), creating potential future implications for saltwater intrusion into freshwater infrastructure, while the port and docking facilities of the islands have both experienced the impacts of storm surge and severe coastal erosion in the past. As major economic and recreational assets, such vulnerabilities warrant thorough consideration of future sea levels and changing wind and wave environments.

Ocean Chemistry

While the visible activity of waves, surge, and inundation at the sea surface are often perceived as the primary oceanic threats from climate change, there are also clearly established options for adapting to these threats. What happens beneath the sea surface, however, is proving to be a more complex problem with regard to climate adaptation. Both the temperature and pH of the ocean surrounding Tinian and Rota play a critical role in maintaining the conditions necessary for the sustained health of the CNMI’s marine ecosystems. As extreme events in the past have illustrated, changes to these conditions, even for a few weeks, can prove detrimental, and even fatal to the natural resources that Rota and Tinian have based much of their economy and partial subsistence lifestyles upon.

Sea surface temperatures generally hover within 0.5°C of the average, however, coupled oceanic-atmospheric processes in the region (e.g. ENSO) can lead to conditions in which temperatures remain well outside the normal thermal range for weeks on end. Perhaps the most noticeable indicator of anomalous sub-sea climate conditions is the presence of bleached coral. Bleaching events generally occur when sea temperatures in a given location remain at a temperature significantly higher than the average for an extended period of time. This temperature anomaly and thermal stress disturbs corals, causing them to expel symbiotic algae that provide color.

Although the records are spotty, published and anecdotal reports indicate that the CNMI experienced mild to moderate bleaching events in 1994, 2001, 2003, and 2005 (Bearden et al. 2005; Starmer et al. 2008) while Guam experienced similar events in 1994, 1996, 2006, and 2007 (Paulay & Benayahu 1999; Burdick et al. 2008). These events were largely restricted to shallow-water and thermally sensitive taxa and resulted in little overall mortality.

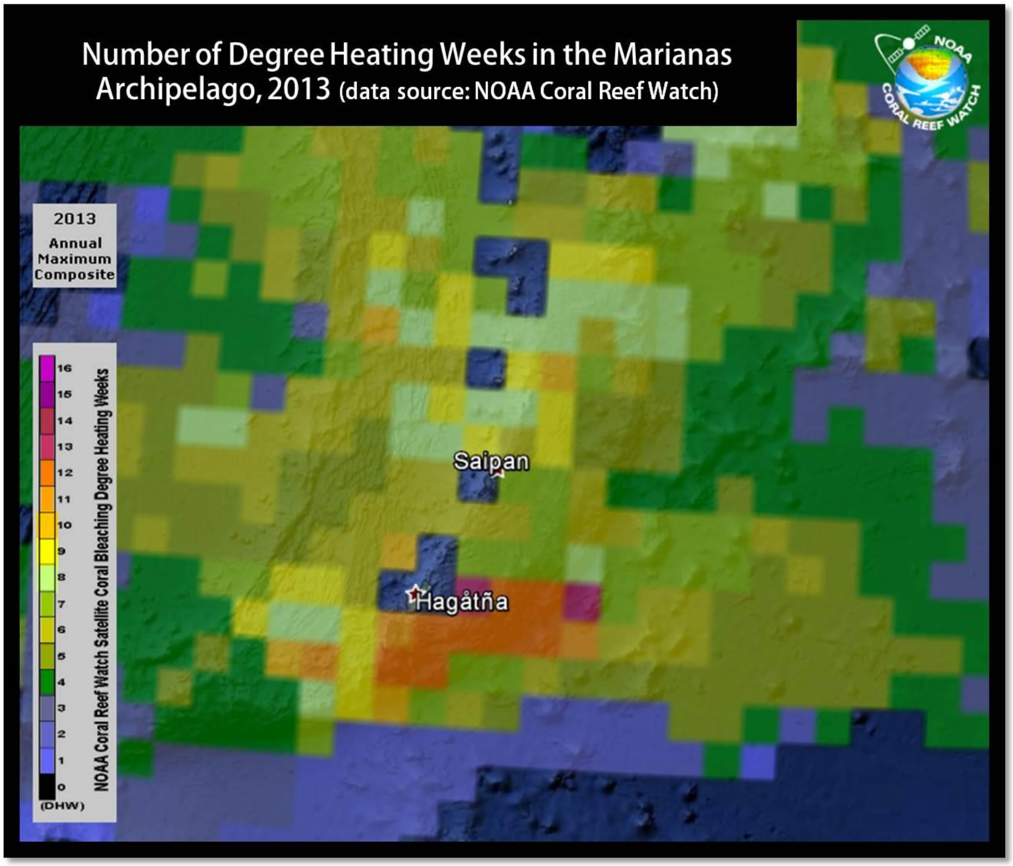


Thermal Stress on CNMI Reefs (50 km. Resolution Grid around Saipan, Tinian, Rota)

Year	DHW	Max SST Anomaly (rounded to nearest 0.5)	Max Bleaching Alert
2001	4	2.5°C	Warning (2)
2002	1	2.0°C	Warning (2)
2003	2	2.0°C	Warning (2)
2004	0	1.5°C	Watch (1)
2005	0	1.0°C	Watch (1)
2006	1	1.5°C	Warning (2)
2007	2	2.0°C	Warning (2)
2008	0	1.5°C	Watch (1)
2009	2	2.0°C	Warning (2)
2010	0	1.5°C	Watch (1)
2011	0	2.0°C	Watch (1)
2012	0	2.0°C	Watch (1)
2013	9	2.5°C	Alert Level 2 (4)
2014	4	2.5°C	Warning (2)

Then, in 2013 and 2014, several years after the last observed bleaching, the region experienced consecutive moderate to severe bleaching events that affected up to 85% of taxa (Reynolds et al. 2013) and devastated shallow-water coral assemblages across the archipelago. In the remote Northern Islands, many shallow-water sites experienced over 90% mortality of *Acropora* and *Pocillopora* spp. corals. At Maug island, severe coral bleaching that affected most taxa down to at least 20 m was observed, with high mortality of sensitive taxa and some mortality of more resistant taxa such as massive *Porites* spp. apparent during the peak of the event in 2014 (CNMI BECQ; Heron et al. *publication pending*). In the Saipan lagoon, over 85% of staghorn *Acropora* corals at long-term monitoring sites were dead by the end of the 2014 (CNMI BECQ). At some of these sites, the coral thickets bleached in 2013, recovered after the water cooled, and then died during the 2014 thermal stress event.

This occurrence where corals reached mortality even after recovering from a previous bleaching event presents a serious dilemma as reef and marine ecosystem managers begin planning for climate impacts. If the frequency of thermal stress conditions increases over the next several decades (discussed in the next section), the recovery of coral from isolated bleaching events may become less likely.



Our ocean chemistry also involves normal baseline levels of acidity that sustain pH conditions in which calcification and reef building (among other significant processes) can occur. Recent research into the relationship between historic climate shifts and reef building have gone so far as to suggest that enhanced climate variability for an extended duration led to a widespread shutdown of vertical reef accretion for a period of 2,500 years (Toth et al. 2015). Additionally, lower pH levels in tropical waters may not only inhibit coral growth, but also disrupt the balance of reef accretion and erosion resulting in a net-loss of reef (Silbiger et al. 2014).

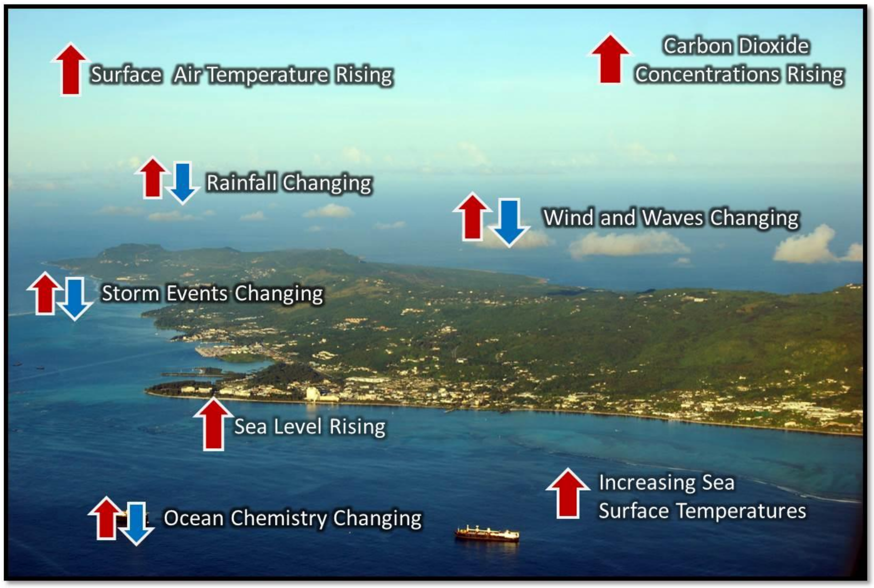
Given these implications, and the low capacity for island communities to change trends in global ocean chemistry, components of this balance such as sea surface temperature and acidity will continue to rise to the forefront of climate adaptation discussions as one of the most important, and perhaps most troubling impacts that our island communities face.

While it is useful to examine past and current impacts of climate both in the CNMI and globally, a shift in discussion toward potential future climate scenarios is warranted at this point. The following sections explore possible future change and vulnerabilities in Tinian and Rota. Additional data related to the historic climate backgrounds of Rota and Tinian is available in Appendices B and C.

Possible Changes to CNMI Climate & Future Scenarios

The Western North Pacific and Western Micronesia will be subject to the same large-scale shifts in global climate that the rest of the world is preparing for; however, broad-scale climate change manifests differently across space and time, particularly with the presence or absence of continental features and large expanses of ocean. Given its location in an ocean expanse that is greatly impacted by natural climate variability and regional patterns, there is some uncertainty in how the WNP climate will shift. In addressing this uncertainty, as well as Rota and Tinian community members' tendency to focus on historic climate extremes, this VA has adopted the use of (1) the upper range of projections for various climate phenomena, based on the most recent scenarios that have served as the basis for much of the global climate change research in the past two years, and (2) inclusion of extreme, isolated climate events (e.g. storms) in a discussion of future climate, despite low confidence in frequency of future occurrence of such events.

Natural variability and storms aside, the figure below summarizes expected long-term changes in climate variables at a global scale. This figure is a simplified version of more specific climate projections, and distills multiple scenarios used in the IPCCs fourth and fifth Assessment Reports (primarily RCPs from AR5) into generalized statements (see IPCC 2014 for more information). Due to its general applicability, this figure is borrowed from the Saipan VA, and was originally adapted from the 2012 Pacific Islands Regional Climate Assessment (Keener et al. 2012).



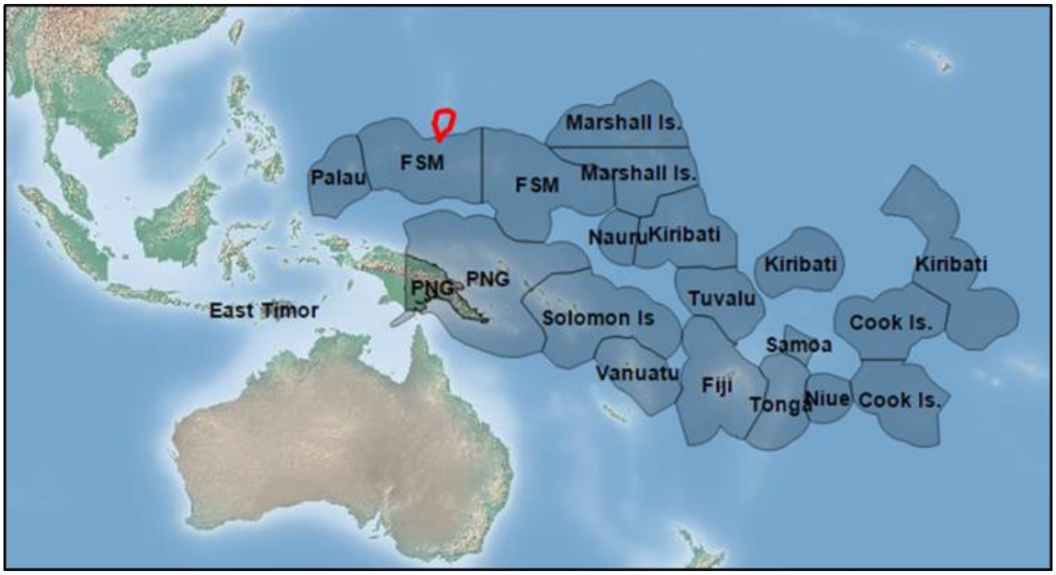
In exploring the upper range of climate change projections and resulting scenarios in the WNP, the VA embraced the IPCC use of Representative Concentration Pathways (RCPs), which describe four different 21st century pathways of greenhouse gas emissions and atmospheric concentrations, air pollutant emissions and land use. The four RCPs represent the wide range of scenarios in the mitigation literature, which suggest a large range of impacts based on how effectively the world is able to mitigate greenhouse emissions. They include a rapidly improved mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one scenario with very high greenhouse gas emissions (RCP8.5). Scenarios without additional efforts to curtail emissions beyond those currently in place lead to pathways ranging between RCP6.0 and RCP8.5 (IPCC 2014). The following projections reflect the upper range of RCPs.

Temperature and Rainfall

Any projections of changes to the hydrologic cycle in the WNP in a warmer world must take into account the substantial inter-decadal variations of rainfall imposed by the climate phenomena already described (Lander 2004). This is no easy task, as precipitation records and historic atmospheric data may not span a large enough range to remove inter-annual and inter-decadal masks. Long-term hydrologic projections at a sub-regional scale involve a level of uncertainty that many scientists are not entirely comfortable with; however, these are precisely the types of projections needed to provide an approximate basis for adaptation planning.

Despite the difficulties in distinguishing near-term variability from long-term trends, overall WNP rainfall projections suggest that the wet season will get wetter and the dry season drier, with overall increases in mean annual rainfall in the western portion of the region (e.g. Palau). Changes to mean *annual* rainfall in the CNMI do not appear to be overwhelming; however, both the intensity and frequency of days of *heavy* rainfall are projected to change over the 21st century (Australian Bureau of Meteorology & CSIRO, 2011). This presents significant flooding possibilities, especially when compounded by increases in sea level and potential coastal inundation.

In the grand scheme of climate adaptation, focusing on projections that have great uncertainties or occupy upper extremes of a range of outlooks may not prove detrimental. In the WNP in particular, preparing for a worst-case scenario fifty years in the future may actually enhance resilience to extreme events five years from now. All scenarios under the category of *Temperature and Precipitation* were analyzed using CSIRO and Australian Bureau of Meteorology’s Climate Futures 2.0 Tool, and RCP 8.5 over 50 and 75 year projections. Sub-regional downscaling for this tool was separated into the geographic areas illustrated below.



Temperature Scenarios

Modeled Region: Federated States of Micronesia - West

Emissions Scenarios: RCP 8.5

Time Span: 2065 and 2090 (50 and 75 year projections)

Climate Futures Classification: Temperature (Annual Surface Temp. and Annual Max Daily Temp.)

Representative Models

To identify the representative models, all models were ranked using a multivariate statistical technique (Kokic et al. 2002) to identify the model that is the best fit to the settings for the Best and Worst cases. In addition, where possible, the Climate Futures tool identifies the maximum consensus climate future (i.e. the climate future projected by at least 33% of the models and which comprises at least 10% more models than any other).

Scenario 2065	Model	Consensus	Surface Temp. (Annual Mean)	Max Daily Temp. (Annual Mean)
Best Case (smaller increases)	CMIP5 - GISS-E2-R-CC	Moderate	1.58°C	1.57°C
Worst Case (largest increases)	CMIP5 - GFDL-CM3	Moderate	2.97°C	2.96°C
Maximum Consensus	CMIP5 - CESM1-CAM5	Moderate	2.22°C	2.24°C

Scenario 2090	Model	Consensus	Surface Temp. (Annual Mean)	Max Daily Temp. (Annual Mean)
Best Case (smaller increases)	CMIP5 - GISS-E2-R-CC	Low	2.23°C	2.22°C
Worst Case (largest increases)	CMIP5 - GFDL-CM3	Low	4.3°C	4.29°C
Maximum Consensus	CMIP5 - GFDL-ESM2M	Low	3.07°C	3.08°C

Within the temperature scenarios, which constitute a significant driver of other climate phenomena, the maximum model consensus suggests large increases in both annual surface and maximum daily temperatures. At the very least an increase of over 2.24°C in annual maximum daily temperature represents a public health concern in the CNMI. The overall increase also poses more complex implications for evapotranspiration rates, and consequently the water budgets for Rota and Tinian.

An important consideration when dealing with annual mean temperatures is that these *averages* are similar in magnitude to recent and historic extremes. Contemplating temporary extremes for scenarios 50 and 75 years into the future might yield isolated events in which temperatures exceed 4°C or more of current averages, if only for a short duration. Such events would likely coincide with coupled extremes in sea temperatures and anomalous precipitation, thus these air temperature scenarios may be thought of as a component of more troubling future situations.

Precipitation Scenarios

Modeled Region: Federated States of Micronesia - West

Emissions Scenarios: RCP 8.5

Time Span: 2065 and 2090 (50 and 75 year projections)

Climate Futures Classification: Annual Rainfall

Representative Models

To identify the representative models, all models were ranked using a multivariate statistical technique (Kokic et al. 2002) to identify the model that is the best fit to the settings for the Best and Worst cases. In addition, where possible, the tool identifies the maximum consensus climate future (i.e. the climate future projected by at least 33% of the models and which comprises at least 10% more models than any other).

Scenario 2065	Representative Model	Consensus	Annual Rainfall
Increased	CMIP5 - ACCESS1-3	Very Low	+22.9%
Decreased	CMIP5 - MIROC5	Very Low	-8.7%
Maximum Consensus	CMIP5 - MPI-ESM-MR	Moderate	+9.9%

Scenario 2090	Representative Model	Consensus	Annual Rainfall
Increased	CMIP5 - ACCESS1-3	Low	+31.9%
Decreased	CMIP5 - MIROC5	Very Low	-13.2%
Maximum Consensus	CMIP5 - MPI-ESM-MR	Low	+9.6%

The projected changes shown in the precipitation scenario tables are characterized by low confidence levels, and suggest a wide range of potential futures. In general, the greatest model agreement involves an increase of almost 10% in annual rainfall; however, this scenario was built for all of Western Micronesia. As Keener et al. (2012) and Lander (2004) note, there is more evidence of increases in annual precipitation as one moves west through the region, while a decreasing trend is seen in Eastern Micronesia. Rota and Tinian occupy an area in this region where precipitation trends have not changed significantly compared to the extremes of this latitudinal gradient.

This uncertainty is perhaps more troubling in regard to climate adaptation than a projection with greater confidence, as planning efforts must balance concerns over both increases and decreases in rainfall. This balance is reflected in the VA through consideration of historic events at both extremes (flooding and drought).

The issue that requires the greatest attention is the manner and frequency in which this potential annual precipitation falls. An increase in precipitation of roughly 9%, spread evenly through Rota and Tinian's daily averages, would likely provide an opportunity for greater water security, and provide opportunities for adaptation in the form of advances in agricultural technique and water storage. However, studies indicating an increase in storm precipitation, though low in confidence, would counter this even distribution of rainfall. Increased precipitation in the form of storms and other isolated events presents severe implications for storm water infrastructure, non-point source pollution, and nuisance flooding in populated areas.

A more detailed discussion of shifts in storm and cyclone behavior is offered later in this discussion.

Winds and Waves

From a geophysical perspective, the islands of Rota and Tinian are well situated to accommodate the winds and waves that dominate the WNP and CNMI. Elevated limestone terraces buffer the islands from the vast majority of persistent swell emanating from the NE during most of the year, while fringing reef attenuates occasional wave energy that arises during less frequent swells from the West. Changes to dominant and temporary wind regimes, and consequent swell size and direction are therefore a concern as the primary natural mitigation capacity that Rota and Tinian are afforded through their physiology is reduced.

The most recent and thorough down-scaled study of wind and wave environments in the Western North Pacific (Storlazzi et al. 2015) suggest a potential decrease in average threats from extended periods of west swell or extreme wave heights. Wave directions in equatorial Micronesia during June-August will experience an approximate 30° clockwise rotation from primarily west to northwest, and September-November wave heights decrease throughout the 21st century. In addition, under the RCP8.5 scenario wave periods decrease in western Micronesia during December-February, and extreme wind speeds decrease, with the largest decreases occurring in the September-November season.

Potential decreases in wind and wave energy may prove beneficial for human uses such as marine sports and coastal development. However, these changes have complications for reef hydrology and the overall hydrodynamic regimes around Tinian and Rota's reefs. Changes in flow via wave energy have the potential to alter levels of turbidity and flushing. Additionally, weakening trends in hydrodynamic flow could potentially lead to localized increases in sea surface thermal stress. This is not a welcome implication considering the projected increases in sea surface temperatures through the 21st century.

As with precipitation, average changes to annual and seasonal wind and wave environments become a more significant concern if these shifts are interspersed with short-term extremes. The latter present a great threat when considered in tandem with SLR and SLC scenarios.

Sea Level Rise and Change

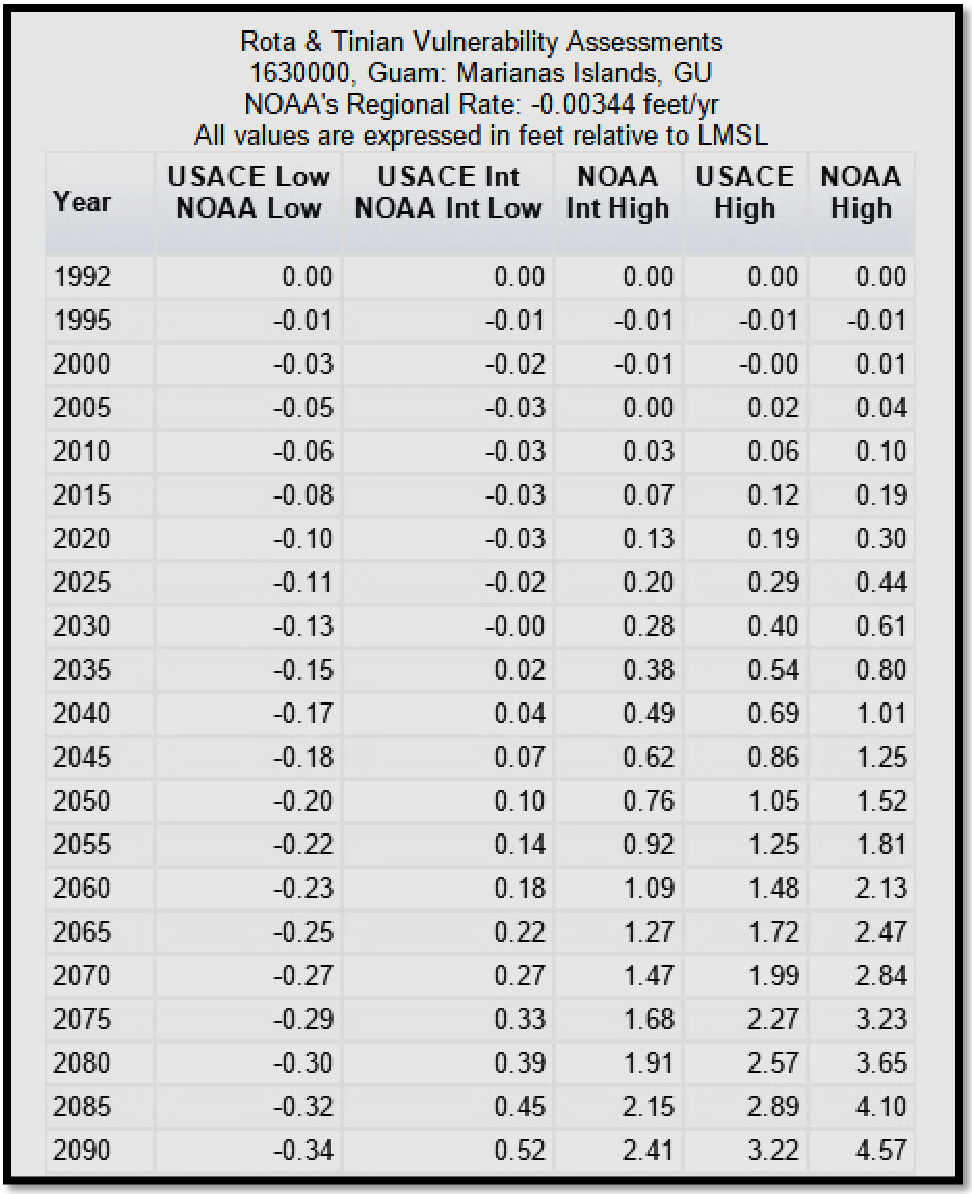
Climate change induces SLR through heating of the ocean surface, causing water to expand, and through heating and melting of glaciers and ice sheets, which transfer water from the land to the ocean. Collectively, these actions increase the volume of the ocean. Sea level can also change relative to a specific landmass if that land is moving vertically (Marra et al. 2012), as is the case in Guam, and potentially the CNMI by extrapolation.

