Climate Change in the Federated States of Micronesia
Food and Water Security, Climate Risk Management, and Adaptive Strategies

APPENDICES 2010

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APPENDIX 1 – Events, Purpose, Partners, Methods

In the winter of 2007 and again in 2008, coastal communities throughout the Federated States of Micronesia (FSM) experienced unusually high tides that flooded homes, washed out beaches, and undercut and damaged roads and other infrastructure.[3] Drinking water supplies were contaminated and stocks of taro, breadfruit, banana, sweet potato, yam, sugar cane, coconut, citrus, and other foods were damaged or destroyed as seawater inundated coastal wetlands and surged up through the groundwater table. Reports described saltwater in the ground "bubbling up" through freshwater wetlands.[4] Taro fields and other crop sites that had been in use for generations were destroyed; freshwater wetlands turned salty and agriculture on approximately 60 percent of the inhabited islands suffered some damage or was destroyed.[5]

The Governors of Kosrae, Pohnpei, Chuuk, and Yap each announced states of emergency followed by President Emanuel Mori of FSM who declared a nationwide state of emergency on December 30, 2008.[6] Teams of damage-assessment specialists, accompanied by emergency medical personnel and food supplies, travelled by plane and boat to nearly all of the 61 inhabited islands of the nation. Micronesia, which had previously dealt largely in conceptual terms with the impacts of global climate change, suddenly faced the harsh and destructive realities of sea-level rise. Food security was identified as the number one problem in the nation.[7]

Micronesia lies in the heart of the western Pacific where sea-level rise and drought, modulated by a poorly understood connection between global climate change and ENSO[8] variability, is felt first-hand on the shores of low-lying sandy atolls and narrow coastal plains of the high volcanic islands. Balancing developing communities with fragile resources and natural hazards has been an unrelenting challenge. Such hardships have characterized life on these distant atolls since they were first settled two thousand years ago. Climate change, however, is exacerbating these issues.

Chronic coastal erosion as well as erosion associated with inundation events threatens to diminish the already narrow atoll islets and coastal plains of the high volcanic islands. Marine inundation and sea-water intrusion threaten the taro, breadfruit, coconut, and banana grown by nearly every family, casting into doubt the sustainability of dozens of island communities on remote atolls. Land degradation is extensive across the nation. Water supplies and transportation arteries have been interrupted and require costly repairs. Freshwater resources on many atoll islets are no longer able to support some human communities. Émigrés from the outer islands are moving to the main islands of each state straining infrastructure and the capacity of government to provide assistance.

In the course of international climate-treaty negotiations, the FSM government has stated that it is unwilling to become a nation of climate refugees.[9] Now, faced with the challenge of remaining on islands that were initially settled thousands of years ago by seafaring ancestors in open canoes, Micronesia must determine how to climate-proof its communities in the 21st century.[10]

Purpose

The objectives of this study are to: 1) assess the extent and consequences of sea-level rise, including food and water security, coastal erosion, and marine inundation on communities in the FSM; 2) meet with government officials to initiate development of a comprehensive coastal management strategy; and 3) describe adaptive strategies that utilize ecosystem services for managing impacts of sea-level rise.

Study Partners

This study was made possible through a partnership of the following entities: the National Government of the FSM, Office of Environment and Emergency Management (OEEM); the individual state governments of Micronesia; Kosrae, Pohnpei, Chuuk, and Yap; the U.S. Forest Service, Institute of Pacific Islands Forestry

(Agreement No. 08-PA-1 1272177-106 Ecosystem Services in the Face of Global Climate Change); the U.S. Geological Survey; the University of Hawai'i at Manoa; and the Mark and Joann Schindler Coastal Geology Fund at the University of Hawai'i Foundation.

Study Methods and Logistics

This study was initiated at the request of the federal and state governments of FSM and the U.S. Forest Service. Using internet resources, scientific journals, and reports and personal accounts provided by partners, investigators reviewed previous work on coastal issues in the FSM. Investigators also reviewed: 1) the state of knowledge describing coastal environmental response to sea-level rise; 2) the extent of scientific understanding of sea-level rise and variability; and 3) the status of global climate change. Reference materials are described in footnotes throughout this report.

From April 14–16, 2009 partners convened in Majuro, Republic of the Marshall Islands, at a conference entitled "Climate Change and the Micronesia Challenge: Ways Forward in Collaboration and Adaptation." There, representatives of the governments of Palau, FSM, Guam, the Commonwealth of the Northern Mariana Islands, and the Republic of the Marshall Islands summarized climate impacts, described government initiatives and engaged in activities to formulate goals and prioritize adaptation initiatives. Between April 17 and May 6, 2009 investigators were guided to field sites with representative coastal problems, assessed and recorded relevant data, interviewed state and federal resource personnel, met with island communities, and familiarized themselves with local to national management policies and strategies.

Climate Risk Management

"Climate Risk Management" or "CRM" is a generic term referring to an approach to climate-sensitive decision-making increasingly seen as the way forward in dealing with climate variability and change.[11] The approach seeks to promote sustainable development by reducing the vulnerability associated with climate risk. Climate Risk Management involves proactive "no regrets" strategies aimed at maximizing positive and minimizing negative outcomes for communities and societies in climate-sensitive areas such as the coastal zone, agriculture, food security, water resources, and health. The no regrets aspect of CRM relates to the adoption of climate-related decisions or actions appropriate in themselves to development goals, whether or not a specific climate threat materializes in the future.

The National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS) co-hosted a "Sea-Level Rise and Inundation Community Workshop" in Washington D.C. in December, 2009. The draft proceedings of that workshop declares

> The vulnerability of coastal communities to coastal inundation is increasing. The impacts affect nationally significant economies, critical infrastructure, and ecological, public health and social services. Inundation from coastal storms and inland flooding, exacerbated by long-term erosion and climatic variations, such as El Nino events on the west coast, already poses a substantial risk to communities ranging from major urban centers to smaller coastal-dependent communities. The risk is projected to increase due to continued coastal development, changes in the frequency and intensity of inundation events, and, critically, acceleration in the rate of sea-level rise along our vulnerable shorelines.

The desired outcome of the workshop was to develop a "shared framework" for a broad partnership to reduce coastal vulnerability and increase coastal resilience at local and regional levels: "The most important thing is for coastal communities to get started in preparing for a future with a higher stand of sea level and more frequent flooding." The planning framework emerging from the workshop (below) provides a strategy for moving forward.

- o Define the Problem
- o Explore the issues of sea-level inundation with the community.
- o Develop a shared vision of what is at risk and what qualities to protect.
- o Form a steering committee of stakeholders.
- o Gather Data, Information, and Tools
- o Make maps of the problem on time scales of concern (5, 10, 25, 50 years).
- o Identify and value the assets at risk.
- o Develop models and monitoring of flooding hazards.
- o Identify and Explore Alternative Strategies
- o Identify strategies for dealing with inundation scenarios.
- o Develop guidance/policies.
- o Stage strategies on appropriate time scale.
- o Build and Sustain Capacity and Support
- o Align existing programs.
- o Build the institutional capacity and the political will to execute strategies.
- o Institutionalize the program and keep current.

Vision and Primary Findings

Climate change is affecting the FSM. The impacts threaten food and water security, island and oceanic ecosystems, the fabric of culture, the national economy and the future of communities throughout the nation. Climate change, in the words of FSM President Emmanuel Mori "…has continued to threaten food security and our very existence."[12]

This document assesses climate-related events in Micronesia, explores the climate risk of Micronesian communities and describes proactive steps to adapt to changing climatic conditions. The strategy described here aims to achieve this vision in a way that minimizes land degradation, protects and employs the services offered by the natural environment (ecosystem services), promotes food and water security and economic prosperity, and embraces the nation's traditional culture.

This study finds that a national strategy to manage climate risk would facilitate adapting to climate changes. The population of FSM is relatively small. It is projected to reach 105,830 by the year 2015; equivalent to a modestly sized U.S. city (e.g., Cambridge, Massachusetts; Clearwater, Florida; West Covina, California).[13] A community of this size would rank ~242 on a list of U.S. cities by population. It is entirely possible to significantly redevelop such a community, even with the geographic challenges of the FSM, over the course of several decades. However, redevelopment is most likely to achieve success with policies and adaptation designs that emerge from community involvement. If local communities and non-governmental organizations become stakeholders in crafting, supporting, and promulgating new policies, the opportunities for success are likely to be strong.

It is easy to question the practicality of nationwide adaptation to climate change. However, rising seas and drought allow for no clear alternatives. Marine inundation is being experienced by FSM communities now; addressing climate risk complexities can begin as soon as possible. Lack of planning and action at this time will result in a growing population of displaced climate migrants with no coherent strategy to accommodate their needs, probably leading to economic and social stress within the FSM.

Land is scarce. Because sustainability has always depended on appropriate land management, decision-making has traditionally rested with local communities, their leaders, and those with land use privileges and tenure. Hence, in the FSM, land equals power and land possession, occupancy (i.e., tenure), and rights of access and use influence political relationships and decision-making.[14] Therefore, among the strategies indicated here are to view climate risk management as an opportunity to strengthen the FSM for the 21st century, and to start a vigorous climate change education program focused on local communities, non-governmental organizations, land owners, land-tenured decision-makers, permitting authorities and staff, and the public. Thus, Micronesians will come to "own" the problem and see the limited but necessary solutions needed for the very survival of their nation.

In summary, this study identified the following four primary findings:

1. A national strategy to manage climate risk is critically important to the future of the FSM.
2. The need to undertake climate risk management is an opportunity to strengthen and enhance the nation.
3. Effective climate risk management will begin with a vigorous climate change education program for local communities, non-governmental organizations, landowners, land-tenured decision-makers, permitting authorities and staff, and the public.
4. Community-based adaptation that involves stakeholders throughout FSM is consistent with the traditional community values prominent in Micronesian culture.

APPENDIX 2 – The Federated States of Micronesia

The FSM is a young nation of islands in the vast ocean of the western Pacific. The FSM emerged as an independent nation from the former United Nations Trust Territory of the Pacific Islands following establishment of a Compact of Free Association (November 1986) with the United States of America.[15] The country consists of four states, which are, from west to east, Yap, Chuuk, Pohnpei, and Kosrae.[16] The political structure, which has bearing on how climate problems are managed, is such that each state has considerable autonomy within the federation, but their union provides greater resources to face the challenges of environmental management and offers a single presence on the stage of world affairs.[17]

By the most recent count (2009) the total population of FSM is approximately 107,973.[18] The population grew until 2007, and has since been declining with projections for decreases to continue to 2015 when it is expected to fall to 105,830. The State of Chuuk accounts for roughly one-half the total, with a population of 53,106; Pohnpei has the next largest with 34,840. The State of Yap has approximately 11,780 people, and Kosrae has a population of approximately 8,247. Since the Compact of Free Association permits FSM citizens to enter the U.S. freely, to maintain "habitual residence" and to pursue education and employment, upwards of 15,000 Micronesians are currently living in the U.S. – 7,000 in Guam, 3,000 in the Commonwealth of the Northern Mariana Islands, and the remainder in Hawaiʻi or on the mainland U.S. The number of people who actually emigrate to the U.S., however, remains relatively low as most FSM citizens eventually return to FSM.

Community

On the national flag of the FSM, a sea of blue holds four white stars, one for each state. The flag design symbolizes the view that while Micronesia is characterized by many cultures, languages, traditions and community practices, they are joined, not separated, by the vast Pacific Ocean. However, the creation of a national identity has not been easy. Numerous ethnic groups are gathered within the FSM, and while these groups have, at times, assumed a unified identity when dealing with external powers, individuals maintain strong ethnic affiliations and a diversity of interests. Ethnic differences are often at the heart of political contention between the states and also contribute to local disputes. Even so, depending on the context, other distinctions, including village, class, kinship, and religious affiliation, can take precedence in defining islander identity.

This complex socio-geographic identity will govern the success or failure of attempts to manage climate risk. Against the backdrop of complex political allegiances and traditional affiliations, decisions regarding managing climate risk must have local acceptance to be successful. It has been said that the true locus of authority in island communities "…is the community itself. An able chief is respected and listened to, but he founds his authority on his ability to listen."[19] Hence, it was a test of methodologies in the 1990s when federal and state forestry offices attempted to change watershed management policies on Pohnpei and were rebuffed by communities that had not been included in the planning and design process. Starting over, agency staff engaged local land users, provided communities with education on the need and strategy for new policies, geared rules to accommodate established practices, and eventually reached success in implementing a new natural resource management policy on Pohnpei.

The lesson is clear: climate risk management in FSM is likely to be most successful if planned and designed hand-in-hand with a well-educated and motivated community. This can come from a climate awareness campaign within each state that spends time working with local communities and their leaders, forms partnerships with local stakeholders and non-governmentalal organizations, and has a planning structure that involves landowners and those with land use rights. When the community most affected by climate change is involved in designing the tools to manage climate risk, the likelihood that adaptation steps will be successfully implemented is increased significantly. This is the core of community-based adaptation.

Geography and Geology

The FSM consists of over 607 islands of which 61 are inhabited.[20] The islands vary in topography from low-lying atoll islets[21] (typically forested islets on or near atoll rims or within lagoons[22]) found in Yap, Chuuk, and Pohnpei, to densely vegetated, eroded volcanic peaks of several hundred meters elevation.[21] The main island (or group of islands) in each state is of volcanic (or in Yap's case tectonic) origin and surrounded by a coral reef. Atoll islets typically have average elevations of less than 3 m above mean sea level with peak elevations of around 7 m.[23]

Hein and others describe the geography of FSM.[24] Yap is the westernmost state and has a total land area of 118.9 km^2 and lagoon area of 1,049 km^2. The main Yap islands consist of an elongated, partially submerged and eroded tectonically uplifted edifice (an accretionary prism), about 24 km long and encompassed by a fringing- to barrier-reef and lagoon com¬plex. Chuuk consists of seven major island groups, the largest being Chuuk proper: a complex of 98 islands, 14 of which are volcanic, surrounded by a barrier reef enclosing 2,072 km^2 of lagoon. Chuuk sits atop a submerged shield volcano, with a triangular lagoon approximately 55 km to a side. Within the lagoon are numerous reef and volcanic islands, the latter rising as much as 442 m above sea level, some with fringing reefs. The atoll islets within the lagoon and at the margins of the lagoon rise typically less than 3 m above sea level. Pohnpei is mountainous, with 342.4 km^2 of land area and 769.7 km^2 of lagoon. Pohnpei is a volcanic island that hosts the highest peaks in the FSM: Totolom (Dolohmwar) at 791 m and Mt. Nahna Laud at 798 m. Kosrae has 111.9 km^2 of land and no lagoon, although there are three natural harbors on the island located at breaks in the fringing reef. The indigenous and modern cultures of the FSM vary through the states, and eight different indigenous languages are spoken.