Changes to sea level will pose a variety of challenges globally, and particularly within island regions. Elevated water levels are projected for most regions around the world, and the chance of more frequent extreme water level events could threaten coastal structures, groundwater, ports and commerce, residential and public property, and critical infrastructure. Short- to medium-term impacts will vary with location depending on how natural sea-level variability combines with less extreme increases of sea levels; however, over longer time scales projected SLR is likely to exceed critical elevations in low-lying areas. This surpassing of low-elevation thresholds has been experienced on Rota and Tinian in the past due to storm surge and high total water levels resulting from persistent wave set-up from the west. Future SLR combined with possible climate-related changes in storm patterns could result in frequent flooding and inundation scenarios (Marra et al. 2012).

Global mean sea level (GMSL) has risen over the past century, with recent studies suggesting higher rates of SLR between 1901 and 1990 than previously thought (Hay et al. 2015), and the highest rates of rise (3.2mm/year) measured by tide-gauges and satellite altimeter data between 1993 and 2010 (IPCC 2013). The recent acceleration has been attributed to natural variability in some areas; however, the overall trend shows a gradual increase. GMSL trends are complicated by a number of regional climate variables and forces that recur on varying time scales. The Pacific Decadal Oscillation (PDO), for example, has a significant effect on SLC in the Pacific Ocean. Removing the influence of the PDO from GMSL trends results in a decrease in the acceleration of SLR observed over the past 60 years (Hamlington et al. 2013), although the overall trend still constitutes a rise. These complications become important when sub-regional SLR trends are discussed.

Rates of SLR around Rota and Tinian for the 21st century are highlighted in the table on the following page. These rates and future sea level values were calculated using the U.S. Army Corps of Engineers' (USACE) sea level curve calculator, which was developed by the USACE in collaboration with NOAA's National Ocean Service and the USGS. This effort was driven by a 2011 mandate requiring the USACE to integrate SLC scenarios into its coastal civil works projects (USACE 2011). The calculator uses an adjusted mean sea level (MSL) trend, based on differences between global eustatic MSL trends and a local MSL trend as measured by the closest NOAA tide gauge.

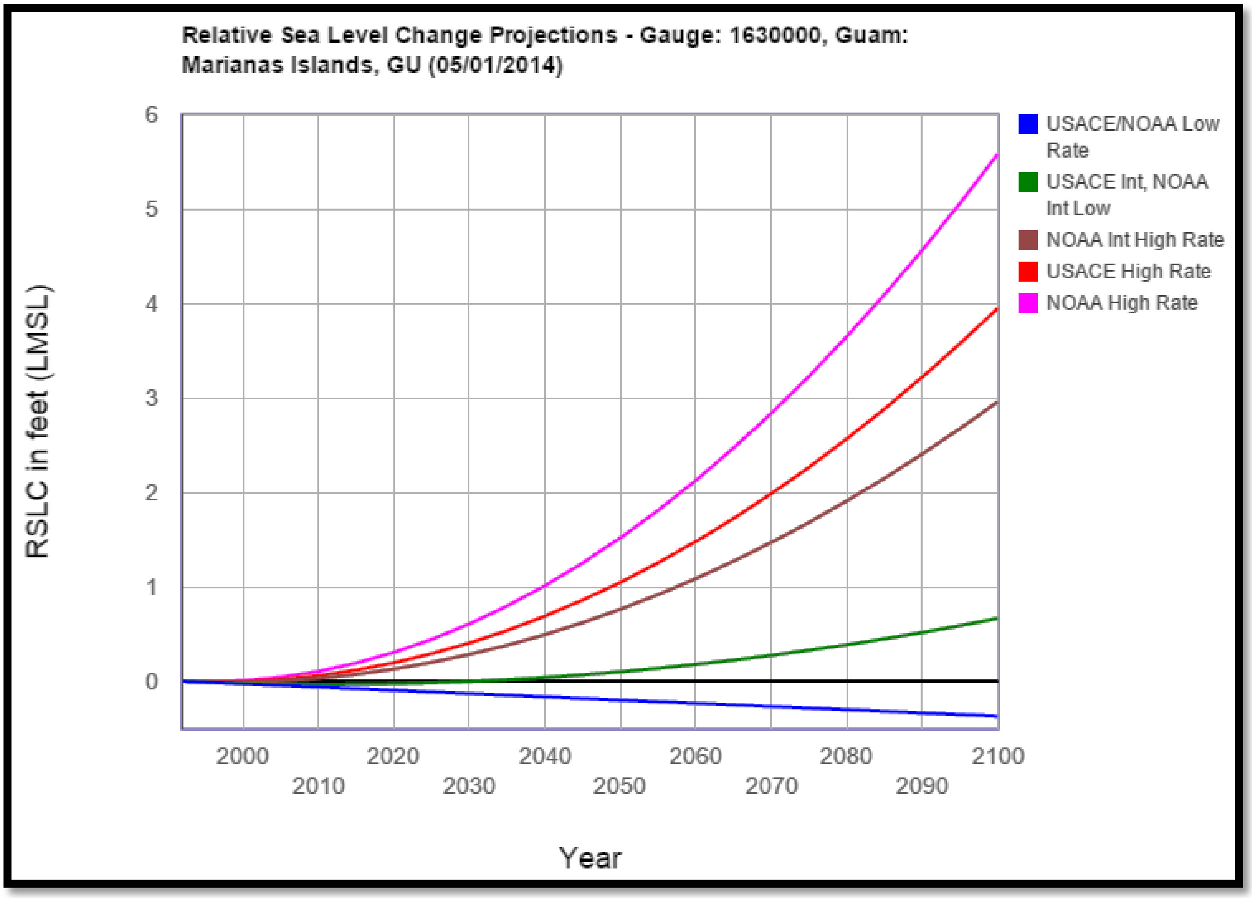
For the Rota and Tinian VA, the local MSL trend was established with the calculator using the NOAA tide gauge on Guam, adjusting for rates of vertical land movement. A lack of consistent and thorough sea level records on Tinian, and Rota's proximity to Guam inspired the use of the Guam tide station, and the vertical rate of land movement due to tectonic uplift on Guam (rising) is assumed for Rota and Tinian as well. Note that the factor of vertical land movement explains negative SLR scenarios where modified NRC Curves are not considered (i.e. “Low Rates”). Application of this rate of vertical land movement to Rota and Tinian introduces some assumptions to the calculation, but does reflect the regional tectonic uplift.



Rota & Tinian Vulnerability Assessments
1630000, Guam: Marianas Islands, GU
NOAA's Regional Rate: -0.00344 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low NOAA Low	USACE Int NOAA Int Low	NOAA Int High	USACE High	NOAA High
1992	0.00	0.00	0.00	0.00	0.00
1995	-0.01	-0.01	-0.01	-0.01	-0.01
2000	-0.03	-0.02	-0.01	-0.00	0.01
2005	-0.05	-0.03	0.00	0.02	0.04
2010	-0.06	-0.03	0.03	0.06	0.10
2015	-0.08	-0.03	0.07	0.12	0.19
2020	-0.10	-0.03	0.13	0.19	0.30
2025	-0.11	-0.02	0.20	0.29	0.44
2030	-0.13	-0.00	0.28	0.40	0.61
2035	-0.15	0.02	0.38	0.54	0.80
2040	-0.17	0.04	0.49	0.69	1.01
2045	-0.18	0.07	0.62	0.86	1.25
2050	-0.20	0.10	0.76	1.05	1.52
2055	-0.22	0.14	0.92	1.25	1.81
2060	-0.23	0.18	1.09	1.48	2.13
2065	-0.25	0.22	1.27	1.72	2.47
2070	-0.27	0.27	1.47	1.99	2.84
2075	-0.29	0.33	1.68	2.27	3.23
2080	-0.30	0.39	1.91	2.57	3.65
2085	-0.32	0.45	2.15	2.89	4.10
2090	-0.34	0.52	2.41	3.22	4.57

Assuming intermediate and high rates of SLR, which are consistent with the VA’s use of RCP 8.5 projections, Rota and Tinian could expect increases in average sea level that are equal to, or beyond, the changes observed in short-term extreme shifts between El Nino and La Nina phases. Unlike the latter, temporary changes, the long-term SLR scenarios for 2065 (50 year) and 2090 (75 year) would be persistent, posing greater possibilities for chronic coastal erosion, nuisance tidal flooding, and decreased wave attenuation over reef flats due to greater depths.



Given the fair amount of confidence in long-term SLR at both global and sub-regional scales, this phenomenon should be viewed as a compounding factor in the magnitude of impact that future waves, extreme tides, and storm surges will have in the region.

Storm Genesis, Tracking, and Intensity

There is an abundance of confusion and uncertainty as to the behavior of tropical cyclones in the later periods of the 21st century. While global media tends to report generalizations about climate impacts such as "stronger, more frequent storms", there is both great heterogeneity in terms of how tropical cyclones could change across various ocean basins, and low confidence in these scenarios of change. Nevertheless, the immense impact that these storms have on the islands of Rota and Tinian merit a discussion of possible futures.

In general, model results suggest that it is more likely than not that the North Pacific storm track will shift poleward, to the north (Christensen et al. 2013). This might place storm tracks that normally fall south of Rota and Tinian closer to the islands, but also put cyclones that normally pass through the Marianas in a position to begin their curve to the North-Northwest at an earlier stage. These situations are primarily speculation, as it is impossible to predict the exact conditions driving individual storms in the future.

That being said, confidence is somewhat better in the WNP than other ocean basins that an increase in the frequency *of the strongest storms* is more likely than not, coupled with a decrease in overall frequency of all storms.

The models generally project an increase in mean lifetime-maximum intensity of storms, which is consistent with a projected increase in the frequency in the more intense storms. Additional assessment of projections in the WNP closely resembles Ying et al. (2012), where numerical projections of 21st century changes in tropical cyclone frequency in the western North Pacific range broadly from –70% to +60%, while there is better model agreement in measures of mean intensity and precipitation, which are projected to change by –3% to +18% and +5% to +30%, respectively.

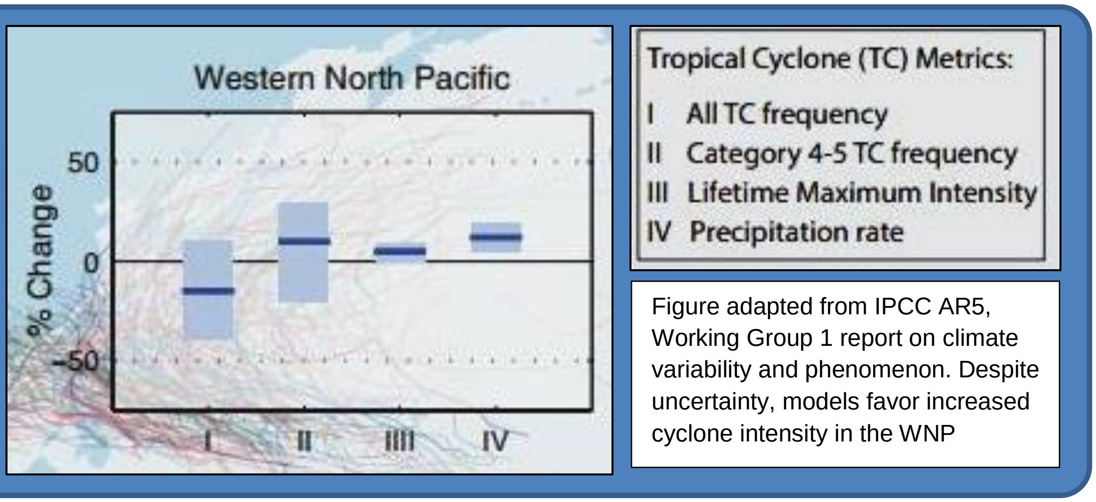


Figure adapted from IPCC AR5, Working Group 1 report on climate variability and phenomenon. Despite uncertainty, models favor increased cyclone intensity in the WNP

The prospect of increased precipitation rates and intensity of tropical cyclones in the WNP is somewhat worrisome when viewed in conjunction with projections for increases in annual precipitation. If the latter is the product of the former, the impacts of flooding, inland erosion, and stormwater runoff will require additional attention from the communities of Rota and Tinian, as these issues have already drawn attention and caused moderate to severe impacts in previous events.

An increase in overall intensity has implications for sea level pressure and wind speeds, which in turn factor into the degree to which Rota and Tinian are impacted by SLC and storm surge. As with precipitation projections, the uncertainties and low confidence associated with future storm scenarios translates into a planning challenge; however, the significant impacts that historic storms have had on the islands should serve as sufficient rationale to prioritize these events in any adaptation initiatives.

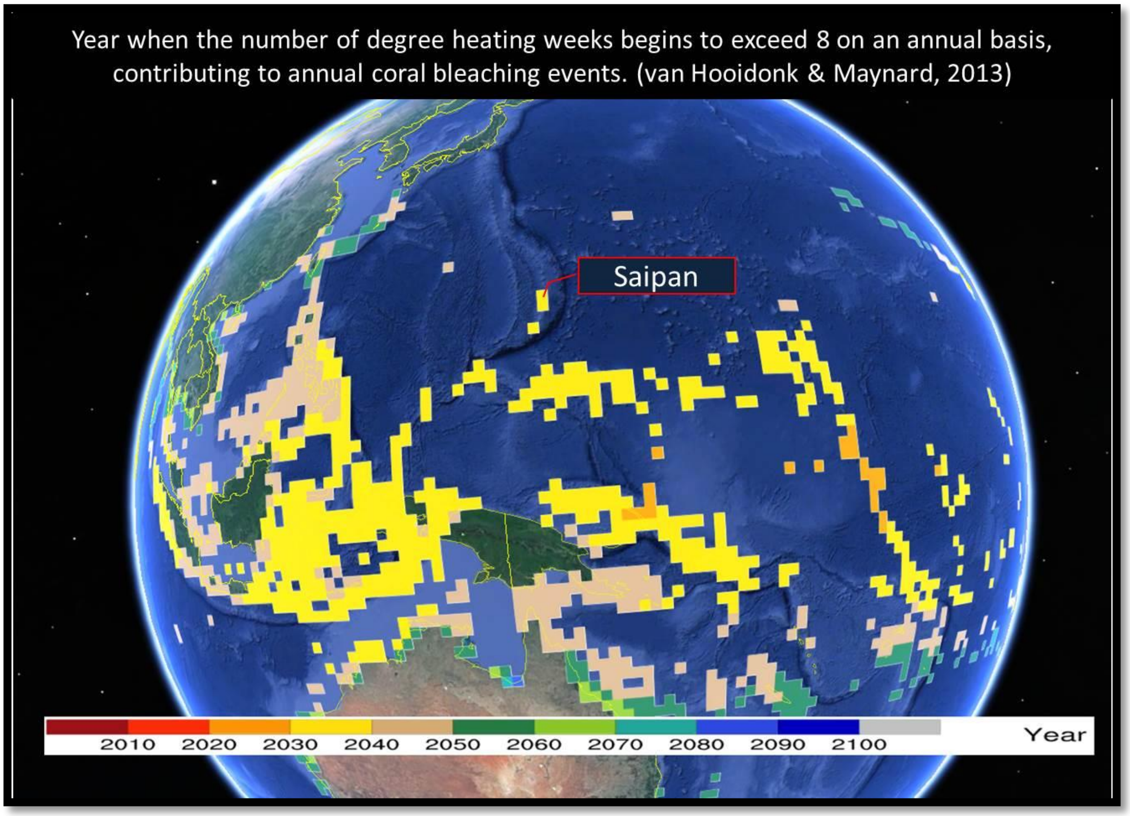
Ocean Chemistry (Temperature & Ocean Acidification)

Of all potential climate change impacts, the effects of changes in ocean chemistry are perhaps the most disturbing for the CNMI, as these changes are largely irreversible and far outlast the devastating but short-term impacts from phenomena such as tropical cyclones. Climate change currently poses the single greatest threat to coral reefs worldwide and in the CNMI. The major climate change associated reef stressors are rising sea surface temperatures and ocean acidification (declining seawater pH due to increased absorption of atmospheric CO_2). Extended periods of warmer-than-average sea surface temperatures cause mass coral bleaching and mortality events while ocean acidification impairs the growth, reproduction, and survival of corals and other calcifying organisms. The two impacts work in concert, with extensive negative consequences for these ecosystems and the communities that depend upon them.

__Sea Surface Temperatures and Coral Bleaching__

As with other oceanic and atmospheric phenomena, ocean temperatures in the Pacific Islands region show significant inter-annual and decadal flux, but since the 1950s there has been a dominant warming trend. Temperatures from the surface to a depth of over 600 feet have risen by as much as 3.6°F (Leong et al. 2014).

Although thermal stress events have occurred periodically in the past, they are expected to increase in frequency and severity with global climate change, inhibiting recovery from individual events. A recent study predicted that under a “business as usual” carbon emissions scenario (RCP 8.5), coral reefs in the WNP will experience annual bleaching between 2030 - 2040 (van Hooidonk et al. 2013).



Year when the number of degree heating weeks begins to exceed 8 on an annual basis, contributing to annual coral bleaching events. (van Hooidonk & Maynard, 2013)

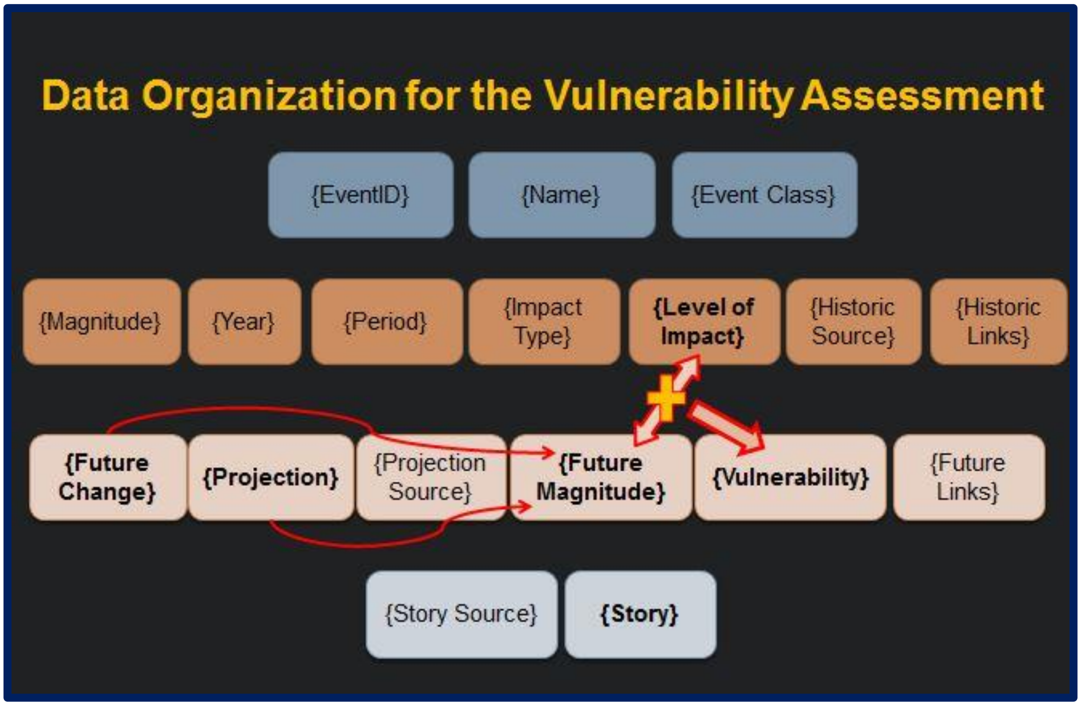
As was seen in the 2013 and 2014 bleaching events in the CNMI, increasing frequency of thermal stress to the point of annual bleaching events may lead to mortality, regardless of temporary recoveries. At the moment, the primary mode of adaptation that appears feasible in the CNMI involves approaching the issue through a reef resiliency management framework. This approach is detailed in the VA discussion section, but essentially focuses on ensuring and enhancing the health of reefs in order to recover from inevitable thermal stress.

The issue of declining pH values in the ocean poses a more complex problem for adaptation. Global increases in ocean acidity have been observed, and are expected to continue through the 21st century, with a decrease in global surface pH of up to 0.30 (IPCC 2013). As mentioned, this creates challenges for calcification, reef building, biological productivity, and overall ecosystem function. Due to limited availability of appropriate research environments for examining the impacts of higher acidity, there is significant uncertainty as to how broader ecosystem services and large-scale dynamics will be impacted by ocean acidification. This uncertainty combined with a lack of local mitigation and adaptation options on Rota and Tinian presents daunting future scenarios for ocean ecosystems in this region.

In the following sections, these potential future scenarios are presented as more intense versions of historic climate extremes and impacts. Rather than a simple discussion of possible climate futures, this connection allows for a more tangible sense of what Rota and Tinian are facing in terms of climate impacts.

Organization of the Analogs

A simple database was developed to organize information about historic extremes, future scenarios, and potential vulnerabilities (Appendix C). The information is arranged in a straightforward manner that allows for analysis of how "vulnerability" is a function of the impact of a particular historic event ("level of impact") combined with potential changes to the magnitude of such events in the future ("future magnitude"). The figure below illustrates this basic formula.


Data Organization for the Vulnerability Assessment

The database columns and categories are defined as follows:

- EventID: A unique identifying number related to the impacted feature and associated story.
- Name: A simple title provided for the impacted story/feature.
- Event Class: The type of climate impact or phenomenon being assessed (e.g. “storm surge”, “drought”, “coastal erosion”, etc.).
- Magnitude: A quantitative description of the historic climate conditions or event.
- Year: The year or period years in which the event occurred.
- Period: Specific dates in which the event occurred, if applicable or available.
- Impact Type: The type of impact on different systems and features (e.g. “coastal erosion of properties and reduced public access”).
- Level of Impact: A general rating of impact level, from low, medium, high, and very high, based on workshop participant input and survey responses.
- Historic Source: The data source for information about the event.
- Historic Links: Online linkage, where available, for data sources and additional information about the event.
- Future Change: The general shift or trend expected for this type of event or climate phenomenon (e.g. shift in annual precipitation, change in cyclone intensity, etc.).
- Projection: A quantitative description of potential future climate conditions related to the event.
- Projection Source: The source of quantitative data related to the projection.
- Future Magnitude: The positive or negative change in future conditions, based on projections.
- Vulnerability: The relative vulnerability level for specific features or systems, based on a comparison of the historic level of impact and the future magnitude.
- Future Links: Online linkage to sources of data or information that details or visualizes future scenarios.
- Story Source: The source of the narrative or information about the specific event (e.g. Workshop participant, specific study, etc.).
- Story: A representative quote or excerpt from workshop narratives or reports (the “Story Source”) on a particular event.

In examining individual climate events and vulnerable features on Rota and Tinian in the following VA section, this database may be referenced in order to point to more specific data. It should also be noted that the absolute (geographic) location of all vulnerable features and areas identified in the database and in the following VA sections can be explored via interactive map and downloaded as spatial data for viewing in desktop GIS or Google Earth environments using the CNMI Division of Coastal Resources Management’s Data Portal (data.dcrm.opendata.arcgis.com), and the CNMI CCWG website (www.climateCNMI.net).

Rota Climate Vulnerability

Analogs and Vulnerabilities

The sections below summarize the historic events and vulnerable features that emerged as common topics of discussion or participatory mapping during the climate vulnerability workshop on Rota. Events and features are organized around a crude classification scheme of climate phenomena (e.g. “precipitation”, “drought”, “surge”, etc.). Each summary of climate events by *class* is followed by a small overview table that outlines the general expected changes in that event class, systems or features that could be impacted in the future, and broad guidance on how adaptive measures could address these changes.

Event Class: Precipitation

Summary

Annual precipitation is a critical component of Rota’s freshwater security, as well as a dynamic factor in habitat health, agricultural productivity, and short-term hazards such as temporary flooding or extreme run-off. As participants in Rota’s climate vulnerability workshop spoke of past impacts and vulnerabilities in relation to precipitation, three events emerged to dominate the discussion: the Okgo River flow reduction, nuisance flooding at the Bank of Guam, and extreme erosion at the Talakhaya Watershed. In general, changes to annual precipitation, or historic anomalies, pose significant hazards under two scenarios: (1) annual precipitation that is well below normal, and (2) short-term precipitation (24 hours – 1 week) that falls at an extreme rate, or in large quantities. The latter creates issues related to temporary flooding, erosion, and stormwater run-off, while the former (below normal annual rainfall) poses potential hazards related to freshwater supply and agricultural resources. The table below summarizes expected changes to annual precipitation in Western Micronesia under 50 and 75 year scenarios, and the general effect this may have on the impacts of future precipitation events, and consequent vulnerabilities.

Future Change	**Projection**	**Projection Source**	**Future Magnitude**	**Vulnerability**
Precipitation Change	Precip. 2065: +9.9% Precip. 2090: +9.5%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5)	Increase in water security (slight increase in precip.)	Low

Events, Features & Historic Conditions

One of the first features discussed on Rota was the “Okgo River”, which is a perennial stream (most years) on the South side of the Island, flowing from the steep slopes of the Talakhaya Watershed and connecting directly to the beach and fringing reef. The road running along the coast through the Sasanhaya and Talakhaya areas takes a sharp turn inland near the Okgo, hugging the contours of the Stream’s ravine. The intersection of the road and the stream offers an opportunity to visually gauge the flow and relative volume of the Okgo, and over the last several decades the stream has apparently been reduced to a trickle of its former self. Workshop participants noted that the stream used to have sufficient flow to cover the roadway in the ravine during years of normal rainfall, but such conditions have rarely persisted for more than a few days at a time in recent years.

Okgo River Flow Reduction (Event ID 7)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
1961-1990: 103.04 in. 1971-2000: 100.61 in. 1996-2008: 98.22 in.	1970	1970 - 2015	Water Security	Low	Rota Workshop Participant USDA - NRCS Western Regional Climate Center

"The river used to flow over the roadway in the 70s and 80s, but doesn't do this anymore."

"Flows have been substantially curtailed and possibly eliminated by increased use of the water for community water supply."

In assessing this situation of reduced stream flow, it is important to consider multiple potential causes for the change over time. Alterations to hydrology, in this case, are not likely the result of significant shifts in climate, but rather anthropogenic stressors. Available data from NOAA's National Climatic Data Center and USDA-NRCS, while not entirely consistent across the decades, suggest that there has been little change in annual rainfall over the last 50 years, with the exception of anomalous periods resulting from annual and decadal phenomena.

In the absence of a major shift in precipitation, it is likely that increased water usage among the community, especially in Songsong Village, has placed additional pressure on the Okgo's source, and thus led to observable reductions in downstream flow. Given a projected increase in annual precipitation over the next 50-75 years, expected changes to the climate might bode well for indicators of a healthy water budget such as this. If this change were to occur in a gradual, linear manner (i.e. increases in precipitation spread evenly throughout the entire year), Rota could be seen as having a potential reduction in vulnerabilities to water security.

However, these changes in precipitation could manifest in a more sporadic nature. Should annual increases in precipitation transpire in the form of extreme, isolated rainfall events, Rota will be more likely to see impacts from run-off, erosion, and nuisance flooding. The latter impact is already observed on a regular basis in the center of Songsong Village, especially where poor drainage capacity overlaps with low-lying areas on the northwest and north-central blocks of the village.

Nuisance Flooding at the Bank of Guam (Event ID 23)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
1961-1990: 103.04 in. 1971-2000: 100.61 in. 1996-2008: 98.22 in. 1989-2013: 59 Tropical Cyclones within 100 nm.	1989	1989 - 2015	Public Health Concerns, Infrastructure Damage	Low	Rota Workshop Participant USDA - NRCS Western Regional Climate Center International Best Tracks Archive

"Since the late 80s that area (in Songsong) near Bank of Guam has always flooded during heavy rain. It doesn't have to be a typhoon, just a lot of rain. It's bad for access and moving around Songsong."

The streets and parking areas that are adjacent to the Bank of Guam and Leadership Park in Songsong are subject to repeated nuisance flooding, particularly during the monsoon season and immediately following isolated storm events. While this type of event doesn't necessarily threaten lives or incur major damage on infrastructure, it does create issues for accessibility, and interrupts the regular flow of business and circulation in the area. Extended ponding of water may also create public health concerns, especially when combined with substantial projected increases in air temperature. While favorable for pests and pathogens, these conditions will not be ideal for those wishing to deposit a check at the bank.

As extreme precipitation poses problems with stagnant water in low-lying locations, those same rainfall events lead to issues with erosion and run-off in steeper terrain. Rota's Talakhaya Watershed, and particularly the restoration area characterized by "badlands", or exposed soil, and ongoing re-vegetation efforts, is perhaps the most striking example of erosion issues on Rota or Tinian. The Talakhaya area is prone to numerous precipitation-related problems, and unfortunately these problems are exacerbated by both wet *and* dry conditions.

Extreme Erosion in the Talakhaya Watershed (Event ID 26)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
1998-2013: 24 Tropical Cyclones within 100 nm. 1998 Precipitation: 67.63 in. (71.4% of annual normal)	1998	1998-2015	Erosion, Habitat Loss, Lowered Reef Resilience	High	Rota Workshop Participants CNMI Office of the Governor, 2012 USFWS 2007 International Best Tracks Archive Lander & Guard 2003

"Not just during typhoons, but any rainstorm there's excessive damage and erosion in the Talakhaya mountain area."

During dry years, particularly those following a large El Nino such as the 1997/1998 event, drought conditions greatly enhance the potential for wildfire. The Talakhaya area has experienced fires due to both natural and human causes, and these events serve to denude the landscape, leaving the steep slopes with a poor vegetative structure and decreased capacity for slope stabilization. These vulnerable conditions then leave Talakhaya especially susceptible to severe erosion during extreme precipitation events.

While re-vegetation efforts continue in the area, the impacts from a single storm event or fire can create major setbacks in ecological restoration, so closer consideration of future climate conditions is warranted as restoration planning efforts move forward. Projected increases in precipitation may reduce the risk of drought conditions under future "normal conditions", yet the long history of climate variability and cyclical ENSO events suggest that normally wet conditions will continue to be punctuated by occasional, extreme dry periods and isolated precipitation extremes. On an extremely steep slope with difficult and at times dangerous access to the focal points of restoration, vulnerability is relatively high. This is true not only of the terrestrial habitat, but for the adjoining reef system at the slope base.

If, however, we were to assume a more optimistic view of the future, characterized by a fairly uniform increase in precipitation over the decades, there could be a potential reduction in the magnitude of future impacts to Rota. The table below summarizes the historic impacts, future changes, and some general adaptation options to precipitation-related events on Rota, assuming that precipitation increases over future decades while being punctuated by cyclical extremes at the same frequency as historically observed. The "relative vulnerability" field assumes no changes are made to build adaptive capacity or modify systems to be less exposed or sensitive. For purposes of prioritizing adaptation actions, the "relative vulnerability" is measured with respect to the relative impacts of other climate phenomena (e.g. vulnerability to increased precipitation will be low compared with vulnerability to future storm events). This principle applies to other Event Classes covered in this section as well.

Event Class Summary

Average Historic Impact	Future Change Magnitude	Relative Vulnerability	Impacted Systems	General Adaptation Options
Moderate – with historic annual normals having a low impact, and isolated extreme events having high impacts.	General increase in water security (assuming appropriate infrastructure), but elevated impacts from flooding & erosion.	Low to moderate, the latter considering the current state of infrastructure with no major enhancements in the future.	Terrestrial and marine ecosystem functions Village stormwater infrastructure & economic activity Public health and freshwater budget	Prioritize drainage infrastructure improvements in Songsong using BMP principles and expanded flood extent projections Plan restoration efforts in Talakhaya using best available ENSO projections, avoiding activities during potential extreme conditions Diversify or enhance freshwater sources and water storage capacity

Event Class: Drought

Summary

While the previous event class concentrated on increases in precipitation, the potential for occasional dry conditions cannot be ignored, particularly as it relates to the dynamics at play in the Talakhaya area and the freshwater budget. The immense impact that historic dry conditions, and particularly the months following the 1997-1998 ENSO event, have had in Rota cannot be understated. Furthermore, projections for increased precipitation do not directly translate into a reduction in drought occurrences, and the projections themselves are not characterized by great certainty and model agreement, particularly in the CNMI (as opposed to other parts of West Micronesia such as Palau). Even expert opinion suggests that drought conditions should remain at the forefront of climate adaptation planning. As a well-known meteorologist in the Western North Pacific put it: *"The projections say wetter, but I've got a gut feeling that things are going to be drier"*. This contrasting prediction, and the increasing value of intuition and precaution under uncertain circumstances, should be kept in mind while viewing the table below, which simply summarizes the future conditions that models agree upon.

Future Change	**Projection**	**Projection Source**	**Future Magnitude**	**Vulnerability**
Precipitation Change	Precip. 2065: +9.9% Precip. 2090: +9.5%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5)	Decrease in Drought (slight increase in precip.)	Moderate
Temperature Change	Temp. 2065: +2.22°C Temp. 2090: +3.07°C	IPCC AR5, WG1		
Storm Change	Storm Frequency: -70% - +60%	Ying et al. 2012		

Events, Features & Historic Conditions

While annual precipitation could increase, this will likely take place in a climate with climbing average air temperatures and a possible reduction in the *quantity* of tropical cyclones. The potential for drought is therefore present throughout the future. If one were to reduce a given year's precipitation on Rota by nearly 50%, as was the case in 1998, wildfire becomes a major threat.

Conservation Area Wildfire (Event ID 4)

Magnitude	**Year**	**Period**	**Impact Type**	**Level of Impact**	**Historic Source**
67.63 in. precip (-44% annual normal)	1998	Jan - Dec, 1998	Habitat and Agricultural Damage	High	Rota Workshop Participant NCDC Guam WERI

"Wildfire was a problem all over the Island that year. It gets worse if people are lighting fires to hunt for the deer, especially if crops are bad."

In the wake of El Niño, fires destroyed large swaths of habitat across Rota, and reduced the stabilizing vegetation and root structure on steeper slopes. Agro-forestry was threatened, while ongoing ecosystem restoration efforts and targeted species recovery actions suffered major blows. Widespread wildfires had a fairly high impact across the island, especially in conservation areas, but the vulnerabilities to these dry conditions are quite variable due to potential for shifts in subsistence practices and community activities.

First and foremost, participants at the Rota workshop were quick to point out that intentional burning of habitat to assist in the harvesting of deer is a major factor in the spread of fire. Removing this behavior from the situation greatly decreases the chances that dry conditions will necessarily translate into issues with fire. That being said, this VA is not intended to promote acute behavior change, particularly at the individual decision-making level, but rather, to identify broader actions and developments that will support efforts to make the community as a whole less vulnerable. Assuming that intentional burns for harvesting of deer are the consequence of a food-related need at the subsistence level, then a direct adaptive response would be to explore avenues for greater food security and agricultural resilience. Resources to encourage this type of exploration should be leveraged, whether it's through the development of contingency planning for low harvest periods or pointed research into diversification and enhancement of existing agricultural practices using an educational extension body such as Northern Marianas College Cooperative Research, Extension, and Education Service (NMC-CREES). Regarding habitat loss in conservation areas, the adaptation suggestion for restoration efforts from the previous section still applies: plan for the investment of time and resources into re-vegetation based on consultation with data and expertise about cyclical climate extremes such as ENSO. This action represents one component of a broader move toward *adaptive management*, which could provide local resource managers the tools to adjust to climate extremes on a shorter temporal scale.

Event Class Summary

Average Historic Impact	**Future Change Magnitude**	**Relative Vulnerability**	**Impacted Systems**	**General Adaptation Options**
Moderate to High	Decrease drought potential assuming model projections for increase precipitation	Moderate, or potentially *low* with climate-smart conservation and agricultural practices implemented	Agriculture and associated food security Habitat restoration and targeted conservation initiatives	Target research into food systems resilience Embed sensitivity to upcoming extreme conditions into more adaptive restoration plans

Event Class: Coastal Erosion

Summary

One of the most prominent topics of discussion among Rota community members was the observation of coastal erosion, both long- and short-term. While Rota does not contain the extremely unstable shorelines that residents of Saipan cope with at Micro Beach and Managaha Island, there is still anecdotal and visible evidence of shoreline change at multiple locations and features on Rota. Even without a detailed summary of future conditions under new sea level and storm scenarios, the community expressed concern about current changes and impacts. The table below demonstrates future complications to these current trends. Without the adaptive option of easily relocating infrastructure and property, vulnerability to coastal erosion is likely to remain high.

Future Change	**Projection**	**Projection Source**	**Future Magnitude**	**Vulnerability**
Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012	Increase in Erosion (short and long term)	High

Events, Features & Historic Conditions

The greatest concentration of coastal erosion stories is situated along the west shoreline of Songsong Village, as well as along the northwest roadway and shoreline connecting Songsong with the airport and Rota Resort.

Songsong Coastal Erosion (Event ID 8)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
1948-1993 SLR: -0.98 mm/yr. 1993-2014 SLR: 7.23 mm/yr.	1950	1950 - 2015	Erosion, Public Access Loss	Medium	Rota Workshop Participants

"The shoreline has just continued to erode over the years. The beach has gotten much smaller in recent decades."

In general, the residents of Songsong have seen a loss of beach over the past 55 years. This impact is the likely result of several factors working in concert, including rising sea levels, extreme short-term alterations from tropical cyclones and westerly wave action, and a deficit in the sediment budget that normally allows for shoreline accretion. The direct implication of this is a loss of public shoreline, with relatively minor implications for accessibility, but the long-term consequence is essentially the continual loss of the primary natural buffer between the sea and existing infrastructure and private property. This impact raised significant concerns for some residents.

Disappearing Backyards (Event ID 9)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
1948-1993 SLR: -0.98 mm/yr. 1993-2014 SLR: 7.23 mm/yr.	1976	1976 - 2015	Erosion, Public Access Loss, property damage	Medium	Thomas Mendiola

"In 1976 Typhoon Pamela took away lots of the sand, up to my backyard. The sand never came back, and has been continuing to slowly disappear to the present."

The quote above speaks to a deficit in beach re-generation, but also brings the issue of coastal erosion closer to home (literally) for some residents of Songsong. The timeframe, over which the gradual loss of beach has occurred (40 years), is sufficient to establish evidence of a long-term trend, and unfortunately, in Songsong, space for relocation is limited. As sea levels continue to rise, private property will suffer impacts, and there is little that individual property owners can do but observe and attempt to attenuate the impacts of extreme short-term erosion (see Event Class "Surge").

The notion that few long-term adaptation responses exist aside from mitigating short-term extremes applies to public beaches as well. The west shoreline of Songsong offers some exceptional recreational opportunities, and as a focal point for access to a rich marine environment, this area can be perceived as a cultural asset as well.

Disappearing Beaches (Event ID 10)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
1948-1993 SLR: -0.98 mm/yr. 1993-2014 SLR: 7.23 mm/yr.	1970	1970 - 2015	Erosion, Public Acces Loss	Medium	Rota Workshop Participants

"In the 1970s the beach used to extend out to where the shipwreck is in the water, but has receded to the point where there's almost no beach at all."

It came as a bit of a surprise to workshop facilitators that the west shoreline of Songsong once featured beaches that extended to features such as the shipwreck referenced above (see spatial data and maps at data.dcrm.opendata.arcgis.com), which now require wading for access. While the historic level of impact is only listed as "medium", it does not take much imagination to extrapolate this trend over 50-100 years and visualize future shoreline positions.

One specific location where the visualization of future shoreline erosion issues might resonate strongly is at Rota's "Swimming Hole", which serves as a recreational asset for both residents and visitors.

Beach Loss at the Swimming Hole (Event ID 12)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
1948-1993 SLR: -0.98 mm/yr. 1993-2014 SLR: 7.23 mm/yr.	1970	1970 - 2015	Erosion, Public Access Loss	Medium	Rota Workshop Participants

"There are signs of beach retreat around the Swimming Hole. The beach has been getting smaller over the years."

Should sea level changes and isolated extreme events (storms) continue to drive the erosive trend that community members have observed at the Swimming Hole, questions of accessibility, and perhaps public safety will need to be taken into account. While future sea level scenarios are unlikely to completely submerge the shoreline and terraces that provide access to the Swimming Hole, a moderate increase in sea level *will* allow for additional wave energy and surge to enter the Swimming Hole over the existing reef structure. At the very least, increased turbulence within the Swimming Hole could detract from the relatively placid setting of this currently protective swimming area. In more extreme scenarios, the

Swimming Hole could constitute a safety hazard, as its reputation as a friendly recreational feature might not correspond with future water conditions. As a consequence, even if physical access to the Swimming Hole remains intact, access could be limited or degraded due to safety concerns.

Coastal Erosion at Teteto & Guata Shorelines (Event ID 25)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
1948-1993 SLR: -0.98 mm/yr. 1993-2014 SLR: 7.23 mm/yr.	1994	1994 - 2015	Erosion, Public Access Loss	Low	Rota Workshop Participant

"Since the mid-90s we've lost a lot of sandy beach up at Teteto and Gauta Beach sites. We think it's the rising ocean level."

In between Rota's Swimming Hole and Songsong are a series of other public beaches that remain popular with residents and visitors. As with the Swimming Hole, workshop participants noted the ongoing loss of beach along the Teteto and Guata shoreline. Interestingly, the anecdotes about beach loss in this area are situated within a time frame that has seen greatly increased rates of SLR in Western Micronesia. The temporal reference in the quote above is consistent with regional and local SLR data, reflecting SLR rates of 7.23mm/year beginning in 1993. While such extreme rates of SLR are not expected to continue over the next few decades due to regional variability in trade winds, the projected 50 and 75 year sea level scenarios still reflect a future in which the beaches at Teteto and Guata have further receded.

Two considerations must be taken into account when contemplating responses to these observed trends and future changes. First, there *is* capacity to adapt to periodic erosive events through the promotion of natural buffers. Second, while relocation of existing infrastructure and the development of permanent shoreline positions via extensive armoring or hardening is not likely due to limited resources, any future growth or development in low-lying areas and along the shoreline can take into account erosion-prone areas, and site-planning can address these challenges accordingly. These considerations are reflected in the summary table below.

Event Class Summary

Average Historic Impact	Future Change Magnitude	Relative Vulnerability	Impacted Systems	General Adaptation Options
Medium (omitting extreme short-term erosion covered in Event Class "Surge")	Increased erosion and loss of beach Consequent enhancement of coastal inundation potential	High, particularly with respect to a low adaptive capacity as far as major physical alterations to the shoreline are concerned	Public accessibility reduced and recreational assets impacted Limitations to future development or infrastructure enhancement Private property and residential features threatened	Near-term enhancement of natural vegetative buffers along sandy areas and strand ecosystems Regulatory responses for shoreline setback requirements Identification of long-term zones for safe growth and development, identification of locations where shoreline hardening may be necessary as a last resort

Event Class: Surge

Summary

Similar to coastal erosion vulnerabilities, the threat of storm surge is one that is likely to increase in the future. This heightened threat is a function of increased sea levels and potentially stronger storms working in concert. At the upper extent of the range of projections, Rota could experience three additional feet of sea level rise over the next 75 years. Even a modest storm surge of 2-3 feet at present would constitute a dangerous scenario with an additional 2-3 feet of total water level. Under such circumstances, the occurrence of a tropical cyclone with an intensity comparable to a 10 year storm would create storm surge levels and inundation impacts on par with a 25 or 50 year storm (assuming the storm took a track conducive to coastal inundation). While there is uncertainty surrounding the quantity of future tropical cyclones, and projections are now suggesting a possible reduction, the occurrence of *high intensity* storms may become more frequent. Regardless, consideration of extreme historical anecdotes, as well as unique, low-lying configuration of Songsong village, highlights very high levels of storm surge vulnerability for Rota.

Future Change	Projection	Projection Source	Future Magnitude	Vulnerability
Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18% Storm Precipitation: +5% - +30%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012	Increase in surge	Very High

Events, Features & Historic Conditions

An aerial tour of Rota’s shoreline will reveal particular stretches along the northwest side of the Island that appear different from the typical mix of limestone terrace, sand, and strand vegetation. These are stretches where the shoreline has been armored, and in some cases the road has been repaired as a direct result of storm surge damage and wave action.

Mochong Road Washout (Event ID 1)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
Surge: 10 feet Still Water Level (Apra, Guam): +1.9 ft.	2002	12/8/2002	Infrastructure Damage; Erosion	High	Rota Workshop Participant NCDC Storm Events Database Apra, Guam Tide Gauge

"The road was partially washed out at Mochong Beach, with approximately three feet of sand covering it in some areas."

While the focus of storm surge resulting from Typhoon Pongsona in 2002 was largely on Songsong Village, workshop participants noted that the coastal roads elsewhere were also subject to damage. The northwest side of Rota experienced less severe surge levels than Songsong, but they were still significant enough to badly damage sections of roadway, and according to some community members, deposit enough sand on the road to effectively block transportation and access between locations. This was the impact experienced along a stretch of road at Mochong Beach.

The response to this particular event resulted in expensive road repair, and the armoring of shoreline in some locations. While the transition from natural to hardened shoreline is not preferable in most cases, the high potential for future coastal erosion and surge impacts warranted this drastic, albeit site-specific alteration. As Rota moves forward in thinking about adaptation, the option of shoreline hardening should not be taken off the table completely, but rather kept as a response to specific geographic areas where destruction of critical infrastructure is imminent or extremely likely in the future and where "soft" or "green" interventions such as enhanced shoreline buffers or permeable embankments are not viable.

In some scenarios, however, damage to infrastructure and property is unavoidable, as was the case in Songsong during Typhoon Pongsona.

Songsong Coastal Flood (Event ID 2)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
Surge: 20 feet Still Water Level (Apra, Guam): +1.9 ft.	2002	12/8/2002	Infrastructure Damage; Property Damage; Erosion	Very High	Guard, et. Al 2003 NCDC Storm Events Database Apra, Guam Tide Gauge

"Afterward, you could walk outside and collect fish and (fruit) bats that had been washed out of the ocean and blown from the trees."

The storm surge that hit Songsong on December 8th, 2012 was unprecedented, and speaks to the unique geographical orientation and configuration of Wedding Cake peninsula. This geomorphic feature is perfectly situated to focus oncoming wave energy and surge at the center of Songsong village, which also happens to be the lowest-lying residential and business center on Rota. With post-storm damage assessments by the National Weather Service placing surge estimates between 18-22 feet on the isthmus, the ocean had nearly crossed the entire strip of land at the height of the storm, and the village was inundated from both sides due to the near passage of Pongsona's eye.

While any coastal village, municipality, or community in the world could be considered vulnerable to a surge of this extreme, several aspects of the village infrastructure contribute to high levels of vulnerability. These include a lack of evacuation routes to other parts of the island that avoid low-lying coastal roads, and stormwater infrastructure that already has difficulties in handling extreme precipitation events, and therefore compounds coastal inundation events. During this particular event, these vulnerabilities were clearly demonstrated.

The Marlin Wash Up (Event ID 3)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
Surge: 20 feet Still Water Level (Apra, Guam): +1.9 ft.	2002	12/8/2002	Property Damage	Very High	Guard, et. Al 2003 NCDC Storm Events Database Apra, Guam Tide Gauge

"After the storm there was a 200 pound blue marlin washed up in front of the Post Office."

Of all the anecdotes and past stories told during the Rota workshop, the most recurrent was the "Marlin Wash Up", in which Pongsona effectively relocated a large blue marlin from the ocean to the current location of the U.S. Post Office in town. While the threat of inundation by predatory fish is not explicitly addressed in this VA, the prospect of surge events of this magnitude increasing in the future is not to be taken lightly.

Although community members of Songsong have the option of preparing homes and businesses the best they can, and seeking shelter elsewhere before large storm events, there are critical facilities and infrastructure features that must remain such as the docking facilities and port on the east and west sides of the isthmus. These two features represent a major vulnerability in that their significant function in terms of commerce can easily be threatened by extreme events such as a major storm surge. Because Rota requires these critical facilities to function and because there are no alternative areas on the island suitable for port commerce, the adaptive capacity to relocate or significantly alter these structures is curtailed.

Rota West Docking Facility Damage (Event ID 27)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
Surge: 20 feet Still Water Level (Apra, Guam): +1.9 ft.	2002	12/8/2002	Infrastructure Damage	Very High	Guard, et. Al 2003 Rota Workshop Participant Apra, Guam Tide Gauge

"The Seaport facility was badly damaged during the surge, especially the docking facilities. It took over $100,000.00 in repairs for the dock repairs alone."

Rota East Docking Facility Damage (Event ID 28)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
Surge: 20 feet Still Water Level (Apra, Guam): +1.9 ft.	2002	12/8/2002	Infrastructure Damage	Very High	Guard, et. Al 2003 Rota Workshop Participant Apra, Guam Tide Gauge

"The East Dock area was badly damaged from the waves. Reconstruction costs were around three million."

While the repairs to the east and west docking facilities after Pongsona cost millions, the reconstruction of the east dock did constitute a step toward reducing the sensitivity of port infrastructure to future surge impacts. The facility was repaired to be stronger and more resilient, incorporating storm-proof structural designs. This example of a post-impact enhancement is a prime sample of an opportunistic adaptation approach, which streamlines climate-smart designs with pre-existing needs for repairs and upgrades. This type of approach is discussed further in the conclusion of this VA, but it should be noted that the opportunistic adaptation model is particularly relevant where future needs for repairs due to surge and storm impacts are inevitable.

Event Class Summary

Average Historic Impact	Future Change Magnitude	Relative Vulnerability	Impacted Systems	General Adaptation Options
High (Very high in the case of Pongsona)	Increase in surge height and resulting coastal inundation	Very High	Low-lying infrastructure and property Businesses and port commerce Transportation and Island circulation	Improve drainage capacity/infrastructure to reduce inundation time Identify priority sites for shoreline protection where loss of infrastructure is otherwise unavoidable Establish a suite of climate-smart or "storm-proof" design options for the Island to leverage in the event that future surge damage allows opportunities for enhanced repair.

Event Class: Storms & Cyclones

Events Summary

Despite the Rota Climate Vulnerability Workshop's coverage of diverse climate phenomena and climate impacts, the narratives that emerged were most often focused upon storm events. Due to the unique complications that sea level rise adds to storm surge, the latter storm impact was separated into its own event class. The remaining aspects of storms, including extreme winds and short-term rainfall, are covered here by several events resulting from Typhoons Chaba and Pongsona.

As mentioned previously, there is great uncertainty around the character of future storm activity, but model consensus suggests a possible decrease in frequency, but an increase of both intensity *and* precipitation. The shift in precipitation is particularly significant due to its impact on features that have already been described in Event Class "Precipitation". Taking into account the devastating impact from historic storms, and an absence of the resources required for major storm-smart upgrades to structures, future vulnerability is very high.