Atoll Islets

Atolls are low-elevation oceanic environments that arise from submerged volcanoes. They consist of a reef rim enclosing a lagoon of variable depth (~5–80 m). The lagoon may be completely enclosed or contain passages through the reef that allow water exchange with the open ocean. Limited seawater exchange also occurs over the shallow atoll reef rim between islets. Sand and cobble islets may populate the reef rim and interior lagoon. The shape of atolls is controlled by three fundamental processes: 1) volcanic island formation followed by slow subsidence of the oceanic crust; 2) reef growth along the volcano margins which continues past the stage when the volcanic rocks are completely submerged; and 3) chemical weathering of the reef limestone when they are exposed to the atmosphere during lower stands of the sea (during an ice age or other global cooing event).[25] There have been relatively few drilling programs on atolls, but these indicate that eroded Pleistocene reef limestone, often dated to the last interglacial period (ca. 125,000 years ago), occurs at depths of 8–28 m below the surface of the modern platform.[26] During ice-age sea-level low stands, the reef platforms are exposed to weathering processes including (presumably) significant dissolution. Following the last ice age (ca. 21,000 years ago), sea-level rose from approximately 120 to 130 m below present, and reef growth either kept pace, or lagged somewhat behind the rapid rise in water level. The tops of many reef platforms were flooded by the rising sea around 8000 years ago, resulting in 10+ m of reef growth and sediment deposition. There are only a few atolls on which last interglacial limestone has been identified at the surface; for example, Aldabra in the western Indian Ocean, Anna in French Polynesia, and Christmas Island in eastern Kiribati. Hence, it is assumed by most researchers that atolls largely consist of relatively recent reef growth and sediment deposition that continues today. These materials hold the aquifer systems and form the limited soils that atoll communities depend upon.

Dozens of atoll islets in the FSM are occupied by human communities of a few hundred people each. These islets are composed of sedimentary accumulations of calcium carbonate ($CaCO_3$) sands and cobbles derived from the skeletal fragments of reef-dwelling organisms including coral and various carbonate-secreting algae. These deposits may be lithified, meaning that the originally loose sedimentary grains have been bound to one another (cemented) by precipitation of inorganic $CaCO_3$ which develops when interstitial water is oversaturated with dissolved calcium carbonate. Microcrystals of the mineral calcite form around and bind together sedimentary grains, and the formerly loose deposit becomes a solid body.

Cemented deposits are forms of limestone and are found as lithified beach sands (beach rock), fossil reef (*reef rock*), coral heads, sand, and other carbonate debris on the shoreline or stranded on the reef flat (*conglomerate platforms*), cemented ridges (*ramparts*), or dune sands (*eolianite*). Cemented deposits are considered fixed and will presumably be broken up and redistributed, or overrun and drowned in place by rising seas. Cemented deposits may extend beneath the surface of atoll islets and form an important component of their internal structure, known as a *reef-flat plate* (see main report). The same unit may also form a protective rampart on the shoreline that counteracts coastal erosion. Loose sedimentary deposits, however, may presumably be transported in various directions (seaward, lagoonward, or along the shore) and redeposited by physical oceanographic processes. Some researchers hypothesize that the tendency for high water events to carry sediment from the reef margin into island interiors may allow these islands to accrete upward with rising sea level.[27] The islet landform might thus persist under a regime of accelerated sea-level rise associated with global warming. Other researchers speculate that atoll islets are pinned on the reef by ramparts and when rising waters breach these cemented deposits on oceanic shores, the islet will become unstable and rapidly erode out of existence.[28]

The debate among geologists regarding the fate of atoll islets neglects one very important point: marine inundation, the same process that carries sediment to the island interior, is extremely damaging to atoll freshwater supplies, the soil, the forests that supply food, and the wetlands in which island residents grow taro as a consumable staple. Long before the question of atolls surviving sea-level rise is settled, communities will have been forced to abandon these environments unless a climate adaptation strategy is developed that provides them with potable water and sufficient food. Key questions persist however: What are the recovery rates of groundwater, soil, wetlands and other necessary resources after they have been intruded by marine overwash events? Are there adaptation measures that will accelerate recovery rates? Can overwash events be anticipated and incorporated into planning so that community recovery (resilience) is enhanced? Are there key settings on atolls where adaptation steps can protect critical resources? What are the hydraulic properties of atoll aquifers and how severely are they damaged by individual inundation events? Are adaptation strategies available that may promote continued habitation of atolls even if they are inundated on an annual basis? Providing answers to these and other questions, and filling other key data gaps, constitute an important aspect of managing the climate risk in the FSM.

Atoll Hydrology

The reef framework of atolls is typically highly porous (as high as 50 percent porosity). Sea level rises during interglacial periods and falls during glacial periods over a vertical distance of about 120–130 m. Over the past half-million years this cycle repeated approximately every 100,000 years, though with varying vertical amplitude to sea-level change. During a low sea level, carbonates, exposed to the atmosphere, typically experience chemical dissolution, and during a high sea level a reef will accrete on the eroded surface. These changes affect carbonate deposition on atolls creating a mosaic of limestone stratigraphy that greatly influences the distribution of groundwater resources.

Atoll aquifers consist of a layer of freshwater floating on saltwater. Recharge from rainfall typically forms a thin lens of freshwater that is buoyantly supported by denser underlying saltwater, and mixing forms a zone of transitional salinity. The thickness of this mixing zone is determined by the rate of recharge, tidal dynamics, and hydraulic properties of the aquifer. The freshwater zone of atoll islets is formed largely within unconsolidated sand and gravel, with some coral and a few cemented layers of sandstone and conglomerate.[29] The freshwater portion of the aquifer typically follows along the long axis and elongated shape of the islets. The maximum elevation of the water table is near or slightly above mean sea level. The thickest part of the freshwater lens, which may reach several tens of meters, may be located near the center of the islets in areas where there is a greater abundance of fine-grained and less-permeable sediment or on the lagoon side if that location is characterized by finer-grained sediment. Fine sediment has reduced permeability and thus retains water. The center of islets is also typically the lowest point; hence, wetlands and open pools of water fed by the aquifer are not uncommon. Factors that control the thickness of the freshwater lens include variation in rainfall and recharge, shape of the landmass, and lithologic variability that controls permeability.[30] The freshwater–saltwater transition zone is commonly twice as thick as the freshwater lens it underlies, indicating high dispersion from tidal mixing.

The hydrogeologic framework[31] of an atoll islet is conceptualized as four units.[32] The islet itself constitutes the first unit; catching rainfall, a fraction of which is lost to evaporation and transpiration (by plants), islet sediments form a freshwater lens fed by infiltration. There is no surface runoff due to the high permeability of the soil and sediments.

The second unit is the reef-flat plate. The reef-flat plate consists of well-cemented reef cobbles, sands, and other carbonate sediments and runs from the seaward reef flat, under the islet, and thins toward the lagoon shore. The plate forms a stable foundation upon which the islet sediments accumulate. The plate is usually no more than 3–5 m thick and acts as a confining bed to the underlying unconsolidated sediments.

Beneath the plate is a layer of unconsolidated Holocene sediments consisting of fragments of coral, *Halimeda* (a reef-dwelling calcareous alga), and foraminifera. These sediments hold a freshwater lens that may be thickest on the lagoon side of islets if the unit has highest permeability (coarse sediment) on the ocean side and lower permeability (fine sediment) on the lagoon side, thus retaining water.

The fourth unit is the highly permeable Pleistocene limestone beneath the island that was deposited during the last interglacial period, lying approximately 8–28 m below the surface of the modern reef platform. The high permeability of this basement unit is due to erosion and dissolution under lower sea level. This unit typically contains seawater and a thin transition zone where the freshwater lens in the overlying Holocene unit extends to this depth.

The atoll island groundwater system has two components of flow: short-term vertical fluctuations that are driven by tidal stresses, and long-term average flow that is driven by rainwater recharge and subsequent withdrawal. Recharge is the source of freshwater that drives long-term groundwater flow. In the aquifer, hydraulic conductivities control the flow of freshwater and the extent of freshwater–seawater mixing, and the bulk porosity determines the amount of water stored in the aquifer. The thickness of the mixing zone is reduced by an increase in the ratio of island width to length, and bank margin fractures found within the fringing reef system that penetrate the island aquifer tend to increase the thickness of the mixing zone. Tide fluctuations create "pumping" that enhances the mixing process within the pores of fracture networks. Fractures in the fringing reef are likely the seawater conduits responsible for reports of salty water "bubbling" up into islet freshwater wetlands.

APPENDIX 3 – Climate Change, Realities

Climate in FSM is tropical and relatively uniform with temperatures typically ranging between 21°C and 30°C and typical humidity over 80%. Rainfall varies from over 900 cm per year in the mountainous interior of Pohnpei (considered by some the wettest spot on Earth) to about 300 cm per year on other islands.[33] There is heavy year-round rainfall, especially in the eastern islands and the nation is located on the southern edge of the western Pacific typhoon belt with occasionally severe damage.[34] Micronesia has a tropical climate, which is influenced by the northeast trade belt. Strong trade winds prevail from December through April, while weaker winds, westerlies, and doldrums occur from May to November. Like other islands, FSM suffers from occasional natural hazards such as marine inundation due to storm surges, high wave overtopping and extreme tides, droughts and periods of intense rainfall, cyclones, tsunamis, earthquakes, and landslides. Exacerbating these, and especially threatening sustainability in the coastal zone of the FSM, is climate change.

Global Warming

Global warming is the subject of intense study.[35] The potential impacts of warming on the coastal environment include sea-level rise, reef impacts due to ocean acidification and heating, changes in storminess, and changes in processes associated with the ENSO.

Global mean sea level is rising[36] principally as a result of atmospheric warming.[37] Sea-level rise threatens coastal communities and ecosystems, and planners are engaged in assessing options for meeting this threat.[38] Accordingly, it is essential to have an estimate of peak sea-level rise this century to properly design mitigation and adaptation strategies for coastal assets. A target sea level by the end of the 21st century will allow: 1) estimates of future coastal erosion, salinization of water and soil resources, inundation by high water events, and assessments of risk to coastal infrastructure, communities, resources, and ecosystems; 2) development of new responsive management policies and adaptation strategies that integrate climate change science with community and ecosystem planning.

Modeling and direct observations document that Earth's ice volume is decreasing[39] and air temperature is increasing in relation to global warming.[40] As a result, sea level is rising and the rate of rise is accelerating.[41] Studies indicate that a global mean rise of approximately 1 m by the end of the century is likely and constitutes an appropriate planning target at this time.[42] However, sea-level rise will have important local variability that planners can consider as knowledge of that variability improves.[43] Global mean sea level may rise significantly more than 1 m, but is unlikely to rise significantly less.[44] Important questions remain regarding the meltdown rate of ice in West Antarctica and southern Greenland. Also unknown are the actual levels of natural climate variability and greenhouse-gas accumulation that will be reached later this century.[45] However, even if atmospheric composition were stabilized today, global warming and sea-level rise would continue,[46] with sea level rising at rates that are several times greater than the observed rise of the 20th century.[47]

Altimeter measurements indicate that global mean sea level has risen 4.5 cm from 1993 to 2008 at a rate of approximately 3 mm/yr (3.3 ± 0.4 mm/yr). However, this rise is not uniform across the oceans. A map of altimeter measurements depicting the rate of sea-level change since 1993 is included in the main report.[49] Rates are contoured by color: light blue indicates regions where sea level has been relatively stable; green, yellow, and red show areas of sea-level rise; blue and purple indicate areas of sea-level fall. This complex surface reflects the influence of warm and cool bodies of water, currents, and winds.

Sea-level rise in the western Pacific approaches 10 mm/yr. This pool of rising water has the signature shape of a horseshoe, which is typical of the Pacific Decadal Oscillation (PDO). The PDO is a basin-wide pattern of sea-surface temperature consisting of two phases, each commonly lasting 10 to 30 years.[50] In a positive phase of the PDO, surface waters in the western Pacific above 20^{o} N latitude tend to be cool, while equatorial waters in the central and eastern Pacific tend to be warm. In a negative phase, the opposite pattern develops: surface waters in the western Pacific tend to be warm, and equatorial and eastern waters tend to be cool. Hence, rapid sea-level rise in the western Pacific is consistent with surface warming during the current negative phase of the PDO.

This pattern has also been interpreted as an extended La Niña condition, which in the western Pacific corresponds with periods of elevated sea level.[51] Further, because of sea-level variability in some locations in the Pacific (i.e., Chuuk and Yap in FSM), temporary increases in sea level from storms, tides, and ENSO events raise the sea level even higher than is projected for the next century. The degree to which this pattern contributes to the global mean rate of sea-level rise observed in satellite altimetry is not known.

Climate Change among Island States

The U.S. Global Change Research Program studied the impacts of warming on U.S. islands. They released a report in June 2009 that predicts climate impacts will include the following:

1. The availability of freshwater is likely to be reduced, with significant implications for island communities, economies, and resources.
2. Island communities, infrastructure, and ecosystems are vulnerable to coastal inundation due to sea-level rise and coastal storms.
3. Climate changes affecting coastal and marine ecosystems will have major implications for tourism and fisheries.[52]

There are several areas of general concern with regard to the impact of climate change on islands: increased surface temperature, freshwater resources, changes in storminess including increased rainfall intensity, public health and safety, ecosystems and biodiversity, ocean acidification and warming, impacts to food security and sea-level variability. To some extent these six are interrelated and encompass several phenomena:

- Pacific islands will possibly be affected by:
    - o changes in patterns of natural climate variability in ENSO
    - o changes in the frequency, intensity, and tracks of tropical cyclones
    - o changes in ocean currents and winds
- Increases in extreme tides and greater frequency in marine inundation due to sea-level extremes (FSM has already experienced this).
- Sea-level rise, both long-term and episodic, is already an extremely important issue for many Pacific islands. Sea-level rise results in coastal erosion, inundation, and seawater intrusion into freshwater ecosystems and coastal agricultural zones.
- On low islands with aquifer systems near sea level, it is possible that climate change and the resulting sea-level rise will adversely affect water supplies in the future through more frequent droughts, floods, and seawater intrusion into freshwater lenses; on high islands, decreased rainfall may threaten water availability and increased rainfall intensity may produce mass wasting events, flash flooding, and impacts to communication.