Future Change	**Projection**	**Projection Source**	**Future Scenario**	**Vulnerability**
Storm Change	Storm Frequency: -70% - +60% Storm Intensity: -3% - +18% Storm Precipitation: +5% - +30%	IPCC AR5, WG1 Ying et al. 2012	Increase in intensity Decrease in frequency	Very High

Events, Features & Historic Conditions

One of the primary focal points in planning for natural disasters and climate hazards is the quality and availability of shelter and evacuation options. While the CNMI's Public School System has been the primary provider in this respect, alternative shelter has been sought, including the large Tonga Cave adjacent to Songsong.

Tonga Cave - Storm Shelter (Event ID 11)

Magnitude	**Year**	**Period**	**Impact Type**	**Level of Impact**	**Historic Source**
Wind: 121 mph; gusts 150 mph Intensity: Category 3 Pressure: 965.5 hPa Surge: 20 ft.	2002	12/8/2002	Infrastructure Damage; Property Damage; Agricultural Damage; Erosion	Very High	Rota Workshop Participants Guard et. Al 2003

"The cave was used as a Japanese military hospital during WWII, but some used it as a typhoon shelter during Pongsona, and others (storms)."

According to residents, this cave has been used by neighboring village residents as refuge during the larger storms that have passed over Rota. A cave such as this would not be a likely candidate for a feature offering adaptive capacity in other locales, but according to narrative and community knowledge, this has traditionally been an important alternative shelter, especially if evacuation routes to other parts of the Island were blocked or impassable. A look at some of the numbers from Pongsona's passage illustrates the importance of leveraging such local solutions in emergency scenarios.

Guard et al. (2003) conducted an in-depth assessment of Typhoon Pongsona's passage, intensity, and impacts on islands throughout Micronesia. Much of the data describing this event is derived from their post-storm assessment methods, including extrapolation of data collected between the Rota Airport (north), and northern Guam (south).

While no eye passage occurred over the center of Rota, the eye wall passed near the south end of Rota, just offshore in the Guam-Rota Channel. Mean sea level pressure was recorded at the Rota Airport (965.5 hPa) and Guam (937.1 hPa), with pressures falling somewhere in the middle of this over Songsong Village. Winds ranged from 85 mph at the Rota Airport, to an estimated 121 mph (gusts to 150) over Songsong Village, near the Tonga Cave.

Though severe, these conditions are not uncommon for storms passing through the Marianas, and may manifest more prominently in the future under more extreme circumstances. While it is not advisable to recommend the usage of caves over concrete structures for shelter in the event of a storm like Pongsona, the principle behind the Tonga Cave story is one that holds value for adaptation: Leverage local knowledge and traditional responses that have served the community well in the past. This example highlights that primary emergency infrastructure and services may not always be accessible, and it is important that the existence of alternative options is made known throughout the community. As the following event demonstrates, relocation to a storm-proof shelter whether it be a school or a cave, is preferable to staying put.

Teneto Village – A-Frame House Collapse (Event ID 6)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
Wind: 121 mph; gusts 150 mph Intensity: Category 3 Pressure: 965.5 hPa	2002	12/8/2002	Property Damage	Very High	Rota Workshop Participant Guard, et al. 2003

"My A-Frame in Teneto Village collapsed. We had to rebuild completely."

"Most of the Island ended up with no power or electricity from six months to a year."

The collapse of a house was an experience many residents of Rota shared in the wake of Pongsona, but for the purposes of this VA, it is important to concentrate on the *response* to this destruction. While some residents opted for concrete in their efforts to relocate or rebuild, many simply rebuilt to the standards of the pre-existing structure, which in some cases included tin or corrugated metal as the primary building material. Community members have noted that reconstruction of residences that are no more storm-proof than their predecessors is, to some degree, the result of having limited resources and assistance in the rebuilding process, not a lack of foresight.

In recognizing the problems that a lack of resources can pose during a reconstruction period, those responsible for hazard mitigation and adaptation planning in the CNMI may wish to place requests or conditions on post-storm assistance, requiring that reconstruction be carried out to higher design standards than those that were in place prior to the storm, and ensuring resources are available to support this aim.

While there are specific adaptation and mitigation options for Rota to implement in dealing with property damage and at-risk infrastructure, natural features create a more difficult context for adaptation. Flooding of agricultural land, for example, is not necessarily the product of poor drainage design or unsound resource management practices, but rather the existence of a naturally exposed and sensitive landscape. As Niebes, near the Rota Airport, is a prime example of a naturally vulnerable area, with no intrinsic adaptive capacity.

As Niebes Flood During Typhoon Chaba (Event ID 24)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
20.8" Precipitation 958 mb sea level pressure	2004	8/22/2004	Agricultural Damage; Residential Damage	Medium	Rota Workshop Participant

"During Typhoon Chaba there was a major flood in As Niebes. Over 20 hectares of pasture land was flooded. The place looked like a huge lake."

Typhoon Chaba released over 20 inches of rain during its passage over Rota, flooding a large swath of pasture and agricultural land. This is a fairly minor impact in comparison to the devastation experienced in Songsong from storm surge and extreme winds; however, the story is significant as it demonstrates an inherent vulnerability of a relatively small island: limited space for competing land uses. The community on Rota is challenged with effectively balancing the use of land for subsistence agriculture, conservation, and potential future development and growth. While the agricultural land in As Niebes recovered from Chaba, and was sufficient for grazing purposes in a reasonable time frame, a more intensive agricultural use or the existence of residential structures in that same area would have translated into major losses and damage from Chaba's flooding.

As the CNMI continues to grow and prospects for new development and investment evolve over the next decade, the careful planning and placement of specific land uses – especially with respect to possible displacement of previous land use – will be critical to ensure that additional vulnerabilities aren't introduced to the community. When placed in the context of a changing climate where precipitation amounts in storms are projected to increase, it might be useful for the community to re-examine its flood-prone areas and evaluate alternative future scenarios should new land uses be introduced.

Event Class Summary

Historic Impact	Future Change Magnitude	Relative Vulnerability	Impacted Systems	General Adaptation Options
High to Very High	Increased storm intensity and precipitation rates Decreased storm frequency	Very High, especially without storm-smart planning or structural enhancement implemented	Private and public properties Residential and business structures Agriculture and community land use System demand on emergency services	Establish alternative emergency response plans based on local-level knowledge Apply an "enhancement" rule to the use of disaster relief/reconstruction resources and develop mechanisms to support recovery and adaptive capacity Utilize lessons-learned from previous storms in planning for growth or development

Summary of Rota Vulnerability

In assessing Rota's climate vulnerabilities, and placing these vulnerabilities within a framework of broad categorization and high-level guidance, it's important to consider that the community will continue to respond to extreme climate events and long-term shifts in the climate autonomously, without federal or local government intervention or major policy changes. Autonomous adaptation is a phenomenon that has demonstrated short-term effectiveness in other Pacific Islands; however, this type of adaptation is often reactive. It is an answer to damages already incurred, and often does not consider future climate scenarios or stressors or the importance of protecting and promoting critical functions of human and ecological systems.

The value in reviewing the table below, which summarizes both climate vulnerabilities and broad guidance looking forward, lies in the ability to plan for the future, and reduce future impacts at a systems level. Actions taken on individual properties, while helpful as fragmented adaptive options, can benefit from policy supplementation when supported by leadership within appropriate governmental bodies. It is with this in mind that the following summary places its feet inside the doorway of adaptation action planning.

Rota Summary Table

Changes in Impact	Vulnerability Ratings	Impacted Systems	General Adaptation Options
Precipitation: General increase in water security (assuming appropriate infrastructure), but elevated impacts from flooding & erosion.	**Low**, assuming precipitation extremes (wet and dry) are not exacerbated, and infrastructure is updated **Moderate**, assuming projected rainfall increase manifests unevenly, and without adaptive management implemented	Reduced terrestrial and marine ecosystem function where erosion and run-off poses a threat Increased strain on village stormwater infrastructure & potential impact on economic activity Implications for public health and freshwater budget	Prioritize drainage infrastructure improvements in Songsong Plan restoration efforts in Talakhaya using best available ENSO projections, avoiding activities during potential extreme conditions Diversify or enhance freshwater sources and water storage capacity
Drought: Decrease drought potential assuming model projections for increased precipitation transpire.	**Low**, assuming precipitation increases and climate-smart conservation and agricultural practices implemented **Moderate**, if precipitation increases in the form of isolated extremes.	Potential for both threats to, *and* opportunities for enhancement of agriculture and associated food security Some additional strain on habitat restoration and targeted conservation initiatives	Promote and target research into food systems resilience and agricultural diversification, possibly through NMC-CREES and USDA resources Embed sensitivity to upcoming extreme conditions and cyclical climate phenomenon into adaptive restoration plans, such as updates to Conservation Action Plans Consider supporting development of water-efficient irrigation / delivery systems
Continued on following pages…			

Changes in Impact	Vulnerability Ratings	Impacted Systems	General Adaptation Options
Coastal Erosion: Increased erosion and loss of beach Increased coastal inundation potential	**High**, with sea level rise and potential for more intense storms exacerbating existing erosion trends	Resident and visitor accessibility to recreational and cultural features reduced Additional limitations to future development, and risky investment in future infrastructure enhancement (e.g. road stabilization) around low-lying areas Private property threatened in select locations around Songsong	Promote near-term enhancement of natural vegetative buffers along sandy areas and strand ecosystems, including supporting or incentivizing soft protection actions taken by individual landowners Identify and adopt adaptive regulatory responses for shoreline setback requirements and expanded buffers in erosions and flood-prone areas Identify long-term zones for safe growth and development outside of potential high-risk inundation zones Identify locations where shoreline hardening may be necessary as a last resort
Storm Surge: Increased total water level under storm conditions and consequent surge elevation Increased extent and duration of coastal inundation due to higher sea levels and potential for "backwater" effect in a few low-lying areas	**Very High**, assuming moderate to upper-end of 50 & 75 year sea level projections, and a lack of resources for relocation of primary, low-lying settlements and infrastructure	Low-lying infrastructure and property inundated more severely Businesses and port commerce interrupted to a greater extent under storm conditions, albeit potentially less frequently Potential impairment of low-lying transportation routes and general island circulation, with consequences for critical service availability under emergency storm scenarios	Plan and implement improvements to drainage capacity and stormwater infrastructure to reduce inundation duration Identify priority sites for shoreline protection and enhancement through "soft" or "green" infrastructure as well as areas where loss of infrastructure is unavoidable without "hard" protection options Prioritize a site-scale storm surge and sea level rise model for the Rota East/West docking facilities in future research endeavors Establish a suite of "storm-proof" design options for the Island to leverage in the event that future surge damage allows opportunities for enhanced repairs, climate-smart building standards, and post-storm re-design, as well as funding mechanisms to support rapid recovery and restoration Encourage or require new development and infrastructure projects to incorporate "storm-proof" design elements that consider 100-year storm events and the upper range of sea level projections

Changes in Impact	Vulnerability Ratings	Impacted Systems	General Adaptation Options
Storms and Cyclones: Increased storm intensity and precipitation rates, consequent increases in flooding potential and wind damage Possible decrease in storm and cyclone frequency	**Very High**, especially without storm-smart planning or structural enhancements implemented. Vulnerability levels may increase with projections for decreased storm frequency if natural and built systems *over-adjust* to interim periods of calm	Private and public properties and structures threatened by enhanced flooding and wind damage Business and commerce facing longer interruptions in a future scenario with stronger storms Increased strain on agriculture and subsistence land use in years with more storms Increased system demand on emergency services and backup infrastructure, particularly if Rota experiences growth or development in upcoming decades	Establish alternative emergency response plans based on local-level knowledge of opportunities, needs, and deficiencies highlighted in past scenarios Apply an “enhancement” rule to the use of disaster relief/reconstruction resources, wherein storm-smart design standards are codified and applied during recovery operations and that develop mechanisms to support recovery and adaptive capacity Standardize storm-smart building and construction practices for any future development, and require climate-smart investment from developers

Tinian Climate Vulnerability

Analogs and Vulnerabilities

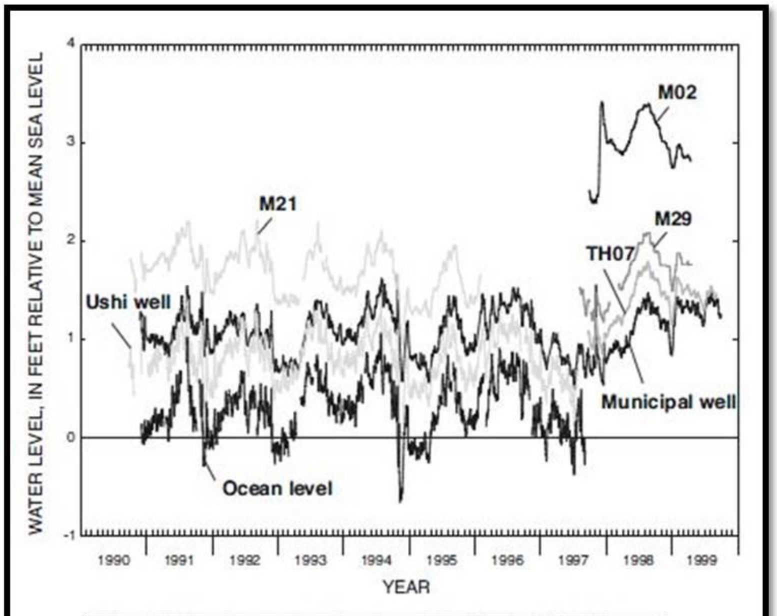
The sections below briefly summarize the historic events and vulnerable features that emerged as common topics of discussion or participatory mapping during the climate vulnerability workshop on Tinian. Events and features are organized around a crude classification scheme of climate phenomena (e.g. “precipitation”, “drought”, “ocean chemistry”, etc.). Each summary of climate events by *class* is followed by a small overview table that outlines the general expected changes in that event class, systems or features that could be impacted in the future, and broad guidance on how to adapt to these changes.

Event Class: Precipitation

Summary

Precipitation, along with Tinian’s freshwater budget and supply, constitute some of the Island’s most significant focal points for potential vulnerabilities. Tinian has significant community investments and reliance on its agricultural resources. It is also facing growth and development from both foreign tourism interests and the U.S. military. These characteristics, viewed in conjunction, create a scenario in which competing demands on both the quantity *and* the sources of water must be taken into account. In addition, impending shifts in land-use around much of the island may re-configure the arrangement of impervious surface, and in some cases localized drainage patterns and consequent run-off during heavy precipitation events. In light of this, Tinian will need to plan for potential future scenarios under both wet and dry conditions.

Complicating matters further, Tinian differs from Rota in that its freshwater sources and wells are based on the Island’s basal lens, which has varying depths and thickness based not only on precipitation patterns, but sea levels as well. In examining well records, almost all of the variations in water level in the monitored wells appear to be directly in response to variations in ocean level, with some slight additional variation due to heavy rainfall (USGS 2002). Consequently, any efforts to plan for climate adaptation on Tinian must take a more holistic systems approach, considering combinations of multiple factors (e.g. sea level rise + precipitation frequency).



Ground water levels and ocean level on Tinian, 1990-1999
Figure from USGS 2002

The following events that are summarized under the event class “Precipitation” focus on the issues of run-off, non-point source pollution, and nuisance flooding. These historic events are emphasized here as the general 50 and 75 year projections for rainfall indicate increases in annual precipitation. Due to the comparatively large impact that *dry* conditions (see event class "Drought") have, the future vulnerability to increased precipitation in the table below is categorized as "low". It is important to note that "Low" vulnerability does not translate to "negligible".

Future Change	**Projection**	**Projection Source**	**Future Magnitude**	**Vulnerability**
Storm Change Precipitation Change	Precip. 2065: +9.9% Precip. 2090: +9.5% Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5) IPCC AR5, WG1 Ying et al. 2012	Increase in nuisance flooding	Low

Events, Features & Historic Conditions

While excess rainfall is preferable to a precipitation deficit, extreme rainfall rates have led to some flash flooding and "nuisance ponding" in the San Jose area.

Nuisance Ponding in San Jose (Event ID 13)

Magnitude	**Year**	**Period**	**Impact Type**	**Level of Impact**	**Historic Source**
1970 - 1980: 29 tropical cyclones within 100 nm. (27.5 is decadal average for period 1950 - 2010; 18 for 2000-2010)	1970	1970 - 1980	Temporary flooding	Low	Tinian Workshop Participants

"Back in the 70s these places would collect water during rain storms, and repeatedly flood. This still happens, but not as extreme."

According to Tinian community members, this temporary flooding is often associated with the near passage of large storms or extended periods of rain during the monsoon season, and has not had a major impact on daily business. In addition, the ponding was cited as more of a problem in the 1970s and early 1980s than at present. Nevertheless, as the U.S. military plans for substantial build-ups on the northern two-thirds of the Island, any additional growth or development will likely be concentrated in or around San Jose. This new growth will need to be sensitive to any actions that could exacerbate existing areas of temporary flooding, especially with projected increases in precipitation.

Impending growth and changes in land uses will also pose implications for the amount of impervious surface in some areas, and the consequent potential for additional stormwater run-off.

Toxic Run-Off at Leprosy Beach (Event ID 20)

Magnitude	**Year**	**Period**	**Impact Type**	**Level of Impact**	**Historic Source**
NCDC (90% Complete Data for SIA): 2009-2014: in./yr 76.17 in./yr	2010	2010 - 2015	Public Health Concerns, Reduced Marine Ecosystem Function; Threat to Subsistence/Fishing	Medium	Tinian Workshop Participant NCDC Annual Climate Summaries, SIA

"The beach and near-shore waters become very toxic after it rains. There is run-off and bo'bu from the landfill and where the leper bodies were dumped long ago."

Community members have stated that the beaches and adjacent shallow waters around "Leprosy Beach" (see maps and spatial data online at data.dcrm.opendata.arcgis.com) become "toxic" during large precipitation events. The groundwater seepage points along the shoreline, referred to locally as "bo'bu", allow for any contaminants in the adjacent landscape to enter the near shore waters, causing negative impacts for both public health/recreation, and the marine ecosystem. The dump site is also in close proximity to this area, creating additional concerns among the community as to what might be emanating from the bo'bu.

While this particular source of possible contamination at Leprosy Beach was referenced explicitly, Tinian workshop participants also cited issues with the freshwater outflows from other bo'bu as well.

Non-Point Source Pollution at Tinian's Bo'bu (Event ID 21)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
Saipan 46 yr. (1954-1999) rainfall database as proxy: 1970-1980: 68.81 in./yr 1981-1990: 80.04 in./yr 1991-2000: 66.48 in./yr NCDC (90% Complete Data for SIA): 2000-2014: 74.89 in./yr	1970	1970 - 2015	Public Health Concerns, Reduced Marine Ecosystem Function; Threat to Subsistence/Fishing	Low	Tinian Workshop Participant Lander and Guard, 2004 Lander 2004 NCDC Annual Climate Summaries, SIA

"The Chamorro word for these sites is 'Bo'bu'. It's a freshwater outflow from groundwater into the ocean and along the beaches. In some areas the bo'bu are often contaminated."

The spatial data resulting from Tinian's participatory mapping activities generated a series of points symbolizing bo'bu around the Island, including sections of shoreline along the northern third of Tinian, directly adjacent to proposed military training and live-fire sites (DOD 2015). Under potential future precipitation scenarios involving increased rainfall, Tinian could expect to see additional outflow of any contaminants that leach into the groundwater near these points. This would be the consequence of both increased contaminant loads and increased flow or groundwater pressure to transport those loads.

Placed in the context of more extreme climate phenomena such as tropical cyclones or extended sea surface heating, the implications of increased precipitation (e.g. nuisance ponding, run-off, etc.) are relatively minor. However, the human-induced changes taking place on Tinian compound even the slightest shifts in climate. Tinian's agricultural resources, for example, are expected to undergo a major shift due to the loss and displacement of a large percentage of prime farm and pasture land from military activity. This increased strain on agricultural systems means that any opportunities to leverage additional precipitation to support new agricultural operations will be critical. In addition, newly proposed development will provide opportunities to enhance stormwater infrastructure, and consequently be a crucial opportunity to implement identified best management practices and prepare for more severe conditions in future storms.

Event Class Summary

Average Historic Impact	Future Change Magnitude	Relative Vulnerability	Impacted Systems	General Adaptation Options
Low, with only minor, temporary interruptions to daily business, and fairly isolated release of pollutants in the ocean	Increase in precipitation, with a potential increase in run-off, but a concurrent increase in opportunities to leverage additional water supply	Low, assuming military activity and future development implement appropriate stormwater controls and precipitation increases at a fairly stable rate	Increased stress on shoreline and nearshore marine environments adjacent to bo'bu Increased pressure on stormwater and drainage infrastructure Increased opportunities for agricultural innovations and resiliency	Incorporate climate-smart stormwater management practices in new growth and development regulations Work with USDA and NMC-CREES to leverage the potential for growing freshwater resources and availability Emphasize groundwater and contaminant mitigation requirements for U.S. Military activities and large development proposals

Event Class: Drought

Summary

One of the most significant climate extremes experienced on Tinian over the past couple decades came in the form of drought. While climate workshop participants on Rota concentrated largely on the impacts of past storms such as Pongsona, many of the participants on Tinian felt that the drought experienced in the wake of El Nino in 1998 resulted in the most severe impacts to the community.

Following the strong ENSO event in the latter half of 1997, a severe drought set in among islands throughout Micronesia, and as a result, Tinian received less than half of its average annual rainfall. While the water supply on Tinian provided water for human-use without disruption throughout the drought, anecdotal evidence suggests that had the drought persisted even a couple weeks longer, strict rationing may have been necessary. Furthermore, while the villages of Tinian were able to squeak by with the available water, the Island's agricultural lands and livestock suffered drastically. This particular hardship framed the events and features highlighted under this event class.

It should be noted that in the summary table of future conditions for drought (following page), the “future magnitude” suggests a possible decrease in drought conditions, yet the “vulnerability” level remains high. This is due to a couple important considerations, including (1) uncertainty surrounding the manner in which precipitation *could* increase, as well as (2) current shifts in growth and land-use that may leave Tinian more vulnerable from a socio-economic perspective than it previously was.

(1) In reviewing projections for future scenarios, a potentially troubling circumstance emerges wherein precipitation increases by roughly 9 to 10%, yet it does so through *fewer, more intense* storms, with up to 30% more rainfall from tropical cyclones. Having additional precipitation is not necessarily a desirable climate condition if it comes in the form of intense, sporadic events. Such a change in precipitation patterns would not accomplish much in the way of removing the threat of dry conditions during periods between storms, as current water capture capacity would likely not be sufficient to store additional input from these events.

Future Change	**Projection**	**Projection Source**	**Future Magnitude**	**Vulnerability**
Precipitation Change	Precip. 2065: +9.9% Precip. 2090: +9.5%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5)	Decrease in Drought (slight increase in precip.)	High
Temperature Change	Temp. 2065: +2.22°C Temp. 2090: +3.07°C	IPCC AR5, WG1		
Storm Change	Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	Ying et al. 2012		

(2) Even with no change in precipitation patterns or quantity, the significant shifts in land use that are currently taking place on Tinian will remove community access to extremely important grazing areas and feed supplies. In addition, the displacement of agricultural activity to the southern end of the island means that land uses will be competing for limited space. If growth continues outward from San Jose and the Tinian Dynasty area over the next few decades there may be conflict with relocated grazing lands. A closer look at some of the events and features involved in the 1998 drought illustrates the potential for such conflict.

Events, Features & Historic Conditions

Lake Hagoi Emergency Cattle Feed (Event ID 5)

Magnitude	**Year**	**Period**	**Impact Type**	**Level of Impact**	**Historic Source**
43 in. precip (-48% annual normal)	1998	Jan - Dec, 1998	Agricultural Damage; Municipal Water Shortage	Very High	NMC-CREES Tinian Workshop Participant USGS Guam WERI

“[In] 1998, there was nothing for months. Cattle were just falling down because no feed, and it was all dry. The heat was so intense.”

“The first limiting factor on cattle is food, not water. Those cattle were starving to death. It affected the whole herd. There was maybe a 75 to 100% loss rate.”

"We had to cut a tractor path to the center of Lake Hagoi to harvest on a daily basis."

At its peak, the 1998 drought eliminated vegetative growth on Tinian, effectively cutting off the feed supply for Tinian’s livestock. The normal grazing areas had no more utility, and as cattle grew weak from starvation and mortality rates began to increase, emergency feed supplies were sought. Community members on Tinian, and especially members of the Tinian Cattlemen’s Association, were able to recall desperate acts to fend off livestock mortality, including the harvesting the vegetation of the Lake Hagoi wetland as emergency feed (see spatial data online).

Even with this emergency feed supply, members of the Tinian Cattlemen’s Association placed estimates of livestock loss between 75 and 100%. A limited alternative supply of livestock feed could constitute a vulnerability in and of itself; however, Tinian’s prospects for adaptation to future drought are further complicated by the fact that the entire area that was harvested in this emergency is proposed to become part of a military training facility, and, under this proposal, would be generally inaccessible to the community (DOD 2015).

Without access to the Hagoi wetland, significant additional pressure will be placed on the Marpo Wetland and the surrounding lowlands for drought relief in the future.

Marpo Wetland Drought Relief (Event ID 14)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
43 in. precip (-48% annual normal)	1998	Jan - Dec, 1998	Agricultural Damage; Municipal Water Shortage	Very High	NMC-CREES Tinian Workshop Participant USGS Guam WERI

“During the drought water disappeared from all the temporary wetlands, but the Marpo Wetland and well retained just enough for us to get by. All the other areas dried up though."

The quote above illustrates the importance of the Marpo Wetland area. As Tinian’s most reliable water supply, the environmental health and appropriate withdrawal of water from this feature is critical in seasons with below-average precipitation. As Tinian workshop participants discussed this feature in the context of the 1998 drought, it became apparent that the water supply there was sufficient to support *only* the existing human uses during this extreme period. This means that under similar drought conditions, the Marpo well may not be able to handle the additional pressures placed on it by future land use demands.

As demand for water may increase in the future, it may become increasingly likely that supplies could be affected by circumstances other than extreme drought. Shortages could easily manifest several decades in the future due to the combination of saltwater intrusion from ongoing pumping during seasons with subpar precipitation and consistent increases in sea level, leading to unacceptable salinity content in pumped water. The potential for this situation is justification enough to devote resources toward diversifying, or at least supplementing primary water distribution on Tinian over the next couple decades. In the meantime, Tinian's agricultural community may wish to develop a strategic plan for community-based management of existing and *new* grazing lands given that much of the existing management scheme involves lands that will be inaccessible if the Department of Defense's proposed live-fire training activities are implemented on Tinian (DOD 2015).

Tinian's Emergency Grazing Lands (Event ID 22)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
43 in. precip (-48% annual normal)	1998	Jan - Dec, 1998	Agricultural Damage; Municipal Water Shortage	Very High	NMC-CREES Tinian Workshop Participant USGS Guam WERI

"During the (1998) drought we had to use our emergency grazing lands. These are areas that we don't normally graze on, but the cattle had used up our primary grazing land. All the emergency grazing land is in areas that the military wants to use."

While effective adaptation will require coordination among the community, especially with regard to schemes for grazing and land-use prioritization, a targeted discussion with the U.S. Department of Defense (DOD) is also warranted to negotiate conditional assistance to farmers and cattlemen in seasons of anomalously low rainfall. As military build-up would significantly reduce the emergency supply of grazing land and cattle feed for future droughts, it is essential that any mitigation on the part of DOD under the current Commonwealth of the Northern Mariana Islands Joint Military Training (CJMT) proposal (DOD 2015) take into account the near-certain mortality of the cattle herd in the absence of these lands.

Mitigation and responses to a climate-related disaster such as this also offer opportunities beyond recovery and compensation. Lessons learned about climate vulnerabilities should be perceived as opportunities for applied research and problem solving. The 1998 drought was severe enough to require FEMA assistance and funds to help mitigate the disaster, and the hardship inspired CUC to enter into a cooperative study with the U.S. Geological Survey (USGS) to investigate the groundwater resources and freshwater budget of the Island (USGS 2002). Given that over 10 years has passed since this study, it might be wise to re-visit the groundwater investigation, informed by over a decade of additional well data, and increasingly refined projections for future rainfall scenarios. This updated information, combined with revised community planning for emergency water and agricultural resources, would provide a foundation to begin adaptive planning to address potential droughts in the future.

Event Class Summary

Average Historic Impact	Future Change Magnitude	Relative Vulnerability	Impacted Systems	General Adaptation Options
High to Very High, with only limited emergency response plans in place for drought conditions	Increase in annual precipitation, with a potential decrease in drought, though cyclical climate phenomena will likely continue to produce occasional dry conditions	High for the community overall, and Very High in the case of Tinian's agricultural systems, which are losing resources that are necessary in drought conditions	Potential public health hazard with extreme heat and limited water availability Severe impacts on agricultural productivity and livestock management	Diversify and enhance freshwater sources and distribution system, including exploring options for rainwater harvest and improved systems efficiency Establish community-based management plans for new agricultural land uses Update groundwater studies and research on freshwater budget, including consideration of latest climate projections

Event Class: Coastal Erosion

Events Summary

Of the three main populated islands in the CNMI, Tinian is most likely to be the least vulnerable to coastal erosion. Unlike its sandy, lagoon-fringed neighbor to the north, Tinian's shoreline consists primarily of elevated limestone terraces, and pocket beaches with protective fringing reef. In addition, the most sensitive shoreline on Tinian (near the port and Taga Beach area), is exposed primarily to the South-Southwest, which is the least common direction for swell energy and erosive wave action in the CNMI. In light of the coastline's protected character, chronic coastal erosion has rarely proved itself to be a major issue on Tinian.

Unfortunately, the same cannot be said for short-term erosive events such as tropical cyclones or wave action from "westerlies". In the uncommon event that there is wave action or storm surge from the south, west, or southwest, the sand beaches near Taga and the Seaport can be subjected to powerful erosive forces. As the table below suggests, future increases in sea level and storm intensity will likely make such erosive events more severe, and thus translate into high levels of vulnerability.

Future Change	Projection	Projection Source	Future Magnitude	Vulnerability
Sea Level Rise	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft.	U.S. Army Corps - SLR Calculator 2014 (high curve)	Increase in Surge	High
Storm Change	Storm Frequency: -70% - +60% Storm Intensity: -3% - +18%	IPCC AR5, WG1 Ying et al. 2012	Increase in Erosion	

Events, Features & Historic Conditions

While the primary coastal erosion risk that Tinian faces is short-term in nature (e.g. isolated storm events), it is possible for periods of higher sea levels or elevated storm activity in the region to create conditions conducive to long-term erosion. Tinian workshop participants identified the early 1990s as one of those periods, citing visible deterioration of the Tinian Seaport breakwater during that time.

Seaport Breakwater Erosion (Event ID 17)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
1990 - 1998: 19 Tropical Cyclones within 100 nm. (27.5 is decadal average for period 1950 - 2010; 18 for 2000-2010)	1990	1990 - 1998	Infrastructure Damage; Threat to Commerce	Medium	Tinian Workshop Participant

"In the early 90s there was a lot of erosion along the breakwater. There was lots of erosion in general, and the tables that used to be on dry land are now in the water or covered in sand."

The early 1990s was identified on both Tinian and Rota as a time in which coastal erosion began taking its toll on the shoreline. This coincided with local rates of sea level rise that *tripled* between 1990 and 1995. Whether the rapid acceleration of sea level rise and onset of coastal erosion impacts are connected is uncertain; however, future sea level scenarios of 2-3 additional feet would almost certainly threaten the shoreline and recreational features around the Tinian Seaport and Taga Beach.

Although this rapid acceleration in sea level has been attributed to regional decadal climate phenomenon and is not expected to persist, the potential for damages to Tinian's only sheltered venue for ocean commerce and the surrounding tourism assets, poses serious implications. Given current aspirations for building tourism in this area, and re-establishing greater connectivity between Tinian and Saipan via ferry, investment in enhanced Seaport protective features may serve Tinian well in the future. This enhancement does not have to come in the form of a major overhaul of the existing structure, but rather as a phased repair plan that incorporates long-term planning to address future erosion impacts.

Outside of the Seaport there is little in the way of critical shoreline infrastructure. Perhaps the greatest threat is simply to the current appearance of the open, sand beaches in the area. Future sea levels may reduce some accessibility to the pockets of sand around Taga Beach, but elsewhere the simple promotion of natural shoreline stabilization and "managed retreat" may suffice to maintain these desirable features.

Event Class Summary

Average Historic Impact	Future Change Magnitude	Relative Vulnerability	Impacted Systems	General Adaptation Options
Medium near the Seaport/Harbor, and low elsewhere	Increase in erosion processes due to sea level rise and increased storm intensity	High vulnerability around the Harbor and Taga Beach area; low elsewhere	Possible increased damage and stress on Seaport infrastructure Altered beach aesthetics along the shoreline near San Jose and Tinian Dynasty	Conduct post-storm damage assessments along sensitive shorelines and Seaport breakwater to identify priorities for protective enhancement Preserve existing beach/strand vegetation in the San Jose and Taga Beach area, and promote natural buffers to periodic wave action Establish a managed retreat strategy to accommodate future sea level rise and erosion processes

Event Class: Surge

Events Summary

While coastal erosion may not pose a chronic threat to Tinian's coast, the potential for storm surge from tropical cyclones is a constant possibility throughout the year. The event classes of "coastal erosion" and "surge" are separated here as they differ by temporal scale and impact severity. Surge, as demonstrated all too well on Rota, has the capacity to incur extensive damage in a very short amount of time. Whereas coastal erosion may lead to loss of beaches and gradual impacts to shoreline infrastructure, surge overwhelms beaches and shoreline infrastructure, combining short-term erosive forces with the muscle of floodwaters. While this type of event generally requires a strong storm to pass in close proximity to the island, the destructive potential of this rare occurrence, combined with a lack of expectations *for* such an occurrence, creates high levels of vulnerability. The projected changes in sea level and storm behavior highlighted in the table below underscore the need to plan for such events, as their severity will only increase in the future.

Future Change	Projection	Projection Source	Future Magnitude	Vulnerability
Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012	Increase in Surge Increase in Erosion	High

Events, Features & Historic Conditions

Typhoon Paka's passage through the Mariana Islands in December of 1997 created exceptional wave action and moderate storm surge around Tinian Harbor. Although the eye passed closer to Rota and Guam, residents on Tinian noted significant impacts around the Seaport.

Typhoon Paka Floating Dock Surge (Event ID 18)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
(Rota Summary) Winds: 115 mph Intensity: Category 5 Pressure: 948 mb	1997	12/16/1997	Infrastructure Damage; Threat to Commerce	Medium	Tinian Workshop Participant

"During the storm surge from Paka all the floating docks were lifted up out of the harbor and washed onto the land. They were littered on dry land after the storm passed."

The surge and wave set-up caused by Paka on the south end of Tinian was capable of overcoming the Tinian breakwater, passing through the protected harbor, and pushing the secured floating docks up to 50 yards inland. Although there are no residential structures or businesses that could be inundated in this immediate area, this event demonstrated a vulnerability in that community members had not anticipated such an intense scenario. A lack of expectations often translates into lack of preparation, and consequently high levels of exposure and sensitivity during storm events.

As proposals to append new attractions or infrastructure to the area around the Seaport and Taga Beach trickle in, it is imperative that there be consideration of potential surge impacts in a future of higher sea levels and stronger storms. In 2012 the CNMI was introduced to a foreign investor's proposal to create a scale replica of the *Titanic*, permanently moored in Tinian Harbor as a tourist hotel and resort. A storm similar in strength to Paka, passing 80 miles north of its actual track near Rota, would place an ill-fated floating feature such as this in great peril, especially in a future with higher sea levels. Should the Tinian Seaport and Commonwealth Ports Authority secure resources to repair or *enhance* the Tinian breakwater, it may be both beneficial and cost-efficient to combine this work with sophisticated storm surge modeling at a fine resolution, with particular attention paid to the influence of future sea level rise scenarios and possible lower pressure in storm centers. Results of such an inquiry would be immensely useful in planning future growth and development in an area of significant cultural, recreational, and economic importance.

Event Class "Surge" Summary

Average Historic Impact	Future Change Magnitude	Relative Vulnerability	Impacted Systems	General Adaptation Options
Medium, considering infrequent occurrence	Increase in surge height and extent due to sea level rise and raised storm intensity.	High, particularly with projected increases in sea level, and potential for lower pressure in cyclones (temporarily raising sea level further). High vulnerability assumes no additional adaptive actions are taken.	Increased exposure of shoreline cultural and recreational features to surge Increased exposure of Seaport and breakwater to wave energy Potential safety concerns for boaters and any future ferry service or development in/near surge inundation areas	Allocate resources from future investments in the Seaport/Harbor toward breakwater enhancement and repair Prioritize a site-scale storm surge and sea level rise model for the Seaport and Taga Beach areas in future research endeavors to identify high risk areas and adaptation opportunities and priorities Avoid development of structures in high-risk areas to keep people and infrastructure out of harm's way Focus efforts on enhancing shoreline buffers to reduce risks due to storm surge and sea level rise

Event Class: Ocean Chemistry

Events Summary

While climate change impacts to shoreline and terrestrial features pose some significant challenges for planners and resource managers, it is the CNMI's marine resources and coral reef ecosystems that have the fewest options for direct adaptation actions. Furthermore, the current trends and future projections for changes to ocean chemistry, including sea temperatures and pH, have a relatively certain and unfortunate trajectory in comparison to atmospheric phenomena such as precipitation and storms. While community members on Tinian have already noted moderate impacts to the near shore environment and reef systems from periods of extended, anomalously high sea surface temperatures, these conditions are expected to persist for greater durations of time, and occur more frequently in the coming decades. Thus coral bleaching events will not only become more common, but will likely occur often enough to make recovery increasingly difficult.

As temperatures increase the average ocean pH declines, leading to more acidic waters. This climate impact is not as readily visible to community members as the effects of coral bleaching, but the implications are massive for ecosystems and the communities that rely upon them. Alterations to calcification rates among marine organisms will change the manner in which coral reefs accrete and grow. In addition to the direct impacts this impairment will have on benthic habitat in general, it will also lower reef capacity to reduce wave energy and the occasional storm surge, thus exacerbating the impacts of other climate change effects as well. On Tinian, these circumstances could lead to future scenarios in which the popular snorkeling areas and reefs of Taga Beach deteriorate, while coastal erosion, near-shore turbidity, and surge impacts increase. Considering the systemic nature of shifts to ocean chemistry, which are summarized in the table below, vulnerability to these impacts is decidedly "high".

Future Change	**Projection**	**Projection Source**	**Future Magnitude**	**Vulnerability**
Sea Surface Temperature Increase Ocean Acidification Increase	2035 - 2040 avg.: 8 DHW/yr. Annual Bleaching Conditions/Events Occurring: 2030 - 2040 Ocean pH 2090: -0.30 to -0.32	van Hooidonk, et. Al 2013(a) van Hooidonk, et. Al 2013(b) IPCC AR5, RCP 8.5	Increase in thermal stress Decrease in calcification	High

Events, Features & Historic Conditions

Although most climate change assessments in marine areas concentrate on impacts with distinct causal connections such as sea temperatures and bleaching, the first event that emerged in discussions with Tinian participants was the recent increase in jellyfish (*Medusozoa*) around popular swimming and snorkeling areas. Jellyfish blooms have been tied more closely to periodic global oscillations than a linear climate change trend (Condona et al. 2013), but participant insistence on the painful impacts of this phenomenon warranted inclusion in this VA.

Jellyfish Invasion at Taga Beach (Event ID 15)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
2001-2005 avg.: 1.4 DHW/Yr 2005-2010 avg.: 0.5 DHW/yr 2011-2014 avg: 3.25 DHW/yr	2010	2010 - 2015	Public Health Concerns, Reduced Marine Ecosystem Function	Low	Tinian Workshop Participant NOAA Coral Reef Watch

"Along the swimming areas off Taga, and out at Taga Reef, there's been an increase in the number of jellyfish out there since about 2010. They've been stinging people in inappropriate locations."

Short of installing vinegar dispensers at beaches to alleviate stings, there are few options for Tinian to mitigate this problem. Perhaps the most appropriate approach would be to focus on informing both the community and visitors. Locally, authorities and resource managers could take a lesson from Managaha Island on Saipan and issue written and verbal notices about jellyfish presence during periods when they are more abundant. In the long-term, it may be beneficial to monitor ongoing research on jellyfish responses to changes in ocean temperature and cyclical phenomenon in the Western Pacific, as this may help inform managers, and subsequently the community and tourists, about impending jellyfish "blooms".

As far as climate impacts go, this event does not present a threat of the same severity and magnitude as other outcomes from ocean chemistry changes. While a jellyfish bloom could spell short-term pain for the unobservant beachgoer, a *algal* blooms could spell disaster for entire patches of benthic habitat.

Algal Growth Near Taga Beach (Event ID 16)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
2001-2005 avg.: 1.4 DHW/Yr 2005-2010 avg.: 0.5 DHW/yr 2011-2014 avg: 3.25 DHW/yr	2010	2010 - 2015	Public Health Concerns, Reduced Marine Ecosystem Function	Medium	Tinian Workshop Participant

"There is an unusual growth of algae in the past five years. My theory is that it's connected to wastewater percolation and bo'bu from the Dynasty."

Some workshop participants noted a recent increase in harmful algal growth along the reefs and other benthic communities near Taga Beach. Similar to the anecdotal proliferation of jellyfish, the additional algae coincides with some of the warmer sea surface temperatures experienced in the last five years. This is cause for concern as algae increases can not only harm the normal growth and function of coral and sea grass, but can also serve as an overall indicator of the introduction of non-point source pollution and harmful influences from adjacent watersheds. One community member went so far as to connect the growth of algae around Taga Beach and the harbor to effluent and percolated contaminants from the Tinian Dynasty.

While the latter influence is undesirable as a compounding factor in algal blooms, it also offers a silver lining with regard to climate adaptation. Even if the community has no options with regard to maintaining or lowering average ocean temperature, there are steps that can be taken on land and along the shoreline to limit the addition of watershed-based stressors. This same concept holds true for the threat of coral bleaching, where the reduction of land-based stressors can, at the very least, serve to create healthier reefs that will bounce back from, or be more resistant to damage from thermal stress events.

Coral Bleaching in Tinian Harbor (Event ID 19)

Magnitude	Year	Period	Impact Type	Level of Impact	Historic Source
2001-2005 avg.: 1.4 DHW/Yr 2005-2010 avg.: 0.5 DHW/yr 2011-2014 avg: 3.25 DHW/yr	2010	2010 - 2015	Reduced Marine Ecosystem Function; Threat to Subsistence/Fishing	Medium	Tinian Workshop Participant

"Over the past five years the corals in this area have been bleaching. It seems to be happening more now, but there is some new colonization to the north."

Community members have noticed an increase in coral bleaching around the Tinian Harbor over the past five years, which is consistent with the observed change in the average number of degree heating weeks experienced between 2010 and 2015 (as compared to previous five year averages), and the number of bleaching events observed by marine biologists and resource managers in the CNMI. Assuming the Western North Pacific stays on its current trajectory for increases in sea temperature, Tinian can expect to see coral bleaching events occurring on an annual basis beginning as early as 2030, though there is no guarantee that such conditions won't manifest sooner. Given the difficulties in reef recovery between consecutive bleaching events and the impending re-focusing of Tinian's agriculture and tourism industry to the watersheds adjacent to the harbor and Taga Beach, the coral reef ecosystem in this geographic area is particularly vulnerable. Maintaining a management focus on connections between land use/land cover changes and adjacent marine health will be critical as Tinian continues to evolve and adapt.

Event Class Summary

Average Historic Impact	Future Change Magnitude	Relative Vulnerability	Impacted Systems	General Adaptation Options
Medium, though impact has been higher in recent years with increasing frequency of stress events	Increase in sea surface temperatures and acidity, and consequent increase in bleaching and ecosystem damage Potential increase in contributing land-based stressors to near-shore ecosystems	High, especially if marine resource management is not coordinated with shifts in land use configuration and other adaptation actions	Reef degradation from a combination of bleaching, algal growth, and impaired calcification/accretion Aesthetic and recreational impacts from less desirable snorkeling, diving, and swimming areas Negative impacts on subsistence and artisanal fisheries	Coordinate with local scientists and resource managers to continue monitoring efforts and refine a coral bleaching "early warning system" Enhance run-off controls and best management practices for new development in the San Jose area Map and monitor bo'bu to identify land-based influences on reef and benthic health Study new coral colonization observed north of the Harbor for indicators of coral with inherent adaptive capacity (and promote growth of these tolerant species)

Summary of Tinian Vulnerability

Despite being a sparsely populated island, Tinian offers one of the most dynamic examples of how vulnerability levels may shift depending on how the community's expected growth and changes transpire over the next decade. There is a chance for the Island to serve as a source of lessons for other locales that may be facing major reconfigurations of land-use, and there is an immense opportunity to leverage impending development proposals and associated DOD resources to sustain the implementation of adaptation actions. This would set an important precedent in the Pacific Islands, but would require consistent political leadership within the Commonwealth and an ongoing, structured discourse at multiple scales of governance.

Beyond the opportunities and threats unique to the Island, Tinian faces general climate threats and vulnerabilities shared by Saipan and Rota. The uncertainty of future precipitation and storm patterns complicates identification of specific adaptation actions, while the combination of sea level rise, increased storm intensity, and impaired reef capacity as a buffer from wave energy are very likely to cause issues in low-lying coastal areas throughout the Commonwealth. Changes to ocean chemistry, while observable at specific points and features, occur on a much larger scale. Such problems can be addressed locally with broader application to other islands and island communities. The table below summarizes the impacts and vulnerabilities covered in this section of the VA, as specified by residents of Tinian, but the adaptation options are adaptable and transferable themselves. This is important to keep in mind as adaptation strategies and planning in the CNMI may not necessarily progress in an island-specific manner.

Changes in Impact	Vulnerability Ratings	Impacted Systems	General Adaptation Options
Precipitation: Increase in precipitation, with a potential increase in run-off, but a concurrent increase in opportunities to leverage additional water supply	**Low**, assuming military activity and future development implement appropriate stormwater controls and precipitation increases at a fairly stable rate	Increased stress on shoreline and nearshore marine environments adjacent to bo'bu Increased pressure on stormwater and drainage infrastructure Increased opportunities for agricultural innovations and resiliency	Incorporate climate-smart stormwater management practices in new growth and development regulations Work with USDA and NMC-CREES to leverage the potential for growing freshwater resources and availability Emphasize groundwater and contaminant mitigation requirements for U.S. Military activities and other large development proposals
Drought: Increase in annual precipitation, with a potential decrease in drought, though cyclical climate phenomena will likely continue to produce occasional dry conditions	**High** for the community overall, and **Very High** in the case of Tinian's agricultural systems, which are experiencing resource stress that may be compounded in drought conditions	Potential public health hazard with extreme heat and limited water availability Severe impacts on agricultural productivity and livestock management	Diversify and enhance freshwater sources and distribution system Establish community-based management plans for new agricultural land uses Update groundwater studies and research on freshwater budget, including latest climate projections

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Changes in Impact	Vulnerability Ratings	Impacted Systems	General Adaptation Options
Coastal Erosion: Increase in erosion processes due to sea level rise and increased storm intensity	**High** vulnerability around the Harbor and Taga Beach area; low elsewhere	Possible increased damage and stress on Seaport infrastructure Altered beach aesthetics along the shoreline near San Jose and Tinian Dynasty	Conduct post-storm damage assessments along sensitive shorelines and Seaport breakwater to identify priorities for protective enhancement Preserve existing beach/strand vegetation in the San Jose and Taga Beach area, and promote natural buffers to mitigate periodic wave action Establish a managed retreat strategy to accommodate future sea level rise and erosion processes
Storm Surge: Increase in surge height and extent due to sea level rise and raised storm intensity.	**High**, particularly with projected increases in sea level, and potential for lower pressure in cyclones (temporarily raising sea level further). High vulnerability assumes no additional adaptive actions are taken.	Increased exposure of shoreline cultural and recreational features to surge Increased exposure of Seaport and breakwater to wave energy Potential safety concerns for boaters and any future ferry service	Allocate resources from future investments in the Seaport/Harbor toward breakwater enhancement and repair Prioritize a site-scale storm surge and sea level rise model for the Seaport and Taga Beach areas in future research endeavors to identify high risk areas and adaptation opportunities and priorities Apply an "enhancement" rule to the use of disaster relief/reconstruction resources, wherein storm-smart design standards are codified and applied during recovery operations and that develop mechanisms to support recovery and adaptive capacity Avoid development of structures in high-risk areas to keep people and infrastructure out of harm's way
Ocean Chemistry: Increase in sea surface temperatures and acidity, and consequent increase in bleaching and ecosystem damage Potential increase in contributing land-based stressors to near-shore ecosystems	**High**, especially if marine resource management is not coordinated with shifts in land use configuration and other adaptation actions	Reef degradation from a combination of bleaching, algal growth, and impaired calcification/accretion Aesthetic and recreational impacts from less desirable snorkeling, diving, and swimming areas Negative impacts on subsistence and artisanal fisheries	Coordinate with local scientists and resource managers to refine a coral bleaching "early warning system" Enhance run-off controls and best management practices for new development and land use activities, especially in the more densely populated San Jose area Map and monitor bo'bu (groundwater discharges) to identify land-based influences on reef and benthic health Continue work on enhancing resilience and reducing vulnerability in marine systems Study new coral colonization observed north of the Harbor for indicators of coral with inherent adaptive capacity and promote growth of these tolerant species

The sections in this summary table for Tinian that outline general impacted systems and possible, broad responses are combined with the corresponding sections of the Rota summary table in the following section (*Discussion: Steps Forward*). Impacts and adaptive options are reiterated in this discussion of next steps to provide the reader with a coherent dialog highlighting potential responses to key vulnerabilities.