- Some models suggest more persistent El Niño-like conditions across the Pacific while others project that ENSO extremes are likely to increase with increasing greenhouse gas concentrations leading to a reduction of freshwater resources where rainfall is tied to the ENSO. However, climate models do not agree on how ENSO will change with continued global warming.[53]
- The number of intense storms (hurricanes, typhoons, and heavy rain events) is likely to increase.
    - o Hurricane wind speeds and rainfall rates are likely to increase with continued warming.
    - o The peak speed of the most intense storms has already been observed to increase.[54]
    - o Significant uncertainty remains about how increasing global temperatures will affect overall hurricane and typhoon frequency and tracks.
- It is possible that increases in the frequency or intensity of hurricanes would generally favor invasive species.
- Island biodiversity is threatened by invasive non-native plant and animal species, as well as urban expansion, resulting in island extinction rates exceeding those of all other regions of the U.S. Invasive species are often more resilient and tolerant of drought and other environmental extremes conveying a survival advantage over endemics.
- Increased extinction rates of mountain species that have limited opportunities for migration and declines in forests due to floods, droughts, or increased incidence of pests, pathogens, or fire also pose concerns.
- The unique "cloud forests" located on high islands occupy a narrow geographical and climatological niche and a shift in temperature or precipitation patterns would cause this zone to migrate upwards enough to be eliminated. Two processes may lead to shallowing of the cloud band: a rise in the lifting condensation level, or a fall or no change in the trade wind inversion level.
- On islands, a large percentage of people, infrastructure, and economic activities are located near the coast, leading to dense areas of vulnerability. It is possible that the frequency of extreme events may increase with warming, thereby increasing the risk to public health and safety. Improving community resiliency to disasters is now a major goal of federal and local coastal management agencies in the U.S.
- Coral bleaching associated with El Niño, warming seawater events, and long-term chronic warming of surface waters has occurred in both the Pacific and Caribbean since the 1990s.
- Ocean acidification threatens reefs and calcareous plankton in the oceans worldwide.
- Tropical winds in the Pacific have weakened, a phenomenon that may also be related to changes in rainfall (rainfall changes have not been detected in FSM).

Tide-Gauge Records

Local relative sea level in the FSM is measured by tide gauges maintained by the University of Hawai'i Sea Level Center (Figure A). There is no tide station for Kosrae, and the Chuuk station was terminated in 1994. The record at Pohnpei indicates a long-term rising sea level at 3.10 mm/yr, and relative sea level in Yap is rising slower at 0.42 mm/yr. Yap Island is affected by tectonic uplift associated with plate flexure adjacent to the Yap Trench. The Yap and Pohnpei records both show high variability in sea level that is consistent with ENSO/PDO climatology. The FSM generally experiences rapid sea-level rise during periods of protracted La Niña conditions related to persistent trade winds in the north Pacific. In Pohnpei rapid sea-level rise began in approximately 2002–2003, lagged by Yap where sea level accelerated in approximately 2005. These rapid trends are reflected in the satellite altimetry map, which shows a well-developed warm pool in Micronesia. Ensuing El Niño conditions can be expected to decrease trade winds. Whether this will reduce the regional rate of sea-level rise in coming years is unknown.

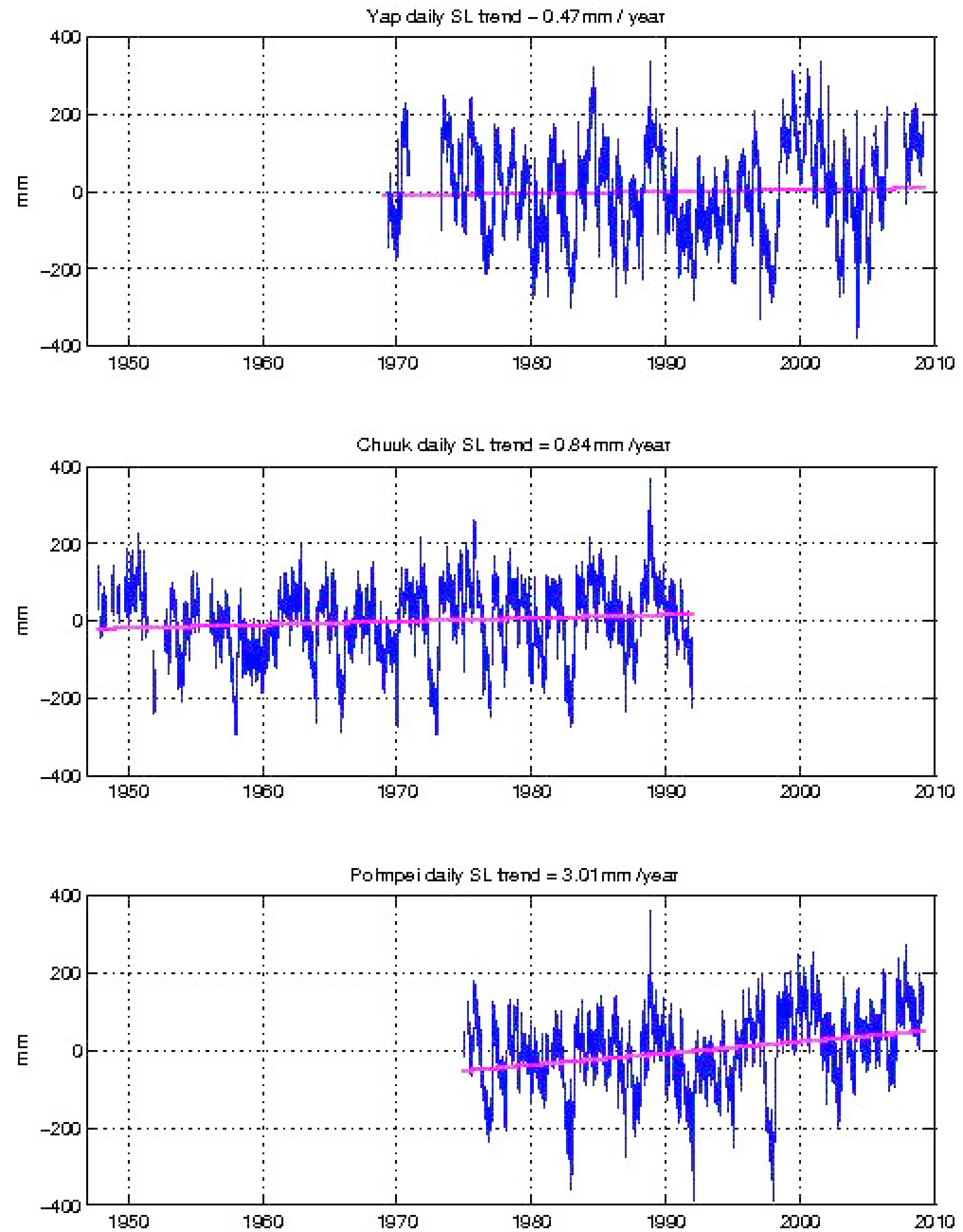


Figure A. Tide records of Yap, Chuuk, and Pohnpei, FSM.
(Source: University of Hawai‘i Sea Level Center).[55]

Micronesian Climate Adaptation Concepts

A conference was convened entitled “Climate Change and the Micronesia Challenge: Ways Forward in Collaboration and Adaptation,” April 14–16, 2009 in Majuro, Republic of the Marshall Islands. There, representatives of the governments of Palau, FSM, Guam, the Commonwealth of the Northern Mariana Islands, and the Republic of the Marshall Islands summarized climate impacts, described government initiatives, and engaged in activities to formulate goals and prioritize adaptation initiatives. Working groups identified challenges and opportunities related to climate adaptation. They also described adaptation strategies in terms of unfunded and funded scenarios.[56]

Guam- Commonwealth of the Northern Mariana Islands (CNMI)

Challenges:

1. Lack of baseline data and strategy
2. Perception and low awareness of climate change
3. Overwhelming immediate/acute issues that force climate change to take a “back-seat” to competing issues and concerns

Opportunities:

1. Guam/CNMI partnership and collaboration
2. Opportunities for better policy and infrastructure and exploration of alternative energy

Palau

Challenges:

1. Lack of national framework, including policy and planning
2. Lack of coordination
3. No clear definition of adaptation strategies to allow resource managers and practitioners to work together

Opportunities:

1. There is capacity and willingness to do the work
2. Second national Communication IPCC provides strategies

Federated States of Micronesia

Challenges:

1. Limited technical capacity and resources
2. Sustainable financing, access to international funding and resources

Opportunities:

1. Access to international funding and technical assistance
2. Chance to engage all stakeholders (communities and policy makers)
3. Climate change receiving exposure at local traditional activities as a means of expanding public awareness
4. Incorporate climate change adaptation lens into existing on-the-ground programs that are ongoing with NGOs and other government sectors in various parts of FSM
5. With new funding it may be possible to implement climate change adaptation policies at the appropriate scale across various sectors
6. Potential leaders and major stakeholders are already included within existing plans
7. Monthly weather broadcasts, NGO plans, Office of Historic Preservation, and existing government agencies can all insert a climate change “lens” into existing plans and activities

Republic of the Marshall Islands

Challenges:

1. No funding
2. Food security
3. No mountains, everything is coastal
4. Needs new weather equipment

Opportunities

1. Revival of traditional culture and local knowledge
2. Education and capacity building and lessons learned
3. Opportunities for introduction of new technologies

Unfunded Climate Adaptation Strategies

1. Explore traditional practices and strengthen them
2. Establish a climate change working group
3. Enhance education and outreach already in place, mobilize climate change stories
4. Stream-line existing activities to support climate change adaptation
5. Synthesize existing efforts under the rubric of climate change
6. Gather existing information, including traditional knowledge, and analyze for climate change impacts and trends
7. Conserve energy and water
8. Explore traditional ways of collaboration
9. Change political will

Funded Climate Adaptation Strategies

1. Increase support for climate change adaptation activities
2. Enforcement of policy and funding
3. Create a climate change network with a funded coordinator staff
4. Hire a group of civil staff to address multi-sectoral climate change impacts
5. Fill gaps in scientific information to conduct vulnerability assessments
6. Funds for endowment for adaptation and recovery
7. Increase effectiveness of conservation management
8. Shoreline protection, seawalls, plantings, weather equipment, desalinization, renewable energy, focus on human resources, and education

Chronic Problems and Management Issues

In addition to marine inundation events, chronic problems are present in FSM. There is persistent coastal erosion that threatens roadways, agro-forestry production, habitable dwellings, and shallow coastal aquifers. There is loss of coastal strand forests and mangrove wetlands due to uncontrolled cutting, slow salinization of wetlands and lakes, salt diffusion into soils adjacent to brackish water bodies, and salinization of well water. Interviews with atoll residents on several islands have revealed that freshwater wetlands and lakes that have been historically important for food production have turned brackish over the past two decades. The spread of alien plant and insect species throughout FSM watersheds is decreasing ecosystem diversity and resilience and is threatening food sources.

Incompatible management of coastal development and natural resources exacerbate these problems. For instance, forest thinning and canopy loss tends to dry the soil and reduce the capture of precipitation. Mining beaches, reefs, and lagoons for construction materials can lead to erosion and habitat loss.[57] Continued building along the shoreline with no setback exposes the community to coastal hazards. Use of submersible pumps in wells can encourage over-pumping and salinization. Waste disposal without regard to groundwater resources threatens contamination. An overall lack of data on sustainability parameters underlies many of these issues. An absence of master planning tends to promote *ad hoc* decision-making (further influenced by the need for rapid decision-making in the wake of recent crises). Arable land is scarce and a strongly traditional land use system involving complex land tenure relationships and a high number of invested stakeholders make it difficult to enact changes in policy.

There are also data gaps that hamper comprehensive planning. Water management suffers from a lack of adequate hydraulic modeling and calculations of sustainable yield. Atoll aquifer systems are poorly understood and there is little knowledge of what sustainable groundwater withdrawal rates are appropriate from one island to the next, as well as among the main islands. Rates of coastal erosion are not measured and thus development on eroding shores does not take this hazard into account. As a result shoreline hardening is widespread and beach loss is common. This interferes with FSM plans for the development of tourism. Land elevation is a major data gap that could be resolved with airborne LiDAR surveys available from several sources.[58] Mapping topography and bathymetry in the coastal zone, matched with geospatial information on community parameters (infrastructure, roads, development, etc.) would allow for a risk and vulnerability analysis (RVA). RVA is an important step in developing a plan to manage climate risk and to design adaptation strategies. There are other data gaps as well: soil and agro-forestry geospatial layers, wave and sea level monitoring instrumentation are lacking, geospatial information on climate and ocean processes (for instance, lagoon circulation is poorly understood), and others. Perhaps the most crucial data gap is the lack of site-specific climate data to constrain downscaled global circulation projections. Although this is a problem globally, the need for regional and local-scale climate modeling in the FSM is critical. Projecting future rain, storm, wind, evapotranspiration, surface temperature, ENSO patterns, and other fundamental parameters needs to be the target of focused modeling research so that climate risk management activities can be planned.

Climate change events, chronic problems, data gaps, lack of master planning, and entrenched land uses decrease the sustainability of FSM communities in the face of changing climate conditions. As a result, the following exist:

1. Vulnerability to natural hazards and difficulty recovering from natural hazards.
2. Loss of culture as traditional practice is replaced by imported resources.
3. Vulnerability to global warming.
4. Strain on national and state resources.
5. Problem-solving by crisis management.

Effective climate risk management will be expensive, requiring external sources of funding and partnerships with other nations. These partners are going to be most amenable to providing resources to the FSM when they see that internal programs and policies are being upgraded and improved. Such improvements will raise the overall probability of successfully meeting the climate challenge and increase the likelihood that external investment success will be compounded and consistent with domestic climate risk management.

Internally derived study findings indicate that successful management of climate risk in FSM would be promoted by strategies that encourage adapting to climate change as well as continued attendance at international venues where FSM representatives may share their story.

Successfully achieving climate adaptation within the FSM may be facilitated by two steps: 1) forming international partnerships to aid adaptation efforts and 2) continuing the development of internal policies focused on building resilient and sustainable communities. In the coastal zone this may be facilitated with:

1. Public education on climate risks in FSM including education of government workers and other decision-makers, of community members, and of landowners in particular.
2. Working within traditional land use policies to implement climate risk management, as this will engender more domestic partnerships.
3. Strategic redevelopment of coastal communities vulnerable to flooding now and in coming decades.
4. Conserving and promoting island and oceanic ecosystem services.
5. Preserving and promoting traditional culture to facilitate adaptation strategies and community accord.
6. Improving food and water security with a focus on domestic production as a core strategy in the national economy.
7. Master planning of communities focused on sustainability with enhanced government services such as health, sanitation, water and power, emergency services, and others.