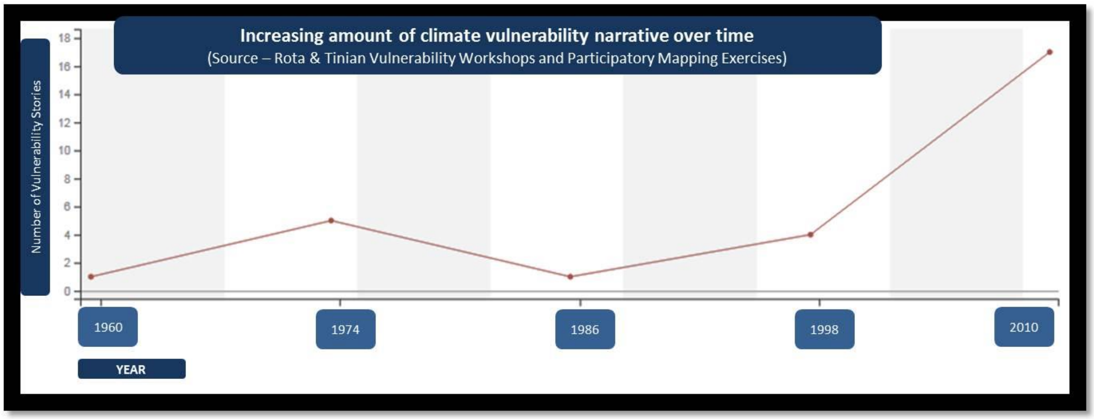
Discussion: Steps Forward for Rota, Tinian, and CNMI

Jazz is a genre of music often characterized by complex, free-flowing arrangements. More so than other genres, the tendency for certain styles of jazz to take an improvisational approach and defy formal structure complicates any efforts to forecast the progression of songs. This type of complication, which results from a lack of predictability and pre-set arrangements, is similar to the challenges facing communities that are attempting to plan for climate change and future extremes. With a constantly shifting social and economic structure in the CNMI, and a climate punctuated by extreme annual, decadal, and long-term fluctuations, it is proving difficult to place climate adaptation in the context of a traditional planning structure. There is simply no universal, step-by-step guide for dealing with rising sea levels, changes in precipitation, shifting ocean chemistry, and uncertain storm behavior, especially when these changes take place in an archipelago that is evolving both socially and economically. As a participant at the 2014 Pacific Risk Management O'hana Meeting described the situation: "We are trained professionals in planning for 'classical' community issues, but now our communities have to deal with 'free-form jazz'. We need to be flexible". Indeed, Rota, Tinian, and the CNMI as a whole may need to proceed with climate adaptation planning in an iterative, elastic fashion. Often referred to as "adaptive management", iterative planning processes enable stakeholders to identify and work towards desirable states of systems – be they ecological, socio-economic, or engineered – in order to ensure that critical functions are maintained over time. This process can be critical to building resilience or supporting transformation to more desired states despite changing climate conditions.

Understanding exactly what this type of flexible planning or experimental management would look like is a challenge of its own, as adaptive models from other island communities are not necessarily transferrable to the CNMI. One of the most significant barriers in this regard is the unique manner in which CNMI government agencies collaborate, and how each entity perceives its relevance to climate adaptation planning. The establishment of the CNMI CCWG in 2012 and its ongoing attempts at collaboration can be seen as a concerted effort to set a precedent for cooperation; however, this type of task force requires an ongoing infusion of opportunities for participants to make the connection between their agency's mission and long-term climate impacts. Only with a broader vision can a participating organization identify forward-thinking options for taking action. In some communities, the establishment of a solid knowledge base among planners and practitioners concerning long-range implications of climate change has been pivotal. This foundation, created through trainings or other types of preparatory conditioning, can help an individual or an agency match their long-term planning to other agencies' strategies and to the gradual projected shifts in climate.

Complicating this goal of syncing long-term planning with climate adaptation is the occurrence of natural disasters and immediate weather impacts, which can focus all resources into efforts to *cope* and *respond*, as opposed to strategizing and adaptively managing for the future. Currently the media appears inclined if not eager to attribute extreme weather events to climate change and global warming. This linkage is often difficult to substantiate due to a fundamental disconnect between the time scales on which extreme events and climate shifts occur. That being said, the increased focus on climate and weather extremes is, in some cases, a boon for organizations and communities that are interested in planning for longer-term climate adaptation. The exposure and public emphasis on short-term phenomena allows for greater support in extended adaptation and hazard mitigation efforts. This is a fortunate relationship, as it is more efficient and inexpensive to explore mutually beneficial opportunities for adaptation now than it is to pay for possible damages and extreme system modifications later (ECA 2009a).

Given the benefits of highlighting short-term extremes, the history of climate impacts on Rota and Tinian situate these islands favorably to justify the use of resources for adaptation in order to reduce current and future vulnerabilities. This is especially pertinent in light of the community emphasis on more *recent* climate extremes. During the community workshops on Rota and Tinian, the majority of references to past climate events were set in the past fifteen years, with the period following the 1997-1998 ENSO event corresponding with a spike in story-telling.



While first appearances depicted on the graph above might lead to the conclusion that extreme climate conditions are being reached on a more regular basis, the trend shown in the figure is more likely due to the tendency of human memories to lose vividness over time. It is easier to recall a flash flood from yesterday than ongoing nuisance flooding that occurred decades ago. The increase in narrative concerning climate impacts may also relate to increases in anthropogenic stresses within the community, such as development and land use intensity, which can compound the effects of climate and weather extremes.

Ideally, the focus on more recent, short-term climate impacts can drive the implementation of adaptation initiatives on a compatible time-scale. Furthermore, regardless of how planners and practitioners match an adaptation strategy to their long-term mission, there are actions that can be taken in the near-term that will help reduce current vulnerabilities and immediate threats.

With these concepts in mind, several suggestions are highlighted in the following sections as to how adaptation can be pursued at both a strategic level and with acute actions at finer resolutions. These recommendations do not constitute an action plan or strategy, which require thorough stakeholder input, ongoing consultation, and most of all, leadership from decision-makers and agency heads. That being said, a table summarizing the vulnerable systems identified in this project and associated adaptation options is provided as a structured summary that may frame and inform a broader, more conceptual discussion.

Summary of Impacted Systems and Avenues for Adaptation

Impacted Systems	General Adaptation Options
<u>Precipitation Impacts:</u> Reduced terrestrial and marine ecosystem function where erosion and run-off poses a threat Increased strain on village stormwater infrastructure & potential impact on economic activity Implications for public health and freshwater budget Increased stress on shoreline and nearshore marine environments adjacent to bo'bu Increased pressure on stormwater and drainage infrastructure Increased opportunities for agricultural innovations and resiliency	**<u>Adaptive Responses to Precipitation Change:</u>** Prioritize drainage infrastructure improvements in Songsong Plan restoration efforts in Talakhaya using best available ENSO projections, avoiding activities during potential extreme conditions Diversify or enhance freshwater sources and water storage capacity Incorporate climate-smart stormwater management practices in new growth and development regulations Work with USDA and NMC-CREES to leverage the potential for growing freshwater resources and availability as well as adaptive management interventions Emphasize groundwater and contaminant mitigation requirements for U.S. Military activities and large scale developments
<u>Drought Impacts:</u> Potential for both threats to, *and* opportunities for enhancement of agriculture and associated food security Some additional strain on habitat restoration and targeted conservation initiatives Potential public health hazard with extreme heat and limited water availability Severe impacts on agricultural productivity and livestock management	**<u>Adaptive Responses to Drought:</u>** Promote and target research into food systems resilience and agricultural diversification, possibly through NMC-CREES and USDA resources Embed sensitivity to upcoming extreme conditions and cyclical climate phenomenon into adaptive restoration plans, such as updates to Conservation Action Plans Diversify and enhance freshwater sources and distribution system while considering opportunities to improve efficiency of existing systems Establish comprehensive community-based management plans to guide new agricultural land uses in the context of development and resource management goals Update groundwater studies and research on freshwater budget, including latest climate projections
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Impacted Systems	General Adaptation Options
Impacts from Coastal Erosion: Resident and visitor accessibility to recreational and cultural features reduced Additional limitations to future development, and risky investment in future infrastructure enhancement (e.g. road stabilization) around low-lying areas Private property threatened in select locations around Songsong Possible increased damage and stress on Seaport infrastructure Altered beach aesthetics along the shoreline near San Jose and Tinian Dynasty	**Adaptive Responses to Coastal Erosion:** Promote near-term enhancement of natural vegetative buffers along sandy areas and strand ecosystems, including supporting or incentivizing soft protection actions taken by individual landowners Identify and adopt adaptive regulatory responses for shoreline setback requirements Identify long-term zones for safe growth and development outside of potential high-risk inundation zones Identify of locations where shoreline hardening may be necessary as a last resort Conduct post-storm damage assessments along sensitive shorelines and Seaport breakwater to identify priorities for protective enhancement Preserve existing beach/strand vegetation in the San Jose and Taga Beach area, and promote natural buffers to mitigate periodic wave action Establish a managed retreat strategy to accommodate future sea level rise and erosion processes
Impacts from Storm Surge: Low-lying infrastructure and property inundated more severely Businesses and port commerce interrupted to a greater extent under storm conditions, albeit less frequently Potential impairment of low-lying transportation routes and general island circulation, with consequences for critical service availability under emergency storm scenarios Increased exposure of shoreline cultural and recreational features to surge Increased exposure of Tinian and Rota Seaports and breakwaters to wave energy Potential safety concerns for boaters and any future ferry service as well as potential impacts to tourism and recreation due to reduced beach access and/or safety	**Adaptive Responses to Storm Surge:** Plan and implement improvements to drainage capacity and stormwater infrastructure to reduce inundation duration Identify priority sites for shoreline protection and armoring where loss of infrastructure is unavoidable without “hard” protection options and focus efforts on enhancing shoreline buffers using “soft” or “green” infrastructure Establish a suite of “storm-proof” design options for the Island to leverage in the event that future surge damage allows opportunities for enhanced repairs, climate-smart building standards, and post-storm re-design, as well as funding mechanisms to support rapid recovery and restoration Allocate resources from future investments to support enhancement and repair of critical infrastructure such as the breakwater in the Tinian Seaport/Harbor Prioritize a site-scale storm surge and sea level rise model for the Rota East/West docking facilities, Songsong Village, Tinian Seaport, and Taga Beach areas in future research endeavors

Impacted Systems	General Adaptation Options
Impact from Storms and Cyclones: Private and public properties and structures threatened by enhanced flooding and wind damage Business and commerce facing longer interruptions in a future scenario with stronger storms Increased strain on agriculture and subsistence land use in years with more storms Increased system demand on emergency services and backup infrastructure, particularly if Rota experiences growth or development in upcoming decades	**Adaptive Responses to Storms and Cyclones:** Establish alternative emergency response plans based on local-level knowledge of needs and deficiencies in past scenarios Apply an "enhancement" rule to the use of disaster relief/reconstruction resources, wherein storm-smart design standards are codified during recovery operations Standardize storm-smart building and construction practices for any future development, and require climate-smart investment from developers
Impacts from Changes in Ocean Chemistry: Reef degradation from a combination of bleaching, algal growth, and impaired calcification/accretion Aesthetic and recreational impacts from less desirable snorkeling, diving, and swimming areas Negative impacts on subsistence and artisanal fisheries	**Adaptive Responses to Changes in Ocean Chemistry:** Coordinate with local scientists and resource managers to continue monitoring efforts and refine a coral bleaching "early warning systems" Enhance run-off controls and best management practices for new development in the San Jose area on Tinian Map and monitor bo'bu (groundwater discharges) of Tinian and Rota to identify land-based influences on reef and benthic health Study new coral colonization observed north of the Tinian Harbor for indicators of coral with inherent adaptive capacity and promote growth of these tolerant species

Clearly these options for exploring adaptation constitute a monumental suite of projects and processes. The following discussions may help frame some of the pathways towards implementation.

Toward Storm-Smart Shorelines

After prompting residents, resource managers, and planners to recall climate impacts, it is no surprise that community members continuously reiterate concerns over storm surge impacts and coastal erosion. The effects are visible, and have the intimidating ability to knock on residents' back doors. In addressing both coastal erosion and surge associated with isolated events, both private and public entities may take a "stair-step" approach to improving physical systems and planning protocols.

To engage in this "stair-step" method, entities such as the Department of Public Works, Commonwealth Utilities Corporation, or the Commonwealth Ports Authority could establish protocols for repairing or reconstructing in a manner that improves the resilience of infrastructure beyond its previous levels whenever the opportunity arises. As a simple example, wooden utility power poles on Guam that were damaged in typhoons were replaced with stronger concrete structures. Although this "step-up" had some unfortunate potential consequences for vehicle collisions, the concept has proven to work in reducing climate vulnerability and post-upgrade damage from storms. Likewise, the re-enforcement of Rota's East Bay docking area after severe storm damage constituted an opportunistic step-up in coastal infrastructure. If these types of enhancements are codified via agency policy, great progress could be made in adaptation, especially if long-term climate projections are incorporated in these planning efforts.

This approach can also be adopted in the natural environment utilizing the concept of "green infrastructure" and "living shorelines". Each time storm surge impacts a beach or property and re-arranges the strand vegetation, re-planting can be informed by the design of a vegetative structure that might be more effective in providing a buffer from wave action. This push for enhanced green infrastructure could be explored with particular interest in areas where significant transportation infrastructure (e.g. roads on Rota's west/north coastline) may be at risk, but where shoreline armoring is not the preferred first step in enhancement.

Adopting this approach could also be more palatable to over-tasked agencies and organizations because immediate action items such as shoreline re-vegetation and managed retreat can be implemented without extensive policy changes or resource commitment (Hawaii Sea Grant 2013). This is especially relevant where great uncertainties still exist in terms of the extent of future sea level rise and storm behavior, which may make extremely expensive hardening options difficult to justify in terms of costs versus benefits.

New adaptation projects that are financially burdensome and resource-intensive are unlikely to gain support in the CNMI if they are framed as responses to the vague threat of "climate change", so the notion of "mainstreaming" climate adaptation into existing upgrades to infrastructure and stakeholder assets should be pursued with emphasis. Plans to "retrofit" infrastructure in the CNMI have been developed in the past (see MAKERS Architecture & Urban Design 2007), thus exploring ad hoc opportunities to implement climate-smart retro-fitting with projects that might achieve enhanced storm protection or surge mitigation would be a viable alternative in the short-term.

Adaptive management of shorelines and coastal hazard mitigation in the short-term may eventually develop into a more structured strategy for adaptation, but such a strategy will be dependent on long-term, consistent leadership and the ability of communities and government agencies to draw direct connections between their work and the goals or objectives of climate adaptation. In the case of stakeholders whose assets or projects occur along the shoreline or within inundation zones, this type of direct connection between their vested interests and the implications of sea level rise and storm surge should be evident. Management of other resources, such as groundwater, might require a more detailed discussion to highlight the direct and indirect impacts of climate change.

Toward Adaptive Management of Water Resources

Possible changes to Rota and Tinian's water resources warrant a staggered, adaptive approach to management similar to the adaptation style outlined in the previous section. Considering the antiquated state of much of the CNMI's stormwater and wastewater infrastructure, and the vulnerable wells and groundwater system, opportunities to streamline adaptation with retrofits and infrastructure upgrades should be a realistic task. The Commonwealth Utilities Corporation could revisit its maintenance and upgrade timeline with future climate impacts and the building of adaptive capacity in mind.

Obstacles for adaptation in water resources management may result from the uncertain and varied changes to precipitation in the CNMI. While long-term projections suggest a potential slight increase in *annual* precipitation, this may come in the form of isolated extreme events, possibly punctuated by equally significant dry periods. This means that storage systems would need to adjust to not only accommodate extreme events or temporary overload, but also increase long-term storage capacity in recognition of periodic El Nino events and the droughts that often fall in their wake. The behavior of El Nino events, and any changes to ENSO should also be monitored closely as the associated changes in salinity in the basal lens (especially below Tinian) will have implications for appropriate well withdrawal depths

Recollection of agricultural damage due to both flooding and drought has also demonstrated a need for a means of contingency planning on agricultural lands. Traditional and local knowledge regarding storm preparations for smaller crop areas (households) could be extrapolated to frame adaptation strategies to future extreme events at a broader, island-wide scale. Likewise, responses to historic droughts such as the 1998 post-El Nino event should inform any opportunities to plan for adaptation actions. For example, in the case of Tinian's Hagoi Wetland and its temporary function as emergency cattle feed, this local drought response could underscore the significance of wetlands not only as ecological systems and habitat features as they are currently perceived through the lens of conservation organizations and natural resource managers, but as a critical agricultural resource as well. Following this line of reasoning, stakeholders may wish to re-evaluate the value of assets in light of their potential to contribute to adaptive capacity of critical functions and systems.

New development and ongoing improvements on Rota and Tinian may place increasing demands and stresses on water resources, and proposed increases in military activity on Tinian will likely alter the agricultural systems that are in place. Given the discussion above, these changes could be viewed as opportunities for adaptation. As groundwater resource studies have been conducted in the past, future studies may include a component that is sensitive to various climate scenarios. Such sensitivity to climate change could also be a condition placed on future mitigation activities or studies that are conducted or contracted by the U.S. Military or other large-scale developments. This re-framing of potential resource threats as opportunities is crucial to successful adaptation in the CNMI, and is applicable not only to terrestrial resources, but also in the marine environment.

Toward Reef Resilience and Adaptive Capacity

While long-term threats to the CNMI's coral reefs paint disturbing portraits of future scenarios, and pose daunting challenges for management, short-term climate extremes and stresses offer opportunities to begin preparing for such challenges. One means of preparation involves the pursuit of a *resilience* based systems approach.

There is growing evidence that local stressors such as land-based sources of pollution, sedimentation, and over-harvesting reduce the resilience of coral reefs ecosystems, making them more vulnerable to the effects of climate change. Healthy, resilient reefs, however, are able to resist or recover from acute disturbances such as bleaching events while maintaining ecosystem functions. By virtue of survival, these reefs will have a greater capacity to adapt to the rapidly changing environment. Promoting reef resilience is therefore one of the most important things that coral reef managers can do to protect reefs in the face of global climate change.

The concept of resilience-based management encompasses several approaches, including eliminating or reducing local anthropogenic stressors that weaken reef resilience, protecting naturally resilient reefs (e.g. establishing marine protected areas around reefs that thrive or recover rapidly), and even actively enhancing resilience by manipulating the biological community or physical environment. An example of manipulating the biological community would be selecting for or even *creating* stress tolerant corals to cultivate in nurseries and out-plant these specimens to a section of reef that has been or will be impacted by climate change and other stressors. This approach has been has been explored in other regions, including Florida and the Caribbean, with varying success. While coral nurseries for restoration/enhancement are not as common in the western Pacific at this time, pilot projects are underway in American Samoa, demonstrating such approaches may also be utilized in the CNMI in the future as coral populations continue to decline.

All of these approaches benefit from reef resilience assessments that explore the spatial variation in resilience potential in a given area. Combined with knowledge of the local anthropogenic stressors, resilience assessments can help identify specific management targets and best strategies to maximize resilience and optimize the use of limited resources. From 2012-2014, the first field-based reef resilience assessment was conducted in the CNMI (Maynard et al. 2015). This assessment was based on resilience indicators such as coral diversity, herbivore biomass, and presence of bleaching susceptible corals, among others, that were measurement at 85 sites across Saipan, Tinian, and Rota. Ultimately, a decision-support framework was developed based on the findings to guide coral-reef management actions in the CNMI and support reef resilience to climate change. This type of combined study that contains a significant, *applied* management component contains the potential to inform adaptation efforts far beyond research that is void of specific recommendations.

That being said, in the arena of new research and monitoring, remote sensing continues to emerge as an effective and particularly efficient means of providing a multi-scale early warning system for bleaching events. Recent development of high resolution (five kilometer) satellite-based reef monitoring products allows for direct observation and near term analysis of SST anomalies, bleaching “hot spots”, degree heating weeks, and bleaching alert areas (Liu et al. 2014). This type of product may prove to be an invaluable component of CNMI reef management toolbox as the resolution of near-term forecasting approaches the scale of local management efforts on the ground.

If Rota and Tinian are able to leverage new developments in research and early warning capabilities, combined with a feasible suite of management recommendations, this would constitute a significant step forward in harnessing the benefits of a resilience-based approach. Such efforts would also help in adding management value to all the work that has gone into data and information gathering over the last several decades.

Toward a New Understanding of Stakeholders

Climate change adaptation is rapidly becoming a world-wide planning phenomenon that places a new type of emphasis on the significance of *diverse* stakeholder involvement and support. It is rare that a planning issue or problem is relevant to such a wide range of organizations, agencies, and missions across multiple sectors, yet climate change presents impacts and opportunities that permeate even the most basic plans and policies.

Acknowledging the wide reach of climate impacts, Rota and Tinian are encouraged to survey their current affairs between different agencies at both local and federal levels, as well as any external influences that might offer *opportunities* to adapt. The current discourse in the CNMI reveals two extremely influential entities that could serve as mechanisms for supporting climate adaptation: the U.S. Department of Defense and private investors/development interests.

The U.S. Department of Defense (DOD) has proposed an expansion of military activity in the Marianas Archipelago, including the expansion of existing exercises for various branches of the military, and the installment and leasing of new areas for training purposes (DOD 2015). In proposing this expansion, the U.S. Department of Defense has directly instigated a conjoined proposal to be stewards of the land and architects of future infrastructure and landscape in specific areas.

While the general structure in which DOD and the U.S. Military operate within these areas has been delineated, there is still the opportunity for ongoing dialog and even *improvements* to some resources, provided this stakeholder is open to creative approaches. On Tinian in particular there is opportunity to re-configure exercises with explicit attention to impacts of groundwater connectivity, *and* work with the agricultural community to identify resources that the military could potentially provide for in the event of future drought or shifts in precipitation. Such discussions would further the DOD's commitment to addressing climate change drivers and impacts in its operations, as articulated in the 2014 Climate Change Adaptation Roadmap (DOD 2014).

Likewise, private investment and proposed tourism development continues to create opportunities to shape the future landscape of the CNMI in a manner consistent with more resilient infrastructure, effectively buffered and partitioned water resources, and enhanced "storm-smart" shorelines. Such efforts to support long-term sustainability planning will entail ongoing dialog and coordination between CNMI Government and private investors to ensure that a climate-smart architecture is implemented throughout the Northern Marianas. While this would seem to require an overarching climate adaptation strategy that guides public-private interactions concerning new development, a creative, adaptation-oriented mindset could also be brought to the table in short-term, ad-hoc discussions and negotiations over new developments. This sort of iterative approach, while contradictory to most guidance on appropriate adaptation planning frameworks, is realistically compatible with the timeframe in which some developments are taking place in the CNMI.

A simple conceptual framework to shape such an iterative discussion would closely follow the logic that was recently employed in updating a conservation action plan on the island of Saipan:

1. Consider the objectives and outcomes of the proposed action or development;
2. Identify relevant climate stressors;
3. Identify impacts climate stressors will have on the resources/assets involved in the proposed action or development; and
4. Brainstorm and propose adaptive solutions that accomplish the objectives and outcomes of Step 1, while addressing those concerns identified in Steps 2 and 3.

In the context of the resources and features that were discussed in this vulnerability assessment, this type of thought process could transpire in the following, simplified discourse over a hypothetical tourist development and hotel on Tinian:

1. Establish an 8 story hotel and casino with *x* rooms on parcel *xxxx*.
2. There is potential for shifting precipitation and storm patterns in the CNMI.
3. This particular parcel could see nuisance flooding and unacceptable rates of Stormwater runoff during extreme events due to the proposed increase in impervious surfaces.
4. Permeable parking designs, combined with strategically and aesthetically placed swales and stormwater retention measures could enhance the aesthetic value of the development while achieving a more adaptive design and reducing the threat of nuisance flooding.

This example, while extremely basic, is also within the current decision-making capacity of CNMI officials, resource managers, and consultants. Such a simple process probably does not satisfy long-term requirements for achieving comprehensive adaptation, but provides a means to incorporate climate change adaptation into current dialogs with significant stakeholders.

In contemplating the long-term engagement of such influential and perhaps non-traditional stakeholders, it would be wise to adopt a “whole of government” approach to collaboration and adaptation. In concept this entails a seamless engagement of all agencies and their federal counterparts in a discussion of how the CNMI is moving forward. This idea of the “Government as a Whole” would require unprecedented collaboration as well as leadership that transcends political shifts and institutional turnover within the CNMI. Recent encouragement at the federal level for the development of comprehensive state-level adaptation plans would provide an appropriate initial goal to focus this whole-of-government approach around.

If this type of seamless coordination is not possible, or not feasible within a 5-10 year timeframe, an alternate means of initially engaging the government in *actionable* adaptation is through a series of individual consultations with key agencies. Despite being able to delineate potential focus areas for adaptation and having a solid supplement of data to inform planning and policy changes, the individual agencies within the CNMI Government do not have the technical capacity, resources, time, or dedicated staff to translate information about vulnerabilities and adaptation priorities into specific plans of action.

A dedicated resource such as a contractor who could consult with individual agencies and resources managers would be a significant asset. Such technical support would enable the development of critical foundations of knowledge about climate change and adaptation planning within existing local expertise as well as build upon the time and effort that has gone into the last three years of climate change planning in the CNMI and empower individual agencies and resource managers to identify actionable items to mainstream climate adaptation within their plans and policies.

Two of the most significant agencies that could be incredibly instrumental in moving climate adaptation forward in the CNMI are the Department of Public Works and the Department of Public Lands. The application of a dedicated climate adaptation planning resource or coordinator to engage in depth with DPW and DPL to develop agency-specific climate adaptation actions would accomplish two important goals. First, near-term outcomes for climate adaptation would be identified for each of these critical resource management agencies. Second, from a broader perspective, the outcomes identified for the individual agency could develop into implementable polices that would then constitute elements of the CNMI's adaptation efforts that could eventually fit into a larger, more comprehensive strategy.

The Department of Public Works has a mission and scope of work that focuses on some of the most critical infrastructure in the CNMI, and their projects are influential in how the landscape and land use configuration of the CNMI evolves. In particular, effective transportation in the CNMI relies on DPW's ongoing planning and maintenance of roads and associated infrastructure that are vulnerable to the impacts of storm surge, coastal erosion, and inland flooding. There is significant opportunity among DPW's transportation infrastructure planning framework for the instilment of climate adaptation considerations, and an in-depth consultation and internal action plan creation could constitute an important investment for the CNMI's future.