Management Realities

Traditional land use and tenure, unstable slopes among the high islands, complexities in groundwater availability, alternative plans for using watershed lands by owners and various groups, low motivation and appreciation of climate risk, data gaps, and lack of adequate financing all signal that managing climate risk will be challenging. Approached carelessly, the situation could lead to displaced communities lacking real economic underpinning and low social standing. Moving and upgrading basic infrastructure will be expensive. There is little public land, and landownership is a complex and traditional foundation of political power in the FSM. Hence, it is incumbent that authorities assess the feasibility of various climate risk management strategies in a realistic light.

Land – On the small, low islands of the FSM, land is scarce. Because sustainability has always depended on appropriate land management, decision-making in the region has traditionally rested with landowners. Hence, in the FSM, land equals power and land possession and occupancy (i.e., tenure) influences political relationships and decision-making.[59] Complex, diverse, and often competing tenure systems governing ownership and access rights to land have developed throughout the islands. Traditionally, inheritance of land rights depended on membership in a lineage or clan (generally patrilineal in Yap and a few atolls in Pohnpei, and generally matrilineal elsewhere).[60] These rights were often subject to chief-centered authority and control, but in most cases, the oldest male member of the lineage managed the estate. However, after a century of colonial rule, systems of land tenure followed a path away from descent group ownership toward a western model of individualized tenure.

Greater individual self-interest accompanying westernization is weakening traditional systems of land tenure based on lineage. However, in Micronesia, authority regarding land use policies lies also with the local community. Hence, to implement any adaptation strategies will require that landowners, local communities, and decision-making bodies are all in agreement with regard to the need for climate risk management and the design of adaptation steps. Non-governmental organizations (NGOs) will be an indispensible partner in these efforts because they lack conflict of interest in most cases. A binding element in this situation can be climate risk education. A program of education involving this complex web of decision-makers may allow the group to approach the problem with a similar level of knowledge and with a more common point-of-view than otherwise.

The reality of land tenure and decision-making authority in FSM means that government agencies seeking to implement new land use policies must work closely with landowners, land users, NGOs, and local communities with whom most real decision-making authority lies. Hence, an early step will consist of instilling a common understanding of climate change impacts specific to FSM. Change is hardest for stakeholders who are invested in the current system (and in current land use policies and practices). As with any similar effort to educate invested stakeholders, there is likely to be an initial tendency toward intransigence and a lack of recognizing the need for change. For this reason, envisioning changes to existing policies within the familiar framework of the existing system may engender greater trust, willingness, and acceptance of changes compared to an approach that does not incorporate familiar elements.

In addition to major redevelopment, successful climate risk management may consist of adopting new polices of *effective coastal zone management*. The FSM Government does not have a system of coastal management. For instance, there is no policy guiding shoreline development. A new house or road may be placed at the water's edge or on infill recently dredged from the reef. Local decision-making on coastal development is based on tradition, convenience, and landowner permission. What may appear to be random placement of houses and other buildings is related to land tenure issues: 1) one builds where one has traditional land rights or are granted these by traditional leaders; 2) there is some squatting, particularly by outer islanders who lack land on a main island where they are employed; 3) government buildings are on rented land as there is almost no public land. Zoning and land use classification has been nearly impossible to achieve given the reluctance of landowners to relinquish any land use options.

Compounding the above, there is an overall scarcity of arable and habitable land. The main islands of Kosrae, Pohnpei, and Chuuk are characterized by a narrow coastal plain backed by steep and unstable slopes. Yap also has unstable slopes related to the lithology of the bedrock (serpentinite, greenstone, and other metamorphics). Studies by hydrologists describe complex and difficult-to-access groundwater reserves that may not reflect the abundance of rainfall.[61] On high islands the typical focus of development and community activity is on or near the coastal fringe. Ocean access is important to nearly every Micronesian. For example, lacking a truck to tow a boat, residents need to live at the water's edge both for mooring opportunities and to protect their boats. Being on the water's edge also allows for dumping garbage, sewage, and pig waste directly into the lagoon. Relocating homes as a step in climate adaptation requires addressing these already problematic sanitation issues. In an era of rising sea level and growing population, exposing new development to high risk with continued development at the water's edge is clearly not in the best interest of the community. Thus, basic social services are interconnected with climate risk management strategies within the limited island geography: waste disposal, transportation, food and water availability, emergency services, local economy, dwelling design, public health, and even family planning (number of members in a dwelling, level of family wealth, multiple generations, etc.) are all impacted by sea-level rise, storm surge, coastal erosion, and drought.

APPENDIX 4 – Findings

Interviews, research, and field visits provided researchers with first-hand observations of climate problems and community concerns in FSM. Micronesian communities are vulnerable to climate impacts in many ways. Effective climate risk management will be expensive, suggesting that external sources of funding and partnerships with other nations will be key aspects to moving forward. These partners are going to be most amenable to providing resources to the FSM when they see that internal programs and policies related to resource management and community planning are being systemically upgraded and improved. This increases the likelihood that external investment success will be compounded and consistent with ongoing domestic climate risk management.

There are several climate mitigation options that are available to FMS communities. This is not meant to be a complete and exhaustive review of the issue. Certainly, additional options and steps will be identified as FSM continues to experience climate impacts in coming years. The findings discussed here range from detailed items to broader discussions of programs and concepts. Most of these options were recommended by community members we interviewed and many are already in place and being used.

Findings by Sector

1) Primary Findings – In the course of meetings with community stakeholders it became clear that a *national strategy to manage climate risk* is needed. In fact, because of the lack of a coastal management program and the absence of detailed sustainability planning (e.g., "What is the sustainable rate of groundwater withdrawal on atoll islets?"), climate risk management actions offer an *opportunity to strengthen and enhance* many aspects of community practices in FSM. However, communities do not take lightly to having new policies levied from above without their involvement. Hence, effective climate risk management can begin with a vigorous *climate change education and planning program* for local communities, non-governmental organizations, landowners, land-tenured decision-makers, permitting authorities, government staff, and the public. These groups, and especially NGOs and communities, can be early partners in designing FSM climate risk management strategies. To develop a national strategy of climate risk management, a method of *community-based adaptation* would involve stakeholders throughout FSM in formulating management options to reduce climate risk. This is preferable to a "top-down" approach and is consistent with the traditional community values that are prominent in Micronesian culture.

2) El Niño of 1998 – The El Niño of 1997/1998 was one of the strongest on record. Micronesia typically experiences drought during El Niño periods and 1997/1998 was no exception. Atoll communities report this was the strongest drought in memory and traditional knowledge did not provide them with tools that fully mitigated the event. Bottled water, reverse osmosis pumps, and bags of rice were provided to every community. Habitability on atoll islets only continued because of outside assistance.

3) Marine Inundation of 2007 and 2008 – High tides related to the close proximity of the moon and Earth, large waves, and low atmospheric pressure led to "tidal surges" throughout Micronesia. Seawater washed onto atoll islet surfaces and into the coastal zones of the main islands, penetrated the groundwater system through subterranean routes and surface infiltration, and widely damaged crops. The 2008 event was worse than 2007, but both required that the FSM and state governments provide many islands with food and water supplies to maintain habitability.

4) Connection of Events to Climate – Some studies indicate that ENSO extremes may increase with global warming. Models are not in agreement on this point, but if El Niño conditions grow more persistent, or stronger, they may impact rainfall and water resources.[62] Tropical wind (Walker Circulation) weakening has already been observed and attributed to the influence of anthropogenic greenhouse gas production and global warming.[63] Sea-level rise has accelerated as a result of global warming. With rising sea level the frequency and severity of marine inundation will increase. It is impossible to unequivocally tie the events of 1998/2007/2008 to global warming. Likewise, it would be inconsistent with sound community planning to ignore the potential for a linkage.

5) Food Security – Residents of atoll islets are concerned with food security. Food stocks on individual atoll islets range from 2–3 weeks to 2–3 months. Many atoll islet communities have lost the ability to feed themselves over the long-term due to some combination of salinization of groundwater, wetlands, and soil. Often, the problem has developed over decades and is periodically exacerbated by storm surge, extreme tides, and other coupled atmosphere-ocean events.

Islands with higher elevations did not experience severe overwash in December 2008 but nonetheless have seen soil, well water, and wetlands used for food increase in salinity. Typhoons Orchid (1984), Lupe (2003), and Sadal (2004) variously affected communities with minor to catastrophic impacts. In the majority of cases, the December 2008 and 2007 extreme tides and past typhoons worsened and accentuated an already deteriorating situation.

Cement taro beds are a successful adaptation to salinization. On Fassarai Island, cement patches have been provided for 21 of 23 families. These are small patches holding approximately one-dozen plants. Construction materials are provided but building must be monitored to ensure high quality. These beds consist of concrete slabs built at ground level with short walls approximately 0.7 m high. Heat emanating off the cement walls can damage taro at the edge of a cement bed but siting the slab deeper in the cool soil can mitigate this. Soil thickness within the bed is approximately 0.3 to 0.6 m and is nourished by interweaved palm fronds and leaves that decay to humus, building rich compost. Currently, rainwater alone provides sufficient moisture in most cases. Cement beds vary in size from community beds approximately 10 m on a side made of poured concrete to individual family-owned 1 by 3 m beds built of hollow tile blocks. Yap State has a plan to provide cement taro beds to outer islands but has not received full funding; this would greatly improve food security.[64]

Reef island communities have become dependent upon external food sources. In most cases this food must be purchased. Financial resources among atoll communities include savings from residents with former jobs on the main islands, donations from relatives working on the main islands, sale of handicrafts, sale of food within reef island communities, and government assistance. Though there is a prevailing and rapidly growing reliance on external food supplies, ship visits to the islands are unreliable, unscheduled, and rare (few times in a year) and only a small number of islands have aircraft landing strips.

6) Water Resources – Rain catchment systems typically provide sufficient drinking water needs. Some communities use brackish well water for washing and other types of utilitarian chores. Generally, drinking water concerns are felt to be secondary to food concerns. There is nonetheless a recognition that drinking water stores are typified by marginal sustainability and have decreased over decades. The first decade of the 21st century has been characterized by protracted La Niña conditions typically providing sufficient rainfall. Awareness of the inevitability of future El Niño drought, already developing again within the period 2009–2010, is a source of concern for island communities. Even main islands with high rainfall do not provide residents with potable tap water due to infrastructure problems and lack of developed groundwater sources.[65] Drought will exacerbate these conditions. Water security is tied inextricably to food security throughout FSM.

Several communities have submersible pumps used in wells. There is no water management plan and sustainable yield has not been determined. Random and unmonitored pumping leads to a cone of depression at wellheads that encourages salinization. Several wells have been closed after pumping due to depletion of the freshwater lens. Infiltration galleries would allow for groundwater use that does not create a cone of depression and thus prevent overuse. A hydrological study would determine sustainable yield, aquifer locations for proper siting of waste disposal, and other necessary hydrological information.

Measurements of specific conductance in dug wells of outer islands in Chuuk State visited by the Preliminary Damage Assessment Team in 2009 found in most cases that well water had increased in salinity since 1984.[66] The maximum and minimum average increases were 312 percent and 20 percent, respectfully. Two out of thirteen measured wells recorded decreased salinity (8 percent and 22 percent). These results are consistent with interviews in which all islands visited in the current study are reported to have decreased groundwater potability.

7) Marine Inundation – Marine inundation is a direct threat to food and water security. Wave run-up and inundation will increase in frequency and severity as mean sea level rises. This process will be modulated by ENSO processes: El Niño periods will likely have decreased sea-level inundation and La Niña periods will likely have increased sea-level inundation. Marine-inundation measurement and modeling that assimilates observations provides a predictive capacity that would allow identification of the exact vulnerability of local settings. This is contingent upon having high resolution (<10 m^2 horizontal and <0.5 m^2 vertical postings), high accuracy digital elevation models such as those produced by LiDAR mapping.

8) Salinization – Salinization threatens food and water supplies as well as island sustainability. Seawater intrusion into island aquifers and marine inundation cause salinization of soil, wetlands needed for food production, water supplies for drinking and irrigation, and standing dry land crops. Salinization occurs by poorly understood subsurface processes, as well as by inundation of the land surface. High sea-level episodes, such as occurred in December 2008, are high intensity events that cause extensive salinization in a short period. As sea level rises, slower forms of salinization (e.g., chemical diffusion) are presumably occurring as well. Successful climate risk management strategies will include monitoring and data assimilation modeling to develop a predictive capacity for the challenges associated with salinization.

9) Health – Food and water are inextricably tied to human life and health. Life expectancy on atoll islets is below the global average. Establishing sustainable island communities will require specific solutions to population control, sewage disposal, reliable food stocks that provide holistic and diverse forms of nutrition, clean and abundant water, care for the young, elderly, and infirm, and treatment and control of disease. Climate adaptation strategies cannot be implemented in isolation from whole community needs. Climate risk management strategies must be part of an overarching community and resource-planning program that includes health and family planning.

10) Coastal Hazards – Sea-level rise increases the vulnerability of FSM communities to storm surge, tsunami inundation, coastal erosion, salinization, and community ripple effects stemming from these issues. The remote character of atoll islets and general lack of fully funded and implemented disaster mitigation make post-disaster recovery especially challenging. Coastal hazards will occur and sea-level rise will make their impacts worse. Specific community resiliency studies can acknowledge this inevitability. Consideration can be given to how post-disaster responses will react to community needs, and also how such episodes can contribute to the enactment of new coastal management steps.

11) Coastal Erosion – Coastal erosion is a problem where human interests are threatened. This suggests that managing human behavior provides a management alternative that gets at the basis for the problem. Coastal erosion is a problem on atoll islets and main islands alike. Concern varies from one place to another. Seawall proliferation on the main islands is partly due to lack of planning for down-drift impacts, near-shore dredging, and protecting filled land. Erosion on atoll islets can breach coastal berms leading to seawater intrusion into freshwater wetlands and aquifers. Erosion poses a real threat to ground and surface water resources. Beach sand and gravel is often used for construction materials and is usually taken from traditional localities. Long-term mining can exacerbate erosion and cause shorelines to lose stability.