Likewise, DPL is responsible for the management of a large portion of the CNMI's coastal properties, including those used for active recreation and tourism operations. DPL is thus in a unique position to work with a variety of stakeholders, including coastal managers, recreational users, tourism authorities, and hotels, to ensure that use of public lands develops in a manner that considers and is responsive to future climate impacts. A thorough consultation and adaptation planning process specific to DPL's work with shorelands and coastal properties would make significant strides in ensuring that the CNMI's future coastal recreation and tourism industry coincides with efforts to reduce vulnerabilities and enhance resilience in response to climate change.

Through the engagement of these two key agencies, a consultant or similar planning resource would set a crucial precedent for other CNMI entities, both public and private. This type of project could serve as an exceptional example of how climate adaptation can be acutely beneficial to individual CNMI agencies or organizations and be relevant to the context of their overall missions and goals. Ensuring that stakeholder resources on Rota and Tinian remain part of the discussion if such actions are identified and measures are implemented will be critical.

Multiple Engines for Adaptation

The CNMI Government does not necessarily need to be the driving force behind adaptation in the CNMI. Although documents such as this promote a fairly structured approach to climate adaptation that relies on the central coordination of the government, and suggest means of multi-sector collaborations, adaptation can also occur in an autonomous context from individual land and resource stewards. This is particularly the case with landowners and tourism operators. Those individuals and enterprises that interact directly with natural resources, whether for economic, recreational, or subsistence purposes, constitute an important force in shaping adaptation in the CNMI.

Despite efforts to regulate or mold their activities, the independent actions of these stakeholders too are a driver of resource trends, and thus the concept of *behavior change* is also relevant. Efforts to provide the necessary information and tools to support natural resource stewardship that do not automatically place stakeholders under strict activity control should be explored. This is easier said than done, and it is difficult to track the effectiveness of outreach materials over time. However, a single principle that could be employed in guiding autonomous stewardship and adaptation is to show stakeholders *what is possible*, as opposed to what is not allowed.

A simple example of this concept is highlighted by the often detrimental practice of walking across a reef flat in order to access deep water for scuba diving or fishing. Immense effort on the Government's part could go into attempting to control, enforce, or even eliminate the trampling of coral and shallow benthic habitat that will be crucial for wave energy reduction in future climate scenarios. However, a simple tool might surpass these controls in effectiveness: a line or rope, clearly visible, leading from the high-water mark out to a cut in the reef, which establishes a path that is (1) easy to follow, and (2) avoids sensitive habitat or species that may be particularly adaptive (or vulnerable) to climate stresses, depending on the management objectives. Instinct drives groups of individuals to follow pre-set paths, and in this scenario, individuals may collectively follow the most desirable practice in terms of stewardship through passive suggestion rather than threat of enforcement. Close attention should be paid to opportunities to implement these types of tools, particularly in areas where community and recreational uses outweigh organized use by a large private enterprise.

Forward to Adaptive Communities

While some adaptation opportunities have been identified here through the process of mainstreaming efforts, and integration with existing management and policy, taking advantage of these opportunities will require a more pervasive action within the respective political institutions and management units. CNMI government agencies that are active on Rota and Tinian will need to adopt climate change as a standard consideration in project development and decision-making processes in order to efficiently implement adaptation considerations into institutional frameworks.

At the legislative level, our representatives and topical committees will need to closely inspect policies that impact community structure, taking into account potential effects on the sources of revenue that rely on vulnerable natural resources (e.g. *sustainable* tourism). As suggested in the previous section, this consideration also applies outside of the CNMI Government, and directly relates to private enterprises and tour operators in the CNMI, which are ultimately dependent on the natural and physical systems that this VA has identified as vulnerable.

In the spirit of this VA's insistent connection between past, present, and future, it is perhaps most appropriate to look forward to adaptive communities on Rota and Tinian by taking a look back at the CNMI CCWG's vision that was established in 2012:

> *"The CNMI is ready and able to proactively adapt to climate change in order to maintain the integrity and resiliency of our communities and ecosystems. The community is aware of the threats posed by climate change, and is implementing a comprehensive adaptation plan to preserve our cultural, natural, and economic resources for current and future use."*

While this project constitutes a small step toward achieving this vision, it most certainly does not outline a clear plan of action. Rather, it is intended to spur further inquiry into specific threats, and subsequently establish some clear adaptation options that may serve as the genesis for the CCWG's referenced "comprehensive adaptation plan". To be responsive to changing conditions and information, this plan will likely be a living document that forms in conjunction with unprecedented collaboration among CNMI Government agencies, federal government, private industry, and community organizations.

In recognizing the significance of such collaboration and resulting planning efforts, Rota and Tinian are encouraged to move forward with climate adaptation keeping in mind that the prospects of a changing climate also present opportunities to enhance the community. Increasing resources, both financial and technical, are available at both the federal and international levels for CNMI organizations and agencies to leverage, provided the initiative is taken to propose a use for them. This assistance should be viewed as a foothold in building adaptive capacity and an opportunity to create more resilient ecological, socio-economic, and engineered systems on Rota and Tinian. With a little creative collaboration among CNMI stakeholders, this resilient community will be one built off of unique local knowledge and driven by a locally-appropriate adaptation initiatives belonging to the community members themselves.

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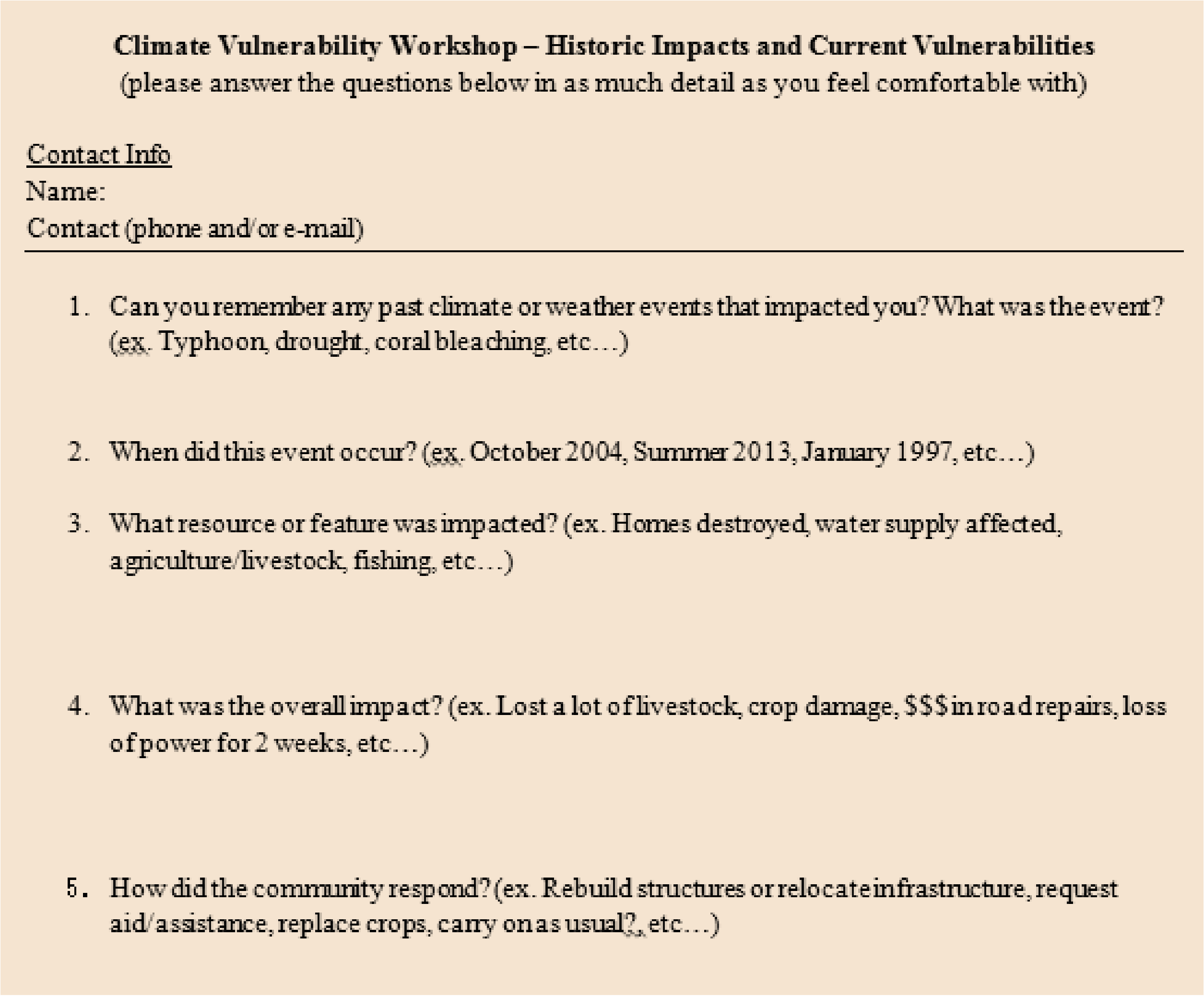
Appendix

A. Survey for Climate Workshop Participants



Climate Vulnerability Workshop – Historic Impacts and Current Vulnerabilities
(please answer the questions below in as much detail as you feel comfortable with)

<u>Contact Info</u>
Name:
Contact (phone and/or e-mail)

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1. Can you remember any past climate or weather events that impacted you? What was the event? (ex. Typhoon, drought, coral bleaching, etc…)
2. When did this event occur? (ex. October 2004, Summer 2013, January 1997, etc…)
3. What resource or feature was impacted? (ex. Homes destroyed, water supply affected, agriculture/livestock, fishing, etc…)
4. What was the overall impact? (ex. Lost a lot of livestock, crop damage, $$$ in road repairs, loss of power for 2 weeks, etc…)
5. How did the community respond? (ex. Rebuild structures or relocate infrastructure, request aid/assistance, replace crops, carry on as usual?, etc…)

B. Resources and Data Sources for Past Events and Future Projections

Resources for Historic Extremes & Future Scenarios:

Historic Events and Periods

Pacific Climate Change Data Portal –

http://www.bom.gov.au/climate/pccsp/

This website provides historical climate information and trends from individual observation sites across the Pacific region and East Timor. The Pacific Climate Change Data portal has been developed through the Pacific Climate Change Science Program (PCCSP) and Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program.

NOAA National Climatic Data Center Climate Data Online and Map Viewer –

https://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=obs_m&theme=ghcndms
http://www.ncdc.noaa.gov/cdo-web/

Climate Data Online (CDO) provides free access to NCDC's archive of global historical weather and climate data in addition to station history information. These data include quality controlled daily, monthly, seasonal, and yearly measurements of temperature, precipitation, wind, and degree days as well as radar data and 30-year Climate Normals. Customers can also order most of these data as certified hard copies for legal use.

NOAA National Climatic Data Center Storm Events Database –

http://www.ncdc.noaa.gov/stormevents/choosedates.jsp?statefips=98%2CGUAM

The storm events database currently contains data from January 1950 to December 2014, as entered by NOAA's National Weather Service (NWS). NCDC receives Storm Data from the National Weather Service. The National Weather service receives their information from a variety of sources, which include but are not limited to: county, state and federal emergency management officials, local law enforcement officials, skywarn spotters, NWS damage surveys, newspaper clipping services, the insurance industry and the general public, among others.

NOAA Historical Hurricane Tracks –

http://coast.noaa.gov/hurricanes/?redirect=301ocm#

The NOAA Historical Hurricane Tracks tool allows interactive querying and viewing of historic paths taken by typhoons and hurricanes in the world's ocean basins. Attribute data for tropical cyclones can be viewed at various points along the storm tracks. Paths for tropical cyclones between 1886 and 2013 are available for the Western North Pacific.

The tool leverages storm data from the International Best Track Archive for Climate Stewardship (IBTrACS).

National Oceanic and Atmospheric Administration (NOAA) Digital Coast. Historical Hurricane Tracks. GIS tool and associated data. Charleston, SC: NOAA Office for Coastal Management. Accessed at *www.coast.noaa.gov/digitalcoast/tools/hurricanes*.

International Best Track Archive for Climate Stewardship (IBTrACS, v03r06) - http://www.ncdc.noaa.gov/ibtracs/index.php

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Western Regional Climate Center - http://www.wrcc.dri.edu/local-climate-data/
The Western Regional Climate Center is a partner in a suite of interconnected services that includes the NOAA National Climatic Data Center (NCDC), Regional Climate Centers (RCCs), State Climate Offices, NOAA Regional Integrated Sciences and Assessments (RISA), and USDI Climate Science Centers (CSCs).

Local climate data summaries are available for Guam through the Western Regional Climate Data Center. Historical time-series data from the Guam International Airport is available online, allowing for querying of annual normal of precipitation and temperature.

USDA – Natural Resources Conservation Services – Engineering Letters

United States Department of Agriculture – Natural Resources Conservation Services. (2008). *Rainfall-Frequency and Design Rainfall Distribution for Selected Pacific Islands*. USDA-NRCS Engineering Technical Note No. 3.

Updated rainfall-frequency values for the Territory of Guam, Saipan and Rota, Yap, Chuuk, Pohnpei, Koror, Majuro (Marshall Islands), Tutuila (American Samoa), and Wake Island are included in the report. Durations from 15-minutes to 72-hours and return periods from 1-year to 500-years were estimated based upon data recorded by NOAA NWS over a period of 10 to 48 years. The rainfall records are from recent years with the measurements extending from as early as 1954 up to and including 2006. A rainfall distribution which distributes the rainfall over a 24-hour design storm period was also developed in order to use these rainfall values for hydrologic analysis and design.

Future Projections and Scenarios

Pacific Islands Regional Climate Assessment - 2012

http://www.pacificrisa.org/projects/pirca/

Keener, V. W., Marra, J. J., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.). (2012a). *Climate Change and Pacific Islands: Indicators and Impacts*. Report for the 2012 Pacific Islands Regional Climate Assessment. Washington, DC: Island Press.

The Pacific Islands Regional Climate Assessment (PIRCA) is a collaborative effort aimed at assessing climate change indicators, impacts, and adaptive capacity of the Hawaiian archipelago and the US-Affiliated Pacific Islands (USAPI). PIRCA engages federal, state, and local government agencies, non-government organizations, academia, businesses, and community groups to inform and prioritize their activities in the face of a changing climate.

Together over 100 scientific experts and practitioners contributed to the 2012 PIRCA, an integrated report that serves as a regional contribution to the Third National Climate Assessment (NCA). The 2012 PIRCA examines climate change impacts in Hawai‘i and the USAPI and also assesses the adaptive capacity of Pacific Island communities. Primary responsibility for the PIRCA is shared by the Pacific Regional Integrated Sciences and Assessments (RISA) program, funded by the US National Oceanic and Atmospheric Administration (NOAA) and supported through the East-West Center; NOAA’s National Environmental Satellite, Data, and Information Service (NESDIS) National Climatic Data Center (NCDC); Pacific Climate Information System (PaCIS); and the Pacific Islands Climate Change Cooperative (PICCC), funded by the Department of Interior’s US Fish and Wildlife Service, National Park Service, and US Geological Survey.

Intergovernmental Panel on Climate Change – Fifth Assessment Report: Working Group 1 Report on Future Climate Phenomena

https://www.ipcc.ch/report/ar5/

Christensen, J.H., K. Krishna Kumar, E. Aldrian, S.-I. An, I.F.A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J.K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D.B. Stephenson, S.-P. Xie and T. Zhou. (2013). Climate Phenomena and their Relevance for Future Regional Climate Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

This chapter of the IPCC's 5th Assessment Report assesses the scientific literature on projected changes in major climate phenomena, and more specifically their relevance for future change in regional climates, contingent on global mean temperatures continue to rise.

Due to the extreme climate variability in the Western Pacific due to these phenomena, the projections in this chapter are crucial to understanding possible future conditions and scenarios in CNMI. This is one of the most thorough reviews of literature on future tropical cyclone scenarios, making the chapter particularly relevant to the concerns of Rota and Tinian.

Global Climate Change Viewer

http://regclim.coas.oregonstate.edu/visualization/gccv/cmip5-global-climate-change-viewer/index.html

The Global Climate Change Viewer (GCCV) is used to visualize future temperature and precipitation changes simulated by global climate models in the Coupled Model Intercomparison Project Phase 5 (CMIP5). The application allows the user to visualize projected climate change (temperature and precipitation) for each country, for all available models and all Representative Concentration Pathways (RCP) emission scenarios (2.6, **4.5**, 6.0 and **8.5**). Data from the experiments are binned into 25-year climatologies that span the 21st century. The GCCV also provides access to plots and quantile breakdowns of monthly temperature and precipitation from 1850-2100. In addition, the application includes access to the currently available model simulations from the Last Glacial Maximum (LGM; 21 ka) and mid-Holocene (6 ka), which are part of the Paleoclimate Modelling Intercomparison Project phase 3 (PMIP3). The primary data on which the GCCV is based can be downloaded in NetCDF format using the Earth System Grid Federation (ESGF) data portal. The GCCV application only includes models with unrestricted access, which is a subset of all models available through the ESGF data portal. A full description and documentation of the application can be found in the GCCV Tutorial.

Citation:

Alder, J.R., Hostetler, S.W., Williams, D., 2013. An Interactive Web Application for Visualizing Climate Data. Eos Trans. AGU 94, 197–198. DOI: 10.1002/2013EO220001.

Alder, J.R. and Hostetler, S.W., 2013. CMIP5 Global Climate Change Viewer. US Geological Survey http://regclim.coas.oregonstate.edu/gccv/index.html doi:10.5066/F72J68W0

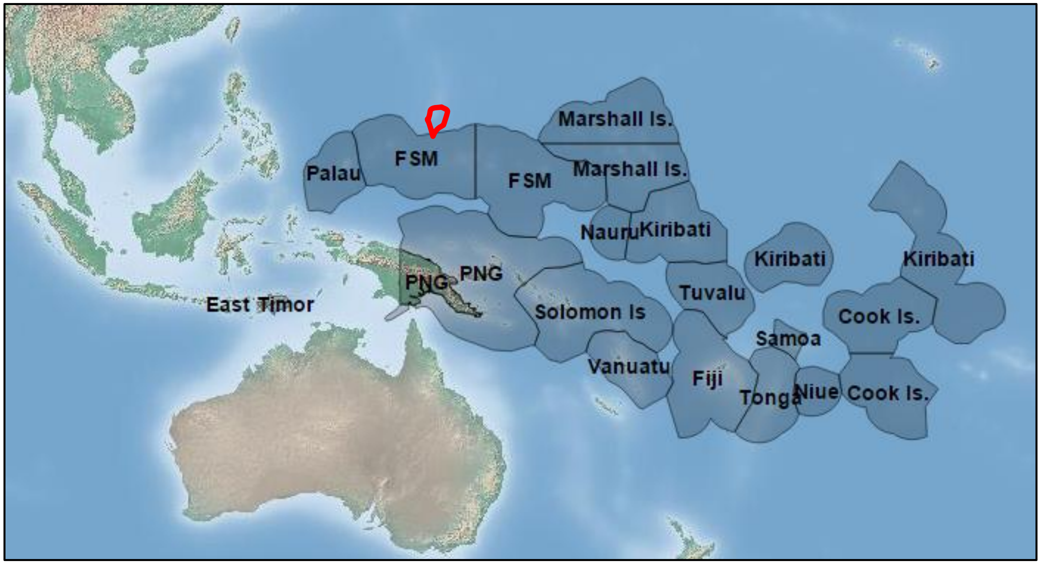
Pacific Climate Futures 2.0 - http://www.pacificclimatefutures.net/en/

Built on CSIRO's Representative Climate Futures Framework (*Whetton et al. 2012*), it includes projections from the global climate modelling experiments (CMIP5) that informed the IPCC's Fifth Assessment Report as well as those used for the earlier Fourth Assessment Report (CMIP3).

The CMIP3 results derive from up to 18 global climate models (GCMs), six of which were dynamically downscaled using a fine-resolution climate model called CCAM. These can be explored for three future time periods (2030, 2055 or 2090) and three emissions scenarios (low-B1, medium-A1B and high-A2). The CMIP5 results are from up to 43 GCMs, six of which were downscaled using CCAM. These projections can be explored for 13 time periods (2030, 2035, 2040...2085, 2090) and four new emissions scenarios (very-low-RCP2.6, low-RCP4.5, medium-RCP6.0 and very-high-RCP8.5).

The Pacific Climate Futures web-tool has been designed to provide information and guidance in the generation of national climate projections and facilitate the generation of data for detailed impact and risk assessments. The tool provides projections for up to 19 climate variables, 14 time periods and six emissions scenarios

Locations of Climate Futures Scenario Projections and CNMI (red)



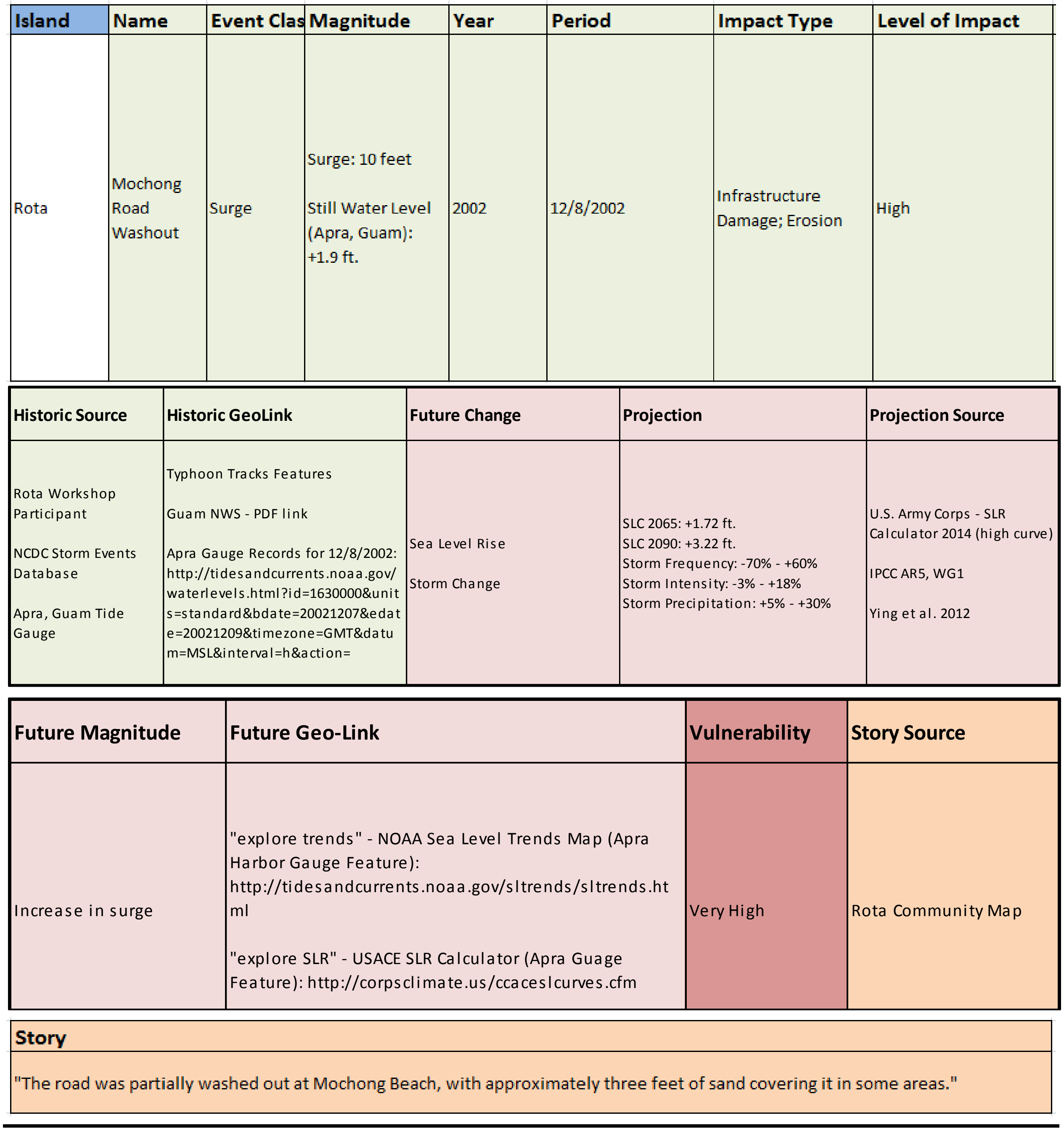
The Climate Futures framework has been developed by CSIRO to provide a mechanism for meeting these requirements. It does this by classifying the projected changes from all available climate models (for a given emissions scenario and future time period) into categories defined by two climate variables. Thus, models can be sorted into different categories or “Climate Futures”, such as “Warmer – Drier” or “Hotter – Much Drier”. A simple table shows the spread in the model results and allows users to explore how this changes under different emissions scenarios and time periods.

The table also shows the amount of agreement among the models (“model consensus”) for each Climate Future. For example, if 14 of 28 models fall into the “Warmer – Drier” climate future, it is given a consensus score of 50%, described as “Moderate Consensus”. Understanding the degree of model consensus for each climate future can help decision makers estimate the likelihoods of particular impacts.

Whetton P, Hennessy K, Clarke J, McInnes K and Kent D. (2012). Use of Representative Climate Futures in impact and adaptation assessment. *Climatic Change* ***115****(3-4):* 433-442. DOI: 10.1007/s10584-012-0471-z.