There is widespread opinion that seawalls fail to stop the problem of coastal erosion. It is recognized that coastal armoring in general is problematic for adjoining, unarmored coasts and often fails within a few years of implementation.[67] This failure is likely due to poor engineering. Seawalls on atoll islets are typically hand built from local reef-derived materials. These seawalls offer some protection to inland soils and trails, usually on non-windward coasts. On the main islands, seawalls range from effective protection of critical roads and causeways at chronically eroding sites to completely enclosing communities that would otherwise be breached by the sea. Beach loss is observed in most cases where walls have been built and is a concern because the government has identified tourism as an area for growth and investment.[68]

Coastal stands of mangroves provide significant protection against storm surge, tidal excursions, and coastal erosion. The species *Sonneratia albe* produces dozens of *pneumatophores* that are effective at trapping sand and tends to quickly recolonize following damage by typhoons and extreme tides.[69] Restoration of coastal mangroves and strand forests is widely viewed by agency staff as an important adaptation tool. Beaches formed and protected by mangrove stands have high aesthetic appeal. Raising awareness among local communities to protect mangroves, rather than cut them to the point of destruction for lumber and fuel, is a challenge. Viewing mangroves as renewable forestry resources and developing a management plan so that mangroves can be selectively pruned or trimmed to provide firewood or building materials has been successful in other areas around the world.

Micronesians have historically practiced coastal infilling to gain new land.[70] There is widespread use of coastal sediments to both fill land and provide construction materials. Dredging may change circulation characteristics affecting water quality and it may cause shifts in sediment processes. Fine sediment stored on lagoon floors may mobilize in the new hydrodynamic environment of higher sea level and threaten coral reef and other coastal marine ecosystems. Mining beach sand and quarrying reefs has led to chronic erosion in several locations. Offshore borrow pits on the fringing reef can fill with beach sand causing beach loss.

12) Invasive Species – Invasive vegetation is a nationwide problem that places additional stress on coastal food sources already compromised by erosion, salinization, and other impacts from sea-level rise and drought. *Meramia pultata* was repeatedly identified in every state as a particularly aggressive species that has taken over whole hillsides and invaded wetlands. Other noxious species of shrubs, creeping herbs, fast-growing vines, and creeping grass include *Chromolaena odorata, Clerodendrum quadriloculare, Sphagneticola trilobata, Rubus moluccanus, Commelina diffusa, Luffa* sp., *Mikania micrantha, Aeschynomene americana, Clerodendrum* sp., and *Ischaemum* sp.[71] Invasive species eradication programs that are ongoing, persistent, and designed to broaden their effect over time would improve food security and climate adaptation throughout FSM. Eradication programs consisting of public-awareness building, youth corps, targeted species, strong funding, adequate staffing, and place-based eradication elements (locally scaled design) have been successful in other island settings.

13) Infrastructure – The FSM has several infrastructure projects that could incorporate climate risk management characteristics to maximize service and longevity. These include a new road in Kosrae and reconstruction of roads and in-ground infrastructure in Chuuk and Yap. Evidence indicates that a 1 m rise in mean sea level can be expected by the end of the 21st century.[72] Raising these roads a minimum of 1 m begins to address the rise of mean sea level expected over the lifetime of the project. Adding supplementary buffering elements such as greater elevation to overcome the expected rise in frequency of storm surge and tidal extremes, energy dissipation by coastal mangrove stands, armoring with anti-wave overtopping features (such as rubble-mound revetments), and enhanced drainage characteristics to mitigate flooding and shorten closure periods from marine inundation would extend the useful service life of coastal roads. Locations on planned transportation routes that are low-lying and adjacent to intertidal environments are especially vulnerable to sea-level impacts.

Elevating these projects does not have to be implemented all at once. Roads and other infrastructure will require periodic replacement and maintenance and "climate-proofing" can be implemented in phases as part of this schedule. For instance, an existing road that is undergoing major retrofit within the next 5 years can be elevated ~30 cm (1 ft) above present level, an additional 30 cm in 25 years, and an additional 30 cm 25 years after that. This schedule would likely allow appropriate management of the climate risk, with relatively affordable impact to the retrofit budget. Of course, the more elevation gains that can be added now, the better are the risk reductions to the infrastructure. Because future costs will be greater than present costs, raising roads and their associated infrastructure more than 1 ft now will prove to be the most economical approach when prorated across the next half century.

In the case of roads, drainage will be a major issue. Drainage problems will arise from increased rainfall intensity and overwash by marine inundation. Because many roads have wetlands that are used for food production on their landward sides, drainage culverts that allow tidal flow beneath the roadbed can be implemented with shut-off gates or one-way flow systems to stop marine incursion to these wetlands during high water events.

14) Management and Planning – On atoll islets especially, but also on main islands, there is a lack of integrated coastal planning. No specific coastal management plan or coastal zone agency exists in Micronesian state or federal government. Instead, the FSM government is in crisis management mode – moving from one crisis to the next without the guidance of a comprehensive plan. Traditional management practices that have proven successful for millennia when sea level was lower are stretched by sea-level rise and drought to deal with mounting challenges.

For instance, on atoll islets there is often no clear plan for waste disposal. Residents bury solid waste in unlined pits, and liquid sewage is disposed *ad-hoc*. There is little doubt that pollutants infiltrate the same aquifer used for irrigation and drinking as waste disposal on atoll islets and water wells have been observed within 100 m of one another. Drinking water is increasingly coming from catchment systems as aquifers experience salinization due to a combination of seawater intrusion and over pumping. Long-term challenges, such as waste disposal and secure drinking water, are increasingly dealt with by implementing short-term solutions. Obtaining drinking water from catchment systems will prove problematic in the coming period of El Niño-induced drought. Atoll communities outfitted with reverse osmosis systems now can be making the transition to this new source of water before they are in the midst of the next crisis, but no comprehensive program has been established to enable these systems among the atolls.

Another example of the lack of overarching planning relates to coastal erosion. On main islands, coastal armoring has been built without consideration of down-drift effects. Hence, much coastal erosion is due to human impacts. On Kosrae, for instance, it is estimated that 80 percent of the shoreline is experiencing chronic erosion and much of this has been attributed to seawall construction.[73] On atoll islets there is little integration of overarching issues such as *per capita* energy requirements, health needs, water use, sewage production, coastal-erosion rates, sources of construction materials, groundwater sustainable yield, food consumption, and others. Decisions in these sectors are made in the absence of an integrated community plan. Sustainable communities, stressed by changing environmental characteristics such as sea-level rise and drought, must be based on objective and reproducible thresholds and limits defined in comprehensive management policies and plans. These thresholds and limits are obtained by monitoring and modeling key sectors: water, food, waste, population, and others.

Upgrading coastal management policies at the national and state level will also be viewed by potential funding partners as examples of Micronesia "h elping itself" and are likely to improve funding opportunities.

15) Technical Specialists and Demonstration Community – There is a pressing need for proven food and water technologies throughout the FSM and especially among atoll islet communities. A *corps of specialists* could improve understanding of problems in hydrology, taro agriculture, diversified forest-agriculture (breadfruit, banana, and others), waste management, coastal engineering, energy systems, and sustainable planning. A *demonstration community* would permit monitoring and analysis of overarching planning data. This would include *per capita* information such as energy use, food use, water use, construction materials, health management (family planning), agriculture needs, waste production, and transportation (of food from external sources). This demonstration project would provide valuable information on sustainability, and how to integrate various community needs and resource-conservation steps into an overarching plan for managing the impacts of rising sea level, storms, alien species, and drought. At the same time that new parameters are being measured within the demonstration community, strategies that have established success can be exported by a specialist corps throughout the country. Land Grant and Sea Grant extension faculty could fill much of this need. Non-governmental organizations could also provide expertise in this sector because of the permanence of many staff and the high level of training many of them possess.

16) Government Alignment – Because climate risk management, coastal policy, environmental conservation, and community sustainability are interwoven issues, a government program that allows specialists to interact creatively would provide greatest synergy of effort. Programs on alien species, drought, sea-level rise, community parameters, public involvement, coastal management, emergency planning, waste management, food and water resources, reef and fishery management, long-range planning, and transportation services are all needed. Ideally staff would have annual access to international meetings and training, as well as regular visits by international experts. In-house expertise would cover the arc of backgrounds from research to engineering to planning and policy to traditional methods to field operations and remote sensing. All of these are valuable skills needed to develop appropriate climate risk management policy.

17) Data Gaps – Ideally, climate risk management strategies would be based on thoroughly parameterized human communities living in well-measured and monitored environments for every island in the nation. A comprehensive program of field operations would facilitate this vision. Successful climate management might consist of socio-environmental assessments that continue through time. Data provided through in-depth study of field sites by a team of specialists, in all aspects of food and water security, may improve understanding of changing natural conditions, community needs, and successful strategies. Specialists in hydrology, health, climate and meteorology, agro-forest ecology, taro/coconut and breadfruit agriculture, reef ecology (particularly marine food sources), coastal processes, soil, cultural sociology, waste engineering, water engineering, community master planning, and other relevant fields could provide critical data from focused study (and monitoring) of field sites.

Maximum information would be gained from the study of an entire atoll system, in pristine or near pristine condition, and inhabited by communities closely tied to traditional cultural practices (e.g., Woleai). It is likely that a community that has successfully achieved a high level of self-sufficiency has done so by incorporating some traditional methods. A community with strong identity and intact social ethics will be confident and thus stand a chance of dealing with the crises that will emerge as a result of global warming. These communities represent a target for establishing adaptation strategies. They can be studied, and their surrounding environment measured and monitored, for the benefit of the nation. An initial field visit to conduct detailed surveys and to establish long-term monitoring stations would provide important data on sustainability thresholds, land degradation and marine management that is presently lacking.

The need to monitor the shift away from sustainability is a subtask of the above described field-site data gap.[74] An atoll in relatively sustainable condition, with minimal climate impacts to date, and a willing host community, may serve as a long-term baseline monitoring site. Ideally, this would be the same atoll(s) used in the field surveys above. Long-term monitoring would improve understanding of physical oceanography, atmospheric processes, food and water use and production, horticulture and agriculture, ground and surface water hydrology, coastal processes, reef environment, water quality, sociology and economics, waste management, health, and other sustainability parameters that are likely to shift with climate change. Data may be applied to developing adaptation strategies. Wolei Atoll and the islands of Falalop, Falalus, Wottegai, and Seliap, and others at Wolei typify such a location.

There are other data gaps as well. There is a lack of adequate technical information to inform the establishment of successful adaptation strategies. Missing elements include:

1. Down-scaled climate models that offer regional-scale climate projections. These will need a grid of monitoring stations for data assimilation modeling of regional climate.
2. A coupled ocean-atmosphere model that predicts marine and atmospheric events on a temporal and spatial scale that allows for useful planning and event preparation.[75]
3. An alert system that predicts marine inundation events and drought. One staff person could be dedicated to tracking the development of ENSO and ocean conditions and receive regular training. For instance, an El Niño is developing in the period 2009–2010.[76] Yet, at this writing, it is not clear that activities are underway to plan for this event.
4. LiDAR-based fine-scale topographic/bathymetric digital elevation models of the coastal zone.
5. Marine inundation models that use LiDAR topography to identify vulnerable regions. These are based on specific topographic and bathymetric conditions and provide detailed predictions of regions that are most vulnerable to marine inundation.

6. Historical shoreline change rates for defining erosion hazard zones and threats to water resources by erosion.
7. Sustainable yield parameters such as hydrology (surface, vadose, and groundwater), detailed ecosystem surveys (marine and terrestrial), detailed crop growth and consumption parameters, historical/traditional sustainability practices, wave overtopping models, groundwater salinization processes, and coupled ocean-atmosphere event forecasting ability.

These and other types of data are sparsely collected, or not in existence, and in most cases are not integrated within a climate risk management point of view.

18) Climate Risk Management Tools – A number of adaptation strategies have been identified that may facilitate managing the problem of food and water security. These have been successfully used in the past within the FSM, are currently in use, or have been successfully employed in other settings. This list is also provided in Table 1.

1. Describe all resource use in terms of *sustainable yield*.
2. *Coastal setback policy* can build community resiliency and reduce environmental impacts.
3. A policy of *strategic retreat from the coast* can be enacted over decades ahead of the major sea-level impacts.
4. *Purchasing coastal lands* can help with strategic retreat.
5. Small-scale *reverse osmosis pumps* provide an important source of water during drought. However, these need to be maintained to continue to be useful.
6. Increasing public and private *rain catchment* can add to available water resources (e.g., airport catchment in Majuro). However, these need constant maintenance to reach full effect.
7. Horizontal *infiltration galleries* avoid over-pumping aquifers.
8. *Cement slab taro* patches with retaining walls protect root beds from seawater intrusion. These can be owned by individual families and used as community assets.
9. *Cement slab* beds for other types of food sources will allow adaptation to salinization problems.
10. Utilizing the *traditional knowledge* of the past for methods and techniques can enhance community self-sustainability and pride.
11. *Develop known and feasible forms of aquaculture* to supplement food sources.
12. The *reef fishery* among many atoll islets appears healthy. Proper management and monitoring of this fishery can ensure this as a continued food resource.
13. *Coastal mangrove* and strand forests protect beaches and coastal environments by dissipating wave energy and trapping sediment; these can be protected and expanded.
14. *Drainage culverts* with gates that can be closed during high tide and other marine-incursion events can protect food-producing wetlands from salt intrusion, potentially buying additional decades of use.
15. New buildings in the coastal zone can be assigned *base flood elevations* designed to raise the lowest horizontal component of the building above projected flood levels due to future marine inundation. Coastal building codes can prescribe *no poured slabs* near sea level and other types of structural design features for coastal development.
16. Anticipate that *funding partners will expect upgrades* and improvements to internal programs and policies. Starting on these now will be most effective. Many steps will require capacity building and technical assistance.
17. Realize that coastal zone *problems largely exist only where human interests are threatened*. Hence, policies that emphasize managing human behavior are most appropriate.
18. *Reduce freshwater wastage and maintain its quality* both within distribution and storage systems as

well as in streams and ponds. Managing disease outbreaks of cholera and Hepatitis A can be improved by mending water lines, maintaining positive pressure, preventing pollution, and treating water.

19. Well-designed and constructed s*eawalls that do not telegraph erosion* along a coast (causing additional problems) have been effectively used in protecting critical coastal infrastructure such as main transportation belts, ports, fuel depots, runways, and others.
20. Preserving the *forest canopy* prevents soil from drying out, captures precipitation from passing clouds, and helps maintain wetlands and fertile soil.
21. *Aggressive replanting programs* can revitalize the mangrove and other coastal strand forests, as well as island interior canopy and lumber resources.
22. Increasing the *diversity of food varieties* increases the resiliency of food sources. Developing salt-tolerant taro is a high priority. As a step toward improved sustainability, it is important to encourage a nationwide return to use of traditional foods; engage in agriculture and reduce the net amount of imported food.
23. *Ground taro* (dry-land taro) can be effectively grown on atoll islets as an alternative food source if not subjected to seawater intrusion.
24. Filling and *elevating taro beds* 1–3 m above previous levels creates a buffer against seawater intrusion.
25. Pacific island *food specialists* can provide improved understanding of alternative food sources for remote communities in the FSM.
26. *Traditional dwellings,* designed on vertical supports, can be large structures serving communities and still be relocated when threatened by coastal erosion and over wash. New design elements can emphasize strategic retreat.
27. Mining the shoreline for *construction materials* causes coastal erosion. Providing construction materials from sources may decrease this harmful activity.
28. *Resource islands* can be identified that can be used as dedicated sources of construction materials.
29. *Lagoon dredging* can cause coastal erosion. However, lagoon locations might be identified that provide construction materials if located far from the shoreline or such that there is no negative impact to developed areas.
30. Finding the *highest elevations* on atoll islets and relocating community activities to that area can mitigate seawater intrusion if the elevations exceed approximately 3 m above mean sea level. These can become food security zones.
31. *Safe islands* can be identified that have significant land area with mean elevations higher than 10 m as relocation areas.
32. Among atolls islands, use of *islands as "food banks"* is a traditional tool that diversifies food resources and raises overall food security. This concept can be extended to include "water banking."
33. *Alien species eradication* projects can facilitate ecosystem resiliency on every island. Manpower to physically remove alien vegetation can be organized around some weekly schedule; perhaps one day per week teams of workers can begin the process of clearing noxious vegetation.
34. *Modeling* the physical and social processes of atoll systems will improve understanding of the problems arising from climate change. This requires comprehensive surveys by teams of researchers recording community attributes and ecosystem services at one or more field sites to determine sustainability parameters and thresholds.
35. *Coastal hazard maps* depicting erosion, marine inundation (storm surge, tsunami, and extreme tides), drought, high winds, intense runoff, and others are needed for all states. These maps will be built as Geographic Information System (GIS) layers to be overlaid with other attributes such as soil type, drainage, wetlands, infrastructure, and others.

36. There is a need to improve scientific understanding of *atoll hydrology* and *geomorphic evolution* with a program of drilling to determine islet stratigraphy, formation history and aquifer characteristics.
37. Data assimilating coupled *ocean/atmosphere models* can provide effective forewarning of sea-level events and ENSO trends. The Pacific Integrated Ocean Observing System (PacIOOS) offers a coupled model.[77]
38. All island communities can be outfitted with *monitoring stations* (climate, meteorology, oceanography, and hydrology) to track status and trends and to supplement data needs of regional, down-scaled climate models.
39. *Predicting ENSO events* is important to planning. The Pacific ENSO Applications Center at the University of Hawai'i provides the Pacific with ENSO updates and predictions; this is useful for planning the occurrence of climate variability (El Niño – drought), and physical oceanography events (extreme tides) in the FSM.[78] The U.S. Weather Service provides a weekly on-line discussion of ENSO patterns.[79]
40. *LiDAR mapping* can identify communities and resources with early vulnerability to sea-level rise and assist with master plan development.
41. *Modeling wave and tidal surge* on the digital elevation model of an entire atoll islet will improve understanding of the increased frequency and magnitude of marine inundation that will accompany continued sea-level rise. This knowledge can be extended to enhance planning on all islets.
42. Improve the capacity of *warning for inundation events.* Few communities get warnings of extreme sea-level events.
43. *Historical shoreline analysis* is an effective predictor of erosion trends and hazard zones. Erosion analysis can be applied to all FSM shorelines.

19) Overarching Need for Island-Scale Analysis – There is a need to improve understanding of sustainability thresholds and hazard mapping. For instance, there are no groundwater sustainable yield guidelines on most islands. There is a lack of information on per capita food and water needs, groundwater yield, minimum necessary rainfall, soil types and management needs, sustainable lumber harvesting guidelines, and others. To improve this, a field site consisting of an entire atoll with several islands and communities can be studied and instrumented, the people interviewed, and monitoring stations installed to gather data on the problem of resource use and depletion, climate processes, and ecosystem services. An entire atoll can be surveyed with bathy/topo LiDAR. A comprehensive drilling program designed to reveal islet internal architecture for understanding hydrology and geomorphic evolution can be implemented. Such studies can be aimed at defining sustainability thresholds. By developing a deep understanding of one island, the knowledge can elevate the entire national effort at climate risk management.

20) National Policy – The most effective climate risk management will be instituted as new national policy. Elements of coastal zone management that employ setbacks, building codes, sand and gravel mining guidelines, a system of environmental review on all projects, steps to emphasize community hazard resiliency and environment conservation, strategic redevelopment of the coast, drought and sea-level prediction and other up-to-date coastal zone management concepts and ideals will be most effective. Potential funding partners will view changes at the national and state level as examples of Micronesia "helping itself" and will be more likely to provide assistance.

21) Training – Many aspects of managing climate risk require technical knowledge. Training and institutional capacity building within the FSM will be necessary to implement and maintain climate risk management tools.

22) Summary – Climate change, specifically sea-level rise and its attendant processes of salinization and marine inundation, is negatively impacting island communities now. To gain momentum in managing climate risk, nationwide climate education and community-based adaptation planning will mark the first successful steps. A national adaptation strategy based on climate risk management needs to be formulated. Successful climate risk management requires integrating multiple community issues including food security, water resource management, coastal erosion, health and family planning, energy use, waste disposal, construction materials, and overarching management plans that incorporate sustainability thresholds. Communities on many atoll islets in the FSM have lost sustainability due to challenges stemming from sea-level rise and inadequate planning. Coastal erosion, salinization, alien species, and the absence of overarching island management policies exacerbate climate change impacts and threaten food and water security. On the main islands, while greater technical knowledge exists, coastal problems also suffer from lack of integrated planning. Part of managing these challenges must come from within communities and part from extrinsic sources.

Table 1 - Climate Risk Management Tools

	Tool	Sector	Application	Strategy
Tools with practical daily uses	#5. Reverse osmosis pumps	Water security	Supplements natural drinking sources	El Niño drought may occur again. Several islands can be outfitted with reverse osmosis systems now and a complete set of pumps can be stocked at staging areas for distribution to other islands. Many islands rely completely on catchment systems; these can be immediately provided with these systems. Reverse osmosis systems can be powered by solar panels. Pumps need better maintenance than the last time they were deployed in 1997/98.
	#6 Rain catchment	Water security	Supplements groundwater	Increase public and private catchment systems. Provide better maintenance than historically provided.
	#7. Infiltration galleries	Water security	Reduces over-pumping	Infiltration galleries can be installed on all islands that still use fresh groundwater.
	#8. Cement slab taro	Food security	Avoids salinization	Every atoll islet community can be provided with large community cement taro patches and every family can have a family cement taro patch. This can be a nationwide goal achieved within 3 years.
	#9. Cement slab food beds	Food security	Avoids salinization	Every atoll islet can increase the use and planting of ground taro as a way to avoid salt-contaminated water.
	#23. Ground taro	Food security	Avoids salinization	Every atoll islet can increase the use and planting of ground taro as a way to avoid salt-contaminated water.
	#24. Elevating taro beds	Food security	Avoids salinization	On each atoll islet efforts to raise taro beds can be immediately instituted. Regular composting schedules can assist this process. Information can be gathered on successful methods of accomplishing this.
	#16. Partners will expect upgrades	Climate risk man-agemet	Provides opportunity to strengthen nation	Adapting to climate change will be expensive and require partners from other nations. Demonstrating that the FSM is willing to revise past policies to meet the reality of climate change provides potential partners with evidence that FSM views climate risk management as a serious national priority worthy of external investment.
	#17. Coastal problems are defined by humans	Coastal zone man-agemet	Applies to erosion management	Coastal zone problems largely exist only where humans are threatened. Hence, policies that emphasize managing human behavior are most appropriate.

	Tool	Sector	Application	Strategy
Tools needing some development prior to application	#10. Utilizing traditional knowledge	Community	Raises community cohesiveness and pride	Each atoll can document and categorize successful traditional practices.
	#13. Mangrove protection; #20. Preserving forest canopy; #21. Aggressive replanting programs	Food security and coastal management	Provides erosion mitigation and raises food security	On each atoll islet, coastal strand forests, mangroves, and tall forest trees can be replanted for erosion control, soil protection, water capture, lumber, canopy restoration, and food security.
	#33. Alien species eradication	Food security and watershed management	Reduces threats to food sources, reduced soil erosion in watersheds	Work crews on each atoll islet and on main islands can work on weekly schedules to physically remove noxious vegetation.
	#25. Pacific island food specialists	Food security	Increases range of food options and their security	A program can be funded in support of bringing expertise on Pacific food sources and diversity into atoll island settings to raise security
	#26. Traditional dwellings	Community resiliency	Reduces damage and improves post-event recovery	Traditional dwellings are light-weight and relatively flexible in design. These designs can be emphasized for their energy economy, ease of relocation, and low cost construction.
	#11. Aquaculture; #12. Reef fishery.	Food security	Improves management of important food source	Existing harvest data can be combined with biological research to develop sustainable take quotas. These need detailed monitoring to establish that sustainability is being exercised.
	#18. Reduce freshwater wastage	Water security	Improves water cleanliness and abundance	Reduce water waste and maintain its quality both within distribution and storage systems as well as in streams and ponds. Managing disease outbreaks of cholera and Hepatitis A can be improved by mending water lines, maintaining positive pressure, preventing pollution, and treating water.
	#14. Drainage culverts with gates	Food security	Buys time for wetland food sources	Coastal roads require drainage culverts. These permit marine inundation of freshwater wetlands used for food production. Culverts can be designed gates to prevent routine and extraordinary inundation events.
	#19. Seawalls that do not telegraph erosion	Coastal management	Establishes best management practices	Well-designed seawalls can be used in ports and locations where critical infrastructure requires protection. In remote areas armoring can cause erosion on adjoining shores. Alternative methods can be used, and principles of coastal processes employed to predict telegraphed erosion.
	#22. Increasing food varieties	Food security	Increases range of food options and their security	Increasing the variety of foods on atoll islets increases resiliency. An important goal is to develop salt-tolerant species of edible plants. As a step toward improved sustainability, it is important to encourage a nationwide return to use of traditional foods, engage in agriculture and reduce the net amount of imported food.
	#37. Establish monitoring stations	Climate risk management	Improves understanding of sustainability thresholds	Monitoring instrumentation can be installed with all island communities in the FSM. Monitoring of the following is desirable: well salinity, soil moisture, wind, temperature patterns, sea-level, waves/currents, forest canopy, meteorology, groundwater fluctuations, and others. Sociological phenomena can be monitored as well.
	#38. Predicting ENSO	Food and water security, community resiliency, climate risk management	Allows for communities to prepare for drought, marine inundation, and other ENSO related	ENSO predictions are available from the U.S. Weather Service and PEAC. These can be monitored weekly and a national communication network can be established to broadcast results.

	Tool	Sector	Application	Strategy
Tools needing research prior to their use	#1. Defining sustainable yield	Food and water security	Improves understanding of sustainability thresholds	All aspects of atoll islet sustainability need measurement and definition. Monitoring and applied research programs can be developed toward this goal.
	#2. Coastal setback	Food and water security	Improves coastal conservation and community resiliency	Coastal construction setbacks are in use in every U.S. coastal state. The general trend is to increase these as one tool to manage climate risk.
	#3. Strategic retreat	Climate risk management	Improves coastal conservation and community resiliency	A national policy of strategic retreat from the coast will establish to external partners that the FSM is engaged in serious climate risk management.
	#4. Purchasing coastal lands	Climate risk management	Improves coastal conservation and community resiliency	A national fund to purchase coastal lands is a strong forward step in climate risk management.
	#27. Mining atoll beaches causes erosion; #28. Designate resource islands for construction materials; #29. Lagoon dredging can have negative impacts to developed areas	Climate risk management, coastal zone management	Provides alternative sources of construction materials that do not have immediate impact on communities	Beach mining is prevalent throughout the FSM. Lagoon mining tends to occur adjacent to shorelines. Fringing reefs are mined as well. All of these activities are inconsistent with sound climate risk management. Construction materials are necessary for adaptation and for other reasons. Distant sources for construction can be identified that will not have local impacts. Cost will increase but partnerships can be developed to absorb these.
	#15. Base flood elevations	Climate risk management, coastal zone management	Climate risk management, coastal zone management	Base flood elevations are used by the U.S. FEMA as part of coastal zone building codes to mitigate damage to structures by costal hazards.[80] Coastal building codes can prescribe no poured slabs near sea level and other types of structural design features for coastal development.
	#30. Highest atoll island elevations	Climate risk management, food and water security, coastal zone management	Climate risk management, food and water security, coastal zone management	The highest elevations on atoll islets can be identified as locations with relatively reduced inundation exposure; these can become food security zones.
	#30. Highest atoll island elevations	Climate risk management	Climate risk management	Islands with significant land areas that have mean elevations above 10 m can become relocation areas for displaced populations or food and water security zones.
	#32. Food banks	Food and water security	Food and water security	Islands that are not inhabited can be developed as food security zones and will likely have useful water resources as well. Each atoll can consider designating an island for this purpose.
	#36. Hydrology and geomorphology	Food and water security	Improve understanding of water resources and future island response to sea-level rise	Drilling and sampling atoll island geology can provide new information regarding aquifer characteristics and the geomorphic response of the island to sea-level rise.
	#34. Modeling; #35. Coastal hazard maps; #42. Event prediction; #40. LiDAR; #41. Inundation modeling; #43. Historical erosion	Data gaps	Climate risk management, food and water security, and other sectors will benefit	There are data gaps that hinder complete understanding of climate risk management. An entire atoll can be identified that will serve as a field site for filling these gaps. Study can emphasize applied science and engineering and range from physical to sociological processes. All islands can be surveyed using LiDAR. This data can allow for construction of coastal hazard maps, and provide for inundation modeling. Historical shoreline analysis using aerial photography can identify chronic erosion and shoreline processes, and produce powerful coastal hazard maps when combined with LiDAR mapping.
	#39. Model ocean/ atmosphere processes	Data gaps, climate risk management	Use computer models to predict marine inundation events, drought, and other types of phenomena that are relevant to FSM communities	Computer models that couple the ocean and atmosphere and that assimilate observations (data) can help to predict specific oceanographic and meteorological events as well as long-term changes in states related to global warming. More climate monitoring sites are needed as data for regional climate projections.