C. Climate Event and Analog Database

Event ID 1: Mochong Road Washout (Rota)



Island	Name	Event Clas	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Mochong Road Washout	Surge	Surge: 10 feet Still Water Level (Apra, Guam): +1.9 ft.	2002	12/8/2002	Infrastructure Damage; Erosion	High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participant NCDC Storm Events Database Apra, Guam Tide Gauge	Typhoon Tracks Features Guam NWS - PDF link Apra Gauge Records for 12/8/2002: http://tidesandcurrents.noaa.gov/waterlevels.html?id=1630000&units=standard&bdate=20021207&edate=20021209&timezone=GMT&datum=MSL&interval=h&action=	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18% Storm Precipitation: +5% - +30%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in surge	"explore trends" - NOAA Sea Level Trends Map (Apra Harbor Gauge Feature): http://tidesandcurrents.noaa.gov/sltrends/sltrends.html "explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	Very High	Rota Community Map

Story
"The road was partially washed out at Mochong Beach, with approximately three feet of sand covering it in some areas."

Event ID 2: Songsong Coastal Flood (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Songsong Coastal Flood	Surge	Surge: 20 feet Still Water Level (Apra, Guam): +1.9 ft.	2002	12/8/2002	Infrastructure Damage; Property Damage; Erosion	Very High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Guard, et. Al 2003 NCDC Storm Events Database Apra, Guam Tide Gauge	Typhoon Tracks Features Guam NWS - PDF link Apra Gauge Records for 12/8/2002: http://tidesandcurrents.noaa.gov/waterlevels.html?id=1630000&units=standard&bdate=20021207&edate=20021209&timezone=GMT&datum=MSL&interval=h&action=	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18% Storm Precipitation: +5% - +30%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in surge	"explore trends" - NOAA Sea Level Trends Map (Apra Harbor Gauge Feature): http://tidesandcurrents.noaa.gov/sltrends/sltrends.html "explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	Very High	Rota Workshop Participant

Story
"Afterward, you could walk outside and collect fish and (fruit) bats that had been washed out of the ocean and blown from the trees."

Event ID 3: Marlin Wash Up (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Marlin Wash Up	Surge	Surge: 20 feet Still Water Level (Apra, Guam): +1.9 ft.	2002	12/8/2002	Property Damage	Very High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Guard, et. Al 2003 NCDC Storm Events Database Apra, Guam Tide Gauge	Typhoon Tracks Features Guam NWS - PDF link Apra Gauge Records for 12/8/2002: http://tidesandcurrents.noaa.gov/waterlevels.html?id=1630000&units=standard&bdate=20021207&edate=20021209&timezone=GMT&datum=MSL&interval=h&action=	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18% Storm Precipitation: +5% - +30%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in surge	"explore trends" - NOAA Sea Level Trends Map (Apra Harbor Gauge Feature): http://tidesandcurrents.noaa.gov/sltrends/sltrends.html "explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	Very High	Rota Workshop Participant

Story
"After the storm there was a 200 pound blue marlin washed up in front of the Post Office."

Event ID 4: Conservation Area Wild Fire (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Conservation Area Wild Fire	Drought	67.63 in. precip (-44% annual normal)	1998	Jan - Dec, 1998	Habitat and Agricultural Damage	High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participant NCDC Guam WERI	NOAA NCDC Extreme Events Database http://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=5639223	Precipitation Change Temperature Change Storm Change	Precip. 2065: +9.9% Precip. 2090: +9.5% Temp. 2065: +2.22°C Temp. 2090: +3.07°C Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Decrease in Drought (slight increase in precip.)	CMIP5 Global Data Viewer	Moderate	Rota Workshop Participant

Story
"Wildfire was a problem all over the Island that year. It gets worse if people are lighting fires to hunt for the deer, especially if crops are bad."

Event ID 5: Lake Hagoi Emergency Cattle Feed (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Lake Hagoi Emergency Cattle Feed	Drought	43 in. precip (-48% annual normal)	1998	Jan - Dec, 1998	Agricultural Damage; Municipal Water Shortage	Very High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
NMC-CREES Tinian Workshop Participant USGS Guam WERI	NOAA NCDC Extreme Events Database http://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=5639223	Precipitation Change Temperature Change Storm Change	Precip. 2065: +9.9% Precip. 2090: +9.5% Temp. 2065: +2.22°C Temp. 2090: +3.07°C Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Decrease in Drought (slight increase in precip.)	CMIP5 Global Data Viewer	High	Tinian Workshop Participant NWS Guam

Story

“1998, there was nothing for months. Cattle were just falling down because no feed, and it was all dry. The heat was so intense.”

“The first limiting factor on cattle is food, not water. Those cattle were starving to death. It affected the whole herd. There was maybe a 75 to 100% loss rate.”

"We had to cut a tractor path to the center of Lake Hagoi to harvest on a daily basis."

Event ID 6: Teneto Village A-Frame Collapse (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Teneto Village A-Frame Collapse	Storm	Wind: 121 mph; gusts 150 mph Intensity: Category 3 Pressure: 965.5 hPa	2002	12/8/2002	Property Damage	Very High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participant Guard, et al. 2003	Typhoon Tracks Features Guam NWS - PDF link	Storm Change	Storm Intensity: -3% - +18% Storm Frequency: -70% - +60%	IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in Intensity Decrease in Frequency	IPCC AR5 WG1 Linkage	High	Nicholas Song-Song Luis Ayuyu

Story

"My A-Frame in Teneto Village collapsed. We had to rebuild completely."

"Most of the Island ended up with no power or electricity from six months to a year."

Event ID 7: Okgo River Flow Reduction (Rota)

EventID	Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
7	Rota	Okgo River Flow Reduction	Precipitation	1961-1990: 103.04 in. 1971-2000: 100.61 in. 1996-2008: 98.22 in.	1970	1970 - 2015	Water Security	Low

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participant USDA - NRCS Western Regional Climate Center	Western Regional Climate Center - Guam Int. Airport	Precipitation Change	Precip. 2065: +9.9% Precip. 2090: +9.5%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5)

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in water security (slight increase in precip.)	CMIP5 Global Data Viewer	Low	Rota Workshop Participant. Talakhaya/Sabana Conservation Action Plan

Story
"The river used to flow over the roadway in the 70s and 80s, but doesn't do this anymore." "Flows have been substantially curtailed and possibly eliminated by increased use of the water for community water supply."

Event ID 8: Songsong Shoreline Erosion (Rota)

EventID	Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
8	Rota	Songsong Shoreline Erosion	Coastal Erosion	1948-1993 SLR: -0.98 mm/yr. 1993-2014 SLR: 7.23 mm/yr.	1950	1950 - 2015	Erosion, Public Access Loss	Medium

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participants	NOAA - COOPS Sea Level Trends for Apra Harbor, Guam: http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1630000	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in Erosion (short and long term)	"explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	High	Rota Workshop Participant

Story
"The shoreline has just continued to erode over the years. The beach has gotten much smaller in recent decades."

Event ID 9: Disappearing Backyards (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Disappearing Backyards	Coastal Erosion	1948-1993 SLR: -0.98 mm/yr. 1993-2014 SLR: 7.23 mm/yr.	1976	1976 - 2015	Erosion, Public Access Loss, property damage	Medium

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Thomas Mendiola	NOAA - COOPS Sea Level Trends for Apra Harbor, Guam: http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1630000	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in Erosion (short and long term)	"explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	High	Rota Workshop Participant (Thomas Mendiola)

Story
"In 1976 Typhoon Pamela took away lots of the sand, up to my backyard. The sand never came back, and has been continuing to slowly dissapear to the present."

Event ID 10: Disappearing Beaches (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Disappearing Beaches	Coastal Erosion	1948-1993 SLR: -0.98 mm/yr. 1993-2014 SLR: 7.23 mm/yr.	1970	1970 - 2015	Erosion, Public Acces Loss	Medium

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participants	NOAA - COOPS Sea Level Trends for Apra Harbor, Guam: http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1630000	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in Erosion (short and long term)	"explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	High	Rota Workshop Participant

Story
"In the 1970s the beach used to extend out to where the shipwreck is in the water, but has receded to the point where there's almost no beach at all."

Event ID 11: Tonga Cave Storm Shelter (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Tonga Cave Storm Shelter	Storm	Wind: 121 mph; gusts 150 mph Intensity: Category 3 Pressure: 965.5 hPa Surge: 20 ft.	2002	12/8/2002	Infrastructure Damage; Property Damage; Agricultural Damage; Erosion	Very High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participants Guard et. Al 2003	Typhoon Tracks Features Guam NWS - PDF link	Storm Change	Storm Frequency: -70% - +60% Storm Intensity: -3% - +18% Storm Precipitation: +5% - +30%	IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in intensity Decrease in frequency	IPCC AR5 WG1 Linkage	Very High	Rota Workshop Participants

Story
"The cave was used as a Japanese military hospital during WWII, but some used it as a typhoon shelter during Pongsona, and others (storms)."

Event ID 12: Beach Loss at the Swimming Hole (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Beach Loss at the Swimming Hole	Coastal Erosion	1948-1993 SLR: -0.98 mm/yr. 1993-2014 SLR: 7.23 mm/yr.	1970	1970 - 2015	Erosion, Public Access Loss	Medium

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participants	NOAA - COOPS Sea Level Trends for Apra Harbor, Guam: http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1630000	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in Erosion (short and long term)	"explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	High	Rota Workshop Participants

Story
"There are signs of beach retreat around the swimming hole. The beach has been getting smaller over the years."

Event ID 13: Nuisance Ponding in San Jose (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Nuisance Ponding in San Jose	Storm	1970 - 1980: 29 tropical cyclones within 100 nm. (27.5 is decadal average for period 1950 - 2010; 18 for 2000-2010)	1970	1970 - 1980	Temporary flooding	Low

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Tinian Workshop Participants	Typhoon Tracks Features	Storm Change Precipitation Change	Precip. 2065: +9.9% Precip. 2090: +9.5% Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in nuisance flooding	CMIP5 Global Data Viewer	Low	Tinian Workshop Participants

Story
"Back in the 70s these places would collect water during rain storms, and repeatedly flood. This still happens, but not as extreme."

Event ID 14: Marpo Wetland Drought Relief (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Marpo Wetland Drought Relief	Drought	43 in. precip (-48% annual normal)	1998	Jan - Dec, 1998	Agricultural Damage; Municipal Water Shortage	Very High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
NMC-CREES Tinian Workshop Participant USGS Guam WERI	NOAA NCDC Extreme Events Database http://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=5639223	Precipitation Change Temperature Change Storm Change	Precip. 2065: +9.9% Precip. 2090: +9.5% Temp. 2065: +2.22°C Temp. 2090: +3.07°C Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Decrease in Drought (slight increase in precip.)	CMIP5 Global Data Viewer	High	Tinian Workshop Participant NWS Guam

Story
"During the drought water dissapeared from all the temporary wetlands, but the Marpo wetland and well retained just enough for us to get by. All the other areas dried up though."

Event ID 15: Jellyfish Invasion at Taga Beach (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Jellyfish Invasion at Taga Beach	Ocean Chemistry	2001-2005 avg.: 1.4 DHW/Yr 2005-2010 avg.: 0.5 DHW/yr 2011-2014 avg: 3.25 DHW/yr	2010	2010 - 2015	Public Health Concerns, Reduced Marine Ecosystem Function	Low

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Tinian Workshop Participant NOAA Coral Reef Watch	NOAA Coral Reef Watch 50km Annual Composite Products (KML): http://coralreefwatch.noaa.gov/satellite/ge/products/CRW_GE_composites_oper50km_annual.kml	Sea Surface Temperature Increase Ocean Acidification Increase	2035 - 2040 avg.: 8 DHW/yr. Annual Bleaching Conditions/Events Occurring: 2030 - 2040 Ocean pH 2090: -0.30 to -0.32	van Hooidonk, et. Al 2013(a) van Hooidonk, et. Al 2013(b) IPCC AR5, RCP 8.5

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in thermal stress Decrease in calcification	van Hooidonk & Maynard (2013) bleaching projections KMZ: http://coralreefwatch.noaa.gov/climate/projections/picc_oa_and_bleaching/all_in_one_with_word_no_line.gif	Low	Tinian Workshop Participant

Story
"Along the swimming areas off Taga, and out at Taga Reef, there's been an increase in the number of jellyfish out there since about 2010. They've been stinging people in inappropriate locations."

Event ID 16: Algal Growth at Taga Beach (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Algal Growth at Taga Beach	Ocean Chemistry	2001-2005 avg.: 1.4 DHW/Yr 2005-2010 avg.: 0.5 DHW/yr 2011-2014 avg: 3.25 DHW/yr	2010	2010 - 2015	Public Health Concerns, Reduced Marine Ecosystem Function	Medium

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Tinian Workshop Participant	NOAA Coral Reef Watch 50km Annual Composite Products (KML): http://coralreefwatch.noaa.gov/satellite/ge/products/CRW_GE_composites_oper50km_annual.kml	Sea Surface Temperature Increase	2035 - 2040 avg.: 8 DHW/yr. Annual Bleaching Conditions/Events Occurring: 2030 - 2040	van Hooidonk, et. Al 2013a van Hooidonk, et. Al 2013b

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in thermal stress	van Hooidonk & Maynard (2013) bleaching projections KMZ: http://coralreefwatch.noaa.gov/climate/projections/picc_oa_and_bleaching/all_in_one_with_word_no_line.gif	High	Tinian Workshop Participant

Story
"There is an unusual growth of algae in the past five years. My theory is that it's connected to wastewater percolation and bo'bu from the Dynasty."

Event ID 17: Seaport Breakwater Erosion (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Seaport Breakwater Erosion	Surge	1990 - 1998: 19 Tropical Cyclones within 100 nm. (27.5 is decadal average for period 1950 - 2010; 18 for 2000-2010)	1990	1990 - 1998	Infrastructure Damage; Threat to Commerce	Medium

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Tinian Workshop Participant	Typhoon Tracks Features	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in Surge Increase in Erosion	"explore trends" - NOAA Sea Level Trends Map (Apra Harbor Gauge Feature): http://tidesandcurrents.noaa.gov/sltrends/sltrends.html "explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	High	Tinian Workshop Participant

Story
"In the early 90s there was a lot of erosion along the breakwater. There was lots of erosion in general, and the tables that used to be on dry land are now in the water or covered in sand."

Event ID 18: Typhoon Paka Floating Dock Surge (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Typhoon Paka Floating Dock Surge	Surge	(Rota Summary) Winds: 115 mph Intensity: Category 5 Pressure: 948 mb	1997	12/16/1997	Infrastructure Damage; Threat to Commerce	Medium

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Tinian Workshop Participant	NOAA NCDC Extreme Events Database: https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=5625018 Typhoon Tracks Features	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in Surge	"explore trends" - NOAA Sea Level Trends Map (Apra Harbor Gauge Feature): http://tidesandcurrents.noaa.gov/sltrends/sltrends.html "explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	High	Tinian Workshop Participant

Story
"During the storm surge from Paka all the floating docks were lifted up out of the harbor and washed onto the land. They were littered on dry land after the storm passed."

Event ID 19: Coral Bleaching in Tinian Harbor (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Coral Bleaching in Tinian Harbor	Ocean Chemistry	2001-2005 avg.: 1.4 DHW/Yr 2005-2010 avg.: 0.5 DHW/yr 2011-2014 avg: 3.25 DHW/yr	2010	2010 - 2015	Reduced Marine Ecosystem Function; Threat to Subsistence/Fishing	Medium

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Tinian Workshop Participant	NOAA Coral Reef Watch 50km Annual Composite Products (KML): http://coralreefwatch.noaa.gov/satellite/ge/products/CRW_GE_composites_oper50km_annual.kml	Sea Surface Temperature Increase	2035 - 2040 avg.: 8 DHW/yr. Annual Bleaching Conditions/Events Occurring: 2030 - 2040	van Hooidonk, et. Al 2013a van Hooidonk, et. Al 2013b

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in thermal stress	van Hooidonk & Maynard (2013) bleaching projections KMZ: http://coralreefwatch.noaa.gov/climate/projections/picc_oa_and_bleaching/all_in_one_with_word_no_line.gif	High	Tinian Workshop Participant

Story
"Over the past five years the corals in this area have been bleaching. It seems to be happening more now, but there is some new colonization to the north."

Event ID 20: Toxic Run-Off at Leprosy Beach (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Toxic Run-Off at Leprosy Beach	Precipitation	NCDC (90% Complete Data for SIA): 2009-2014: in./yr 76.17 in./yr	2010	2010 - 2015	Public Health Concerns, Reduced Marine Ecosystem Function; Threat to Subsistence/Fishing	Medium

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Tinian Workshop Participant NCDC Annual Climate Summaries, SIA	NOAA NCDC Annual Climate Summaries (map interface): https://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=cdo&theme=annual&layers=1	Precipitation Change	Precip. 2065: +9.9% Precip. 2090: +9.5% Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in run-off and non-point source pollution	CMIP5 Global Data Viewer	High	Tinian Workshop Participant

Story
"The beach and near-shore waters become very toxic after it rains. There is run-off and bo'bu from the landfill and where the leper bodies were dumped long ago."

Event ID 21: Non-Point Source Pollution at Tinian's Bo'bu (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Non-Point Source Pollution at Tinian's Bo'bu	Precipitation	*Saipan 46 yr. (1954-1999) rainfall database as proxy:* 1970-1980: 68.81 in./yr 1981-1990: 80.04 in./yr 1991-2000: 66.48 in./yr NCDC (90% Complete Data for SIA): 2000-2014: 74.89 in./yr	1970	1970 - 2015	Public Health Concerns, Reduced Marine Ecosystem Function; Threat to Subsistence/Fishing	Low

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Tinian Workshop Participant Lander and Guard, 2004 Lander 2004 NCDC Annual Climate Summaries, SIA	NOAA NCDC Annual Climate Summaries (map interface): https://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=cdo&theme=annual&layers=1	Precipitation Change	Precip. 2065: +9.9% Precip. 2090: +9.5% Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in leaching and non-point source pollution	CMIP5 Global Data Viewer	Moderate	Tinian Workshop Participant

Story
"The Chamorro word for these sites is 'Bo'bu'. It's a freshwater outflow from groundwater into the ocean and along the beaches. In some areas the bo'bu are often contaminated."

Event ID 22: Tinian's Emergency Grazing Lands (Tinian)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Tinian	Tinian's Emergency Grazing Lands	Drought	43 in. precip (-48% annual normal)	1998	Jan - Dec, 1998	Agricultural Damage; Municipal Water Shortage	Very High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
NMC-CREES Tinian Workshop Participant USGS Guam WERI	NOAA NCDC Extreme Events Database http://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=5639223	Precipitation Change Temperature Change Storm Change	Precip. 2065: +9.9% Precip. 2090: +9.5% Temp. 2065: +2.22°C Temp. 2090: +3.07°C Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Decrease in Drought (slight increase in precip.)	CMIP5 Global Data Viewer	High	Tinian Workshop Participant NWS Guam

Story
"During the (1998) drought we had to use our emergency grazing lands. These are areas that we don't normally graze on, but the cattle had used up our primary grazing land. All the emergency grazing land is in areas that the military wants to use."

Event ID 23: Nuisance Flooding at the Bank of Guam (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Nuisance Flooding at the Bank of Guam	Precipitation	1961-1990: 103.04 in. 1971-2000: 100.61 in. 1996-2008: 98.22 in. 1989-2013: 59 Tropical Cyclones within 100 nm.	1989	1989 - 2015	Public Health Concerns, Infrastructure Damage	Low

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participant USDA - NRCS Western Regional Climate Center International Best Tracks Archive	NOAA NCDC Annual Climate Summaries (map interface): https://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=cdo&theme=annual&layers=1 Typhoon Tracks Features	Precipitation Change Storm Change	Precip. 2065: +9.9% Precip. 2090: +9.5% Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Slight increase in precipitation Increase in Storm Precipitation	CMIP5 Global Data Viewer	Moderate	Rota Workshop Participant

Story
"Since the late 80s that area (in Songsong) near Bank of Guam has always flooded during heavy rain. It doesn't have to be a typhoon, just a lot of rain. It's bad for access and moving around Songsong."

Event ID 24: As Niebes Flood During Typhoon Chaba (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	As Niebes Flood During Typhoon Chaba	Storm	20.8" Precipitation 958 mb sea level pressure	2004	8/22/2004	Agricultural Damage; Residential Damage	Medium

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participant	NOAA NCDC Extreme Events Database: http://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=5432262 Typhoon Tracks Features	Storm Change	Storm Frequency: -70% - +60% Storm Intensity: -3% - +18% Storm Precipitation: +5% - +30%	IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in storm intensity Increase in storm precipitation Decrease in storm frequency	IPCC AR5 WG1 Linkage	Moderate	Rota Workshop Participant

Story
"During Typhoon Chaba there was a major flood in As Niebes. Over 20 hectares of pasture land was flooded. The place lookedlike a huge lake."

Event ID 25: Coastal Erosion at Teteto and Guata Shorelines (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Coastal Erosion at Teteto and Guata Shorelines	Coastal Erosion	1948-1993 SLR: -0.98 mm/yr. 1993-2014 SLR: 7.23 mm/yr.	1994	1994 - 2015	Erosion, Public Access Loss	Low

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participant	NOAA - COOPS Sea Level Trends for Apra Harbor, Guam: http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1630000	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in Erosion (short and long term)	"explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	Moderate	Rota Workshop Participant

Story
"Since the mid-90s we've lost a lot of sandy beach up at Teteto and Gauta Beach sites. We think it's the rising ocean level."

Event ID 26: Extreme Erosion in the Talakhaya Watershed (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Extreme Erosion in the Talakhaya Watershed	Precipitation	1998-2013: 24 Tropical Cyclones within 100 nm. 1998 Precipitation: 67.63 in. (71.4% of annual normal)	1998	1998-2015	Erosion, Habitat Loss, Lowered Reef Resilience	High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Rota Workshop Participants CNMI Office of the Governor, 2012 USFWS 2007 International Best Tracks Archive Lander & Guard 2003	NOAA NCDC Annual Climate Summaries (map interface): https://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=cdo&theme=annual&layers=1 Typhoon Tracks Features	Precipitation Change Storm Change Temperature Change	Precip. 2065: +9.9% Precip. 2090: +9.5% Temp. 2065: +2.22°C Temp. 2090: +3.07°C Storm Frequency: -70% - +60% Storm Precipitation: +5% - +30%	CSIRO (Pacific Climate Futures 2.0, RCP 8.5) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Slight increase in precipitation Increase in Storm Precipitation and intensity	CMIP5 Global Data Viewer	Very High	Rota Workshop Participants USFWS 2007 CNMI Office of the Governor 2012

Story
"Not just during typhoons, but any rainstorm there's excessive damage and erosion in the Talakhaya mountain area."

Event ID 27: Rota West Docking Facility Damage (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Rota West Docking Facility Damage	Surge	Surge: 20 feet Still Water Level (Apra, Guam): +1.9 ft.	2002	12/8/2002	Infrastructure Damage	Very High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Guard, et. Al 2003 Rota Workshop Participant Apra, Guam Tide Gauge	Typhoon Tracks Features Guam NWS - PDF link Apra Gauge Records for 12/8/2002: http://tidesandcurrents.noaa.gov/waterlevels.html?id=1630000&units=standard&bdate=20021207&edate=20021209&timezone=GMT&datum=MSL&interval=h&action=	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18% Storm Precipitation: +5% - +30%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in surge	"explore trends" - NOAA Sea Level Trends Map (Apra Harbor Gauge Feature): http://tidesandcurrents.noaa.gov/sltrends/sltrends.html "explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	Very High	Rota Workshop Participant Rodney James S.N. Taisacan

Story
"The Seaport facility was badly damaged during the surge, especially the docking facilities. It took over $100,000.00 in repairs for the dock repairs alone."

Event ID 28: Rota East Docking Facility Damage (Rota)

Island	Name	Event Class	Magnitude	Year	Period	Impact Type	Level of Impact
Rota	Rota East Docking Facility Damage	Surge	Surge: 20 feet Still Water Level (Apra, Guam): +1.9 ft.	2002	12/8/2002	Infrastructure Damage	Very High

Historic Source	Historic GeoLink	Future Change	Projection	Projection Source
Guard, et. Al 2003 Rota Workshop Participant Apra, Guam Tide Gauge	Typhoon Tracks Features Guam NWS - PDF link Apra Gauge Records for 12/8/2002: http://tidesandcurrents.noaa.gov/waterlevels.html?id=1630000&units=standard&bdate=20021207&edate=20021209&timezone=GMT&datum=MSL&interval=h&action=	Sea Level Rise Storm Change	SLC 2065: +1.72 ft. SLC 2090: +3.22 ft. Storm Frequency: -70% - +60% Storm Intensity: -3% - +18% Storm Precipitation: +5% - +30%	U.S. Army Corps - SLR Calculator 2014 (high curve) IPCC AR5, WG1 Ying et al. 2012

Future Magnitude	Future Geo-Link	Vulnerability	Story Source
Increase in surge	"explore trends" - NOAA Sea Level Trends Map (Apra Harbor Gauge Feature): http://tidesandcurrents.noaa.gov/sltrends/sltrends.html "explore SLR" - USACE SLR Calculator (Apra Guage Feature): http://corpsclimate.us/ccaceslcurves.cfm	Very High	Rota Workshop Participant

Story
"The East Dock area was badly damaged from the waves. Reconstruction costs were around three million."