Overarching and Cross-Disciplinary Findings

Climate risk management issues are highly integrated and span many planning and government sectors.[81] Overarching and cross-disciplinary findings include:

23) One Meter Sea-level Rise – Evidence indicates that the rate of global mean sea-level rise has accelerated to approximately twice the rate of the 20th century.[82] Evidence also strongly indicates that *mean sea level is likely to rise approximately 1 m above 20th century levels by the end of the 21st century* and constitutes an appropriate planning target at this time. However, sea-level rise will have important local variability that planners can consider as knowledge of that variability improves.[83] Global mean sea-level may rise significantly more than 1 m, but is unlikely to rise significantly less.[84]

24) Place-based Coastal Planning – Nationwide, coastal management problems in the FSM include coastal erosion, marine inundation, groundwater salinization, storm and tsunami vulnerability, sand and gravel management, sewage disposal, shortages in food and water, and other issues. Despite this reality, *FSM has no coastal zone management program* that specifically integrates coast-unique problems and their management. There is a lack of systemic, programmatic management and standards to enhance island sustainability. On atoll islets, a comprehensive management plan with place-based elements (recognizing the uniqueness of each locality), with components addressing energy, sewage, health, hazards, water, and food and construction materials would greatly enhance climate risk management. For example, there is no buffer zone (also known as a setback) regulating the location of development along the shoreline. Hence, construction takes place at the water's edge and thus increases community vulnerability to coastal hazards and resource shortages even in the face of growing awareness of accelerated sea-level rise and chronic coastal erosion.

25) Relocation Options – Throughout the world, coastal problems are only perceived as significant where the sustainability of human communities and development is threatened. That is, by choosing to live in the coastal zone, humans expose themselves to natural hazards. In continental settings and among large islands, humans have another choice: to live apart from the coastal zone. However, the geography of the FSM is unique in that on most islands *there is little choice but to live near the ocean*. Sand and gravel islands on atolls and reefs are low-lying and, because of their geologic origin, limited in size. While there are geological reasons to anticipate some atoll and atoll islets to naturally adapt to sea-level rise rather than drown, wave over-toping, the mechanism by which these islands might naturally adapt, also destroys food and water resources, typically long before any advantage to the island is achieved.[85] Hence, atoll islets may survive sea-level rise, but they will be largely uninhabitable.

The larger volcanic islands in the FSM have narrow coastal plains backed against unstable and steep slopes. Historically, the people of FSM have had a strong connection to the sea and have located homes and villages along the narrow coastal strip of these islands. This geographic reality and the national position of choosing to stay and adapt to climate change make clear two important points: 1) FSM communities will benefit by engaging in discussion and identification of climate change adaptation strategies in the immediate future rather than waiting; and 2) The vulnerability of FSM to climate change can become a compelling story for engaging international partners.

There are, however, locations on the main islands where portions of the community might stage a strategic retreat. Kosrae, Pohnpei, Chuuk, and Yap islands all have watersheds and coastal slopes that can be the site of master-planned communities with access to the ocean but are located at higher elevations above the coastal plain and thus are at reduced climate risk.

It is not appropriate in this document to make specific recommendations regarding where and how relocation and retreat might take place. As mentioned earlier, land use, landownership, and land tenure issues are complex and interwoven with traditional community access and land use practices. Because the expectation of individual Micronesian communities is that their access to land and its resources will follow traditional patterns, any attempt to regulate land use policy, such as would be necessary for coastal retreat, will need partnership with stakeholders.

One strategy would entail two fundamental elements: 1) Educate FSM communities, landowners, land use decision-making bodies, government agencies and their staff, and all FSM stakeholders to the reality of climate change and the risks it poses in FSM. This national education and awareness building effort may take a few years before it is common to the daily thinking of FSM citizens. It is certainly appropriate to enlist the aid of international experts in this regard, to develop educational modules for use in school science classes, to host workshops and forums for discussion and training, and to bring exposure to the issue. There are many other types of consciousness-raising steps to be employed as well. 2) Initiate all land use planning related to climate risk management at the community level. Important partners in this effort will be non-governmental organizations and other types of community groups. Once the FSM population is aware of climate threats and sees that they are asked to be the source of mitigation solutions, it is likely that steps toward climate risk management will follow rapidly as they spring from the Micronesian community.

26) Upgrade Resource and Community Planning – *Locally, management practices are a significant factor that decreases sustainability* in the FSM. Nevertheless, these practices are at a level that is little different than those found in many countries, and in numerous FSM locations *traditional management practices have achieved a high level of sustainability*. Now, however, global sea-level rise, magnified by regional ENSO processes, has intensified existing problems and beset previously successful practices. Sea-level rise is stretching the ability of traditional knowledge to deal with changing environmental processes.

27) Climate Change Impacts Have Begun – The ability to live in the Micronesian coastal zone is determined by food and water availability. On many islands these are in short supply and unlikely to recover, hence *some islands in the FSM have already lost sustainability.*

28) Crisis Mode – Traditional management practices that have proven successful for millennia when sea level was lower are stretched by sea-level rise and drought to deal with mounting challenges. Instead, the FSM government enters crisis management mode – moving from one crisis to the next without the guidance of a comprehensive plan. Long-term problems are often dealt with by short-term solutions. *It is appropriate to develop a national plan to manage climate risk.* A national plan can emerge from public and community efforts.

29) Micronesia in the Face of Global Warming – Accelerated sea-level rise is a product of global warming stemming from atmospheric pollution.[86] It has been estimated that less than 0.001 percent of greenhouse gas production originates within the FSM.[87] Coastal problems in the FSM, partially originating with poor management, are nonetheless amplified by the process of global warming. It is highly likely that sea level will continue to rise and accelerate over the long-term (decades), but shorter-term fluctuations may occur in relation to ENSO. Changes in the Micronesian water cycle are also likely, but climate models give differing results on how rainfall abundance and intensity will change. As a global average response to warming, it is likely that tropical areas will experience increased rainfall.[88] Regardless of future changes, sea-level rise and El Niño-related drought has already severely damaged, and in places destroyed, the ability of FSM people to live on long-occupied lands. Continued global warming, if it drives changes such as have already taken place or worse, may make some of the atoll islets and other coastal settings of Micronesia uninhabitable.

30) Adaptation in Micronesia – *Managing the risks related to rising sea level and drought* and other climate processes is necessary to achieving national security. Developing a national plan for managing climate risk is critical to the future of the nation. Adapting to climate change, however, can be viewed as an opportunity for FSM to straighten out some systemic issues with regard to planning and management.

APPENDIX 5 – State-Specific Findings

At the state level, effective climate risk management will be facilitated with external sources of funding. These sources are going to be most amenable to providing assistance to the FSM when they see that internal problems related to coastal zone management and infrastructure upgrades in a framework of climate proofing are being systemically addressed. Partnerships will also be facilitated as the development of community-based adaptation in FSM proceeds. Internal efforts increase the likelihood that external investment will achieve progress in climate risk management.

Kosrae State

The island of Kosrae is the easternmost island in the Federated States of Micronesia. Kosrae is a 112 km2 volcanic island surrounded by mangroves and coastal strand forests that have been historically used for lumber and fuel by residents. There is a shallow fringing reef spotted with boulders of limestone quarried from the fore-reef by high energy wave events (storms, tsunamis, and other overwash processes). There are no outer islands. The island has steep, heavily vegetated watersheds with unstable slopes. Intense rainfall denudes exposed soil in areas of deforestation. Invasive vegetation is prolific and has taken a foothold in every watershed. The population of approximately 8,247 is largely dependent upon fishing and farming for their livelihood.[89]

Coastal erosion has intensified over the last 50 years leading to a landward retreat (between 5 and 30 m) of the shoreline around much of the island.[90] This retreat is of concern because approximately half of Kosrae's coastal fringe is developed. The remainder is in a natural and undisturbed state, and some areas are targeted for development into community-managed marine parks.

Kosrae has unique needs with regard to climate risk management and adaptation. The majority of the coastline is experiencing chronic erosion as a result of engineering projects that have caused down-drift sediment deficiencies over the past four decades.[91] Additional causes of erosion include offshore mining of the reef flat for construction materials, beach mining for sand and gravel resources, interruptions to alongshore sediment transport by engineering projects, and in some areas erosion is occurring for reasons that are not entirely known but are probably, in part, related to sea-level rise. The widespread "telescoping" of erosion along the coast by armoring and beach loss in front of seawalls and revetments have produced a chronic deficiency in sand that formerly constituted beautiful beaches ringing the island. These beaches lent protection to coastal communities, ambience to tourism, and a quality of life to residents that is at risk.

Ramsay conjectures that sand deficiencies are also due to lack of input by major storm events.[92] Typhoons are rare; the main tracks are located to the north and west of the island and the last major occurrence was in 1905. This absence of a significant natural destructive event has had important consequences for the development of the coastal zone in Kosrae. Specifically:

a. Virtually the entire population of the island lives on a narrow coastal plain that is only 1–2 m above spring high tide and slopes landward from the beach ridge into wetlands used for food production.

b. The island's principal road runs along the coast through this community. It lies within 1–2 m of spring high tide and is bordered by open ocean beach on one side and a low freshwater wetland used for food production on the other.

c. The system of coastal zone management in Kosrae does not prescribe the nature of development along the coast and there is a general lack of action among coastal residents regarding adaptation strategies for managing climate change and coastal hazards.

d. Armoring the shoreline has been the dominant management tool in areas of chronic erosion

In 1998, the Kosrae government recognized that an increasing coastal population and changing socioeconomic pressures were causing the majority of the population and infrastructure to be located in the high-risk zone. In response, the government started developing a shoreline management plan. The goal of the plan is to provide a framework for future development and resource management within the context of coastal erosion and coastal hazard management.

The tidal surges of 2007 and 2008 caused significant damage to coastal infrastructure, food resources, and housing. It is apparent that while the Kosrae Shoreline Management Plan sets goals and strategies to build a more resilient community, its implementation is being outpaced by the scale of climate change.

The following findings surfaced in the course of this study:

1. The Kosrae coastal zone is vulnerable to negative impacts stemming from rising sea level.

2. The maximum overwash elevation of the recent tide surges is likely to be reached in future events with greater frequency. Generally, designing structures such that overwash may run beneath the structure increases community resilience. Buildings with their lowest horizontal structural component set above the maximum elevation of the December 2008 overwash plus 1 m will be less prone to damage and more resilient to recovery. The maximum overwash elevation, plus 1 m, represents a base flood elevation (BFE) for new construction and for renovation of existing buildings. Building codes establishing this would increase community resilience and improve climate risk management.

3. Food – Agricultural resources in the coastal zone are vulnerable to future overwash. Steps to manage the climate risk to food include:

    a. Generally raising the elevation at which food is grown can decrease vulnerability to negative climate impacts and increase food security.

        i. Raising the elevation of food production may range from simple steps such as increasing soil thickness with composting efforts, to;

        ii. Delineating and developing upland food production sites at elevations at least 1 m above the maximum overwash elevation from December 2008.

    b. Food is raised in historically freshwater coastal settings. As sea level rises these will increasingly experience salt intrusion. Building gated culverts that can be closed during extreme tide events will protect crop lands from marine inundation and "buy time" before they have to be abandoned.

    c. Steps to manage salt intrusion include "cement taro" patches. These are poured cement slabs with low retaining walls within which soil is developed and taro cultivated. Overwash that breaches the walls becomes permanently trapped saltwater; this problem can be anticipated and mitigated in the design of the taro cultivation.

    d. Cement cultivation may provide protection for other food types as well.

    e. Climate risk management includes decreasing dependence on external food sources. Kosrae can manage risk by targeting sustainable food production as a high-priority statewide goal. The island has the necessary high land to successfully achieve this if adequate steps are defined and funded. Encouraging local food production and consumption is a key step in this. Government can play an important role in providing incentives, market infrastructure, and economic policies in this regard. But, the desire to enact this step must come from the local communities.

4. Invasive Species – The spread of invasive plant species on Kosrae is out of control. Invasive species are a major threat to food security. Invasive species decrease biodiversity, lead to forest ecosystem collapse (a problem that has already happened in some watersheds), directly attack food agriculture, fail to protect soil from erosion on steep slopes, and generally decrease the ecosystem services provided by a healthy forest. Controlling invasive species will be a significant element in successful climate risk management on Kosrae.

    a. Programs to control invasive species are a key activity in managing climate risk.

    b. Invasive species management is a Pacific-wide problem. Successful control efforts can consist of funding Kosrae staff to attend workshops and conferences as part of professional development to learn the latest techniques in this issue and to participate in global discussions on the problem.

    c. Community-based programs (such as education modules and student field-service days) to control invasive species can be a powerful means of addressing this problem.

5. Water – Water security is a significant problem on Kosrae. Community water supplies remain nonpotable. As sea level rises in coming decades, salt intrusion by overwash, as well as by incursion through the groundwater system will increase. Additionally, it is not clear how global warming will impact ENSO conditions; there may be no change, increasing drought, or increasing rainfall. The degree of unknown puts Kosrae water security at risk. These circumstances compound problems currently resulting from pollutants that enter the water system.

    a. Part of climate risk management on Kosrae will be to increase sustainability by providing as many potable water resources as possible from local sources. A drinking water research effort can be initiated with the goal of increasing water security.

    b. Upland drinking water resources developed from groundwater will improve water reliability. Sustainable yield and other long-term use parameters must be defined.

    c. Water delivery infrastructure needs to be upgraded to improve potability. This can incorporate a design element that mitigates climate impacts.

    d. Development of an island-wide "Kosrae Water Management Plan" in partnership with a knowledgeable water research agency such as the U.S. Geological Survey is needed.

6. Roads – New roads in Kosrae that are adjacent to tidally influenced environments, such as mangrove ecosystems and shorelines, will be most resilient to climate risk if they are designed so that their surface elevation lies above the maximum overwash elevation plus 1 m.

    a. New projects adjacent to tidal environments can utilize coastal strand forest and mangrove stands to dissipate overwash energy, promote sediment deposition, and to stabilize shorelines and embankments. These ecosystem services can be part of many climate-proofing steps if envisioned creatively.

    b. A practical alternative for projects that run over budget with new climate management design features may choose to implement a maintenance plan that sets climate elements as future goals to be achieved on a schedule corresponding to resurfacing (or other maintenance). Plans to raise roads approximately 30 cm now, and again every decade thereafter, for instance, may provide important mitigation.

c. As sea level rises and marine inundation becomes more frequent, drainage will be a growing problem on roads. Drainage of seawater will be necessary during extreme tides and eventually at normal high tides, and drainage of rainfall runoff will be difficult during periods of high tide. The worst flooding will occur when marine inundation occurs during rainfall. The resulting brackish water will have difficulty draining into the ocean due to high water levels.

7. Coastal Erosion – Coastal erosion is a problem only where human use of the coastline is threatened. Thus, managing human behavior provides an adaptation alternative that addresses the foundation of the problem. The Kosrae Shoreline Management Plan provides a valuable framework for assessing coastal defense policies.[93] Within this framework, effective climate risk management will emphasize managing human behavior.

   a. Continuing to follow the current trend of armoring along the Kosrae coast will provide mitigation for only a few decades and at the expense of coastal ecosystems, tourism ambience, public access to the ocean and likely cause an increase in coastal population density in the area of greatest hazard. A program of armoring will be expensive and invite scrutiny from funding sources preferring to see a more long-term approach. As sea-level rise proceeds, existing armoring will cease to offer protection and a strategic retreat program will need implementation at greater expense and on an accelerated schedule and with greater social disruption than if implemented now.

   b. Coastal armoring is most effective where it is employed to protect valuable infrastructure (e.g., airport, causeway, port facilities, etc.). Some coastal locations on Kosrae are protected by armoring where the value of the armoring exceeds the protected assets. In other areas, coastal defense can be achieved by utilizing ecosystem services (strand forests). Utilizing erosion hotspots as guideposts to retreat from the coast can prove to be an effective policy. However, these hotspots need to be defined.

   c. Planned expenditures for new armoring may provide better climate risk management if they were reprogrammed to emphasize the long-term systemic nature of the problem rather than the short-term "band-aid" solution of armoring. Systemic solutions include employing ecosystem services, new building codes, sand nourishment and other human behavior-changing options. Reprogrammed funds could also assist redevelopment planning and programs, and other human management, rather than erosion management policies.

8. Policy – Effective climate risk management can be instituted at the community level. Elements of community-based adaptation that employ setbacks, building codes, sand and gravel mining guidelines, a system of environmental review on all projects, and that emphasize community hazard resiliency and environmental conservation can be effective. Policies that originate with the local community can reflect local characteristics and are likely be more effective than island-wide, "one size fits all," policies. Local policies can be embraced by communities and thus achieve desired goals.

   a. Strategic retreat from the coast, ecosystem services, environmental protection, and other behavior management tools can be major principles underlying new coastal zone management policy.

   b. Sea level is going to rise throughout the 21st and 22nd centuries. Roads, buildings, the energy grid, and other human developments in the coastal zone will come under increasing stress from marine inundation. One approach can be to identify an upland area now that will be the focus of future development, establish supportive new government policies, encourage the population to relocate over a period of time, and provide incentives in the form of economic and social benefits. Tofol Village and other inland settings have appropriate attributes for this.

The complex nature of landownership and tenure and the need for local community involvement in policy development will require a pervasive understanding among the Kosrae population that climate change is real and that adaptation steps need to be undertaken soon. Failure to understand the urgency of climate risk is likely to mean that adaptation will be delayed because of the complexities of land use and political power in Kosrae.

9. Data Gaps – A lack of understanding and gaps in data make certain management goals especially difficult to achieve. These include:

   a. There is a need for LiDAR mapping for the Kosrae coastal zone and hinterlands. Detailed mapping of the lowest lying areas, and the steepest slopes, will assist in identifying the areas with greatest climate risk and where relocation can be most successful.

   b. Knowing the detailed pattern of coastal erosion rates will be useful in defining community vulnerability and in planning future shoreline scenarios.

   c. Groundwater resources and hydrologic processes are poorly understood. Improving water security will require improving understanding of potential groundwater resources.

   d. Monitoring stations need establishment in Kosrae. The existing system of beach profiles is a strong step in this direction. However, additional monitoring of groundwater, surface water, salt intrusion, soil resources, alien vegetation, and others is needed. A network of climate stations will facilitate model projections of future climate.

10. Specific Next Steps – The Kosrae population and government agencies need improved understanding of climate risk. Kosrae could advance the cause of climate risk management with a vigorous public education program. At the same time, community groups, NGOs, teachers, landowners, and other partners and stakeholders can begin planning locally applicable adaptation steps and policies.

Pohnpei State – Pohnpei is a “high” volcanic island, having a rugged, mountainous interior with some peaks as high as 760 m. It measures about 130 km in circumference and is roughly circular in shape. Pohnpei Island is the largest, highest, most populated and most developed island in the FSM. A coral reef surrounds the island, forming a protected lagoon. There are no beaches on Pohnpei – the coast is surrounded by mangrove swamps growing on mud eroded from interior wetlands in the rainy environment. Several smaller islets, many of them inhabited, lie nearby within the lagoon-reef complex. The population of Pohnpei is approximately 34,840. Pohnpei is more ethnically diverse than any other island in the FSM; this is largely due to it being home to the capitol of the national government, which employs hundreds of people from the other FSM States having distinct ethnic and cultural origins. The indigenous makeup also includes people from the outer islands within the State, which comprise multiple regional ethnicities. Outer islands to Pohnpei include Pingelap, Mokil, Ant, Pakin, Ngatik, Nukuoro, and Kapingamarangi. These are atoll islets that suffered extreme hardship during the marine inundation events of 2008 and 2007.

Pohnpei’s climate is tropical and humid. Kolonia town receives about 195 inches (4.95 m) of rain annually. Typhoons rarely hit Pohnpei; more often they are spawned in Micronesia and move on to Guam and the

Commonwealth of the Northern Marianas Islands. Every several years or so on average, a mildly damaging tropical storm or depression will affect Pohnpei. Strong El Niño events can cause prolonged drought of many weeks or even months, as was seen in 1997/98. Torrential rainstorms can also strike Pohnpei. These rainstorms have caused serious landslides and mud slides in the past and represent a natural hazard that may worsen as rainfall becomes less frequent but more intense with continued global warming.

The tidal surges of 2007 and 2008 caused significant damage to coastal infrastructure in low-lying areas. Without a specific plan to manage coastal problems, Pohnpei shoreline areas will not be resilient, resources will be depleted, and improvements through investment will be outpaced by the scale of climate change.

Investigators in the current study find that:

1. The Pohnpei coastal zone is vulnerable to negative impacts stemming from rising sea level. Atoll islets were damaged by the overwash and groundwater intrusion of 2007 and 2008. El Niño conditions produce drought and threaten food and water security in Pohnpei.

    a. Investment in a major search for water resources is needed. Potable water in Pohnpei is not currently available from public sources. Investment in the public water delivery system would increase water security.

    b. Staging resources for a major food and water airlift and boat delivery operation associated with either the next tide surge or El Niño drought within the next two years would be appropriate.

    c. It would be appropriate to develop a corps of food and water specialists centered in Pohnpei that work with atoll islets to increase food and water security.

    d. Monitoring stations can be established on all Pohnpei atolls with data collected on meteorology, groundwater, sea level and agro-forestry usage, and ecosystem changes.

    e. Part of climate risk management on Pohnpei will be to increase self-sufficiency (sustainability) by providing as many necessary resources as possible from local sources. This includes water and food. Hence, improving water and food security is a critical step in managing climate risk in the state.

    f. Upland drinking water resources developed from groundwater will improve climate risk mitigation. Sustainable yield and other long-term use parameters can be defined.

    g. Development of an island-wide "Pohnpei Water Management Plan" in partnership with a knowledgeable water research agency such as the U.S. Geological Survey is needed.

2. Agricultural resources in the coastal zone are vulnerable to future overwash. Steps to manage the climate risk to food include:

    a. Generally raising the elevation at which food is grown can decrease vulnerability to negative climate impacts and increase food security.

        i. Raising the elevation of food production may range from simple steps such as increasing soil thickness with composting efforts to:

        ii. Delineating and developing upland food production sites at elevations at least 1 m above the maximum overwash elevation from December, 2008.

b. Food is raised in historically freshwater coastal settings. As sea level rises these will increasingly experience salt intrusion. Building gated culverts that can be closed during extreme tide events will protect crop lands from marine inundation and "buy time" before they have to be abandoned.

c. Steps to manage crop salt intrusion include "cement taro" patches. These are poured cement slabs with low retaining walls within which soil is developed and taro cultivated. Overwash that breaches the walls becomes permanently trapped saltwater; this problem can be anticipated and mitigated in the design of the taro cultivation.

d. Cement crop cultivation may provide protection for other food types as well.

e. Climate risk management includes decreasing dependence on external food sources. Pohnpei can manage risk by targeting sustainable food production as a high-priority, statewide goal. The state has the necessary high land to successfully achieve this if adequate steps are defined and funded. Encouraging local food production and consumption is a key step in this. Government can play an important role in providing incentives, market infrastructure, and economic policies in this regard. But, the desire to enact this step must come from the local communities.

3. Building – The maximum overwash elevation of the recent tide surges is likely to be reached in future events. Generally, designing structures such that overwash may run beneath the structure increases community resilience. Buildings with their lowest horizontal structural component set above the maximum elevation of the December 2008 overwash plus 1 m will be less prone to damage and more resilient to recovery. The maximum overwash elevation, plus 1 m, represents a base flood elevation for new construction and for renovation of existing buildings. Building codes establishing this would increase community resilience and improve climate risk management.

4. Invasive Species – The spread of invasive plant species on Pohnpei is out of control. Invasive species are a major threat to food security. They decrease biodiversity, lead to forest ecosystem collapse – a problem that has already happened in some watersheds, directly attack food agriculture, fail to protect soil from erosion on steep slopes and generally decrease the ecosystem services provided by a healthy forest. Controlling invasive species will be a significant element in successful climate risk management on Pohnpei.

   a. Programs to control invasive species are a key activity in managing climate risk.

   b. Invasive species management is a Pacific-wide problem. Successful control efforts can consist of funding Pohnpei staff to attend workshops and conferences as part of professional development to learn the latest techniques in this issue and to participate in global discussions on the problem.

5. Roads – New roads in Pohnpei that are adjacent to tidally influenced environments, such as mangrove ecosystems and shorelines, will best withstand climate impacts if they are designed so that their surface elevation lies above the maximum overwash elevation plus 1 m.

   a. New development projects adjacent to tidal environments can also utilize coastal strand forest and mangrove stands to dissipate overwash energy, promote sediment deposition, and stabilize shorelines and embankments.

   b. Projects that run over budget with climate appropriate design features may choose to implement a maintenance plan that sets these elements as future goals to be achieved on a schedule corresponding to resurfacing (or other activities) as a practical alternative. Plans to raise roads approximately 30 cm now, and again every decade thereafter, for instance, may provide important mitigation.

6. Dredging – The lagoon surrounding the island of Pohnpei is the source of most construction material on this growing island. Typical dredging activities consist of building a causeway into the lagoon out of dredged material and then back-stripping the fill to a staging point on the adjacent shoreline. This leaves a deep trough in the lagoon floor which becomes a sediment collection point and site of poor water quality.

    a. Lagoon dredging is a practice that requires greater regulation. Currently, the dredging occurs in areas of convenience. An engineering study of the impacts and best management practices of lagoon dredging can be performed in order to end the ad-hoc nature of the current activity. Questions such as the following require answers: What are the long- and short-term impacts of dredging? How will sea-level rise along lagoon shorelines be modulated by past and present dredging activities? Can dredging be confined to specific take areas? Is dredging sustainable and for how long? How does dredging affect water quality?

7. Coastal Zone Management Policy – The majority of Pohnpei development lies above the coastal zone, though there are significant regions at risk located near the shoreline. Because Pohnpei is viewed as a well-developed location within the FSM with a high quality of life, population growth will be strong, especially as atoll islets lose population due to food and water problems.

    The Pohnpei region is vulnerable to climate change and has experienced drought related to El Niño and marine inundation related to La Niña conditions of high sea level. As found elsewhere in the FSM, Pohnpei has no specialized coastal zone management program. Implementation of a base flood elevation to buildings, a construction setback, a ratified land use plan with required update on a regular basis and other modern elements of coastal policy would improve the management of climate risk in the state. The most effective climate risk management will emerge from discussions with local communities and non-governmental organizations. A bottom-up, community-based adaptation approach is better than a top-down approach that may not win support at the local level. Elements of coastal zone management that employ setbacks, building codes, sand and gravel mining guidelines, a system of environmental review on all projects, and that emphasize community hazard resiliency and environmental conservation will be most effective if they can emerge from community stakeholders.

    a. Before new coastal zone management policy can be devised, a state-wide climate education effort can be enacted. Community groups, landowners, decision-making bodies, agency staff, the general public, and the education system can all be included. Once a public discussion on climate change has begun, new management policies, such as a coastal zone management policy, can be envisioned and discussed to enable local acceptance.

    b. Strategic retreat from the coast, ecosystem services, sustainable traditional and local practices, environmental protection, and other behavior management tools can be the major principle underlying new coastal zone management policy.

    c. Sea level is going to rise throughout the 21st and 22nd centuries. Roads, buildings, the energy grid, and other human development in the coastal zone will come under increasing stress from marine inundation. Now is the time to identify an upland area for future development, with supportive new government policies, that encourages the population to relocate, over a period of time, to this new area. Pohnpei has several inland settings which have appropriate attributes.

Incorporating smart growth design elements in this new community offers improvements to the quality of life of island residents and visitors.

8. Data Gaps – A lack of understanding and gaps in data make certain management goals especially difficult to achieve. These include:

   a. A need for LiDAR mapping for the Pohnpei coastal zone and hinterlands. Detailed mapping of the lowest-lying areas and the steepest slopes will assist in identifying areas with greatest climate risk and locations where relocation can be most successful and where landslides may be a potential problem.

   b. Groundwater processes are poorly understood. This includes processes of seawater inundation, over pumping, wetland vulnerability to salinization, and improving water security and infrastructure island wide. The first step to providing effective mitigation and climate risk management is to define the problem based on in-depth understanding of physical, biological, and chemical environmental processes.

   c. Knowledge of the detailed pattern of coastal erosion rates among atoll communities will be useful in defining community vulnerability and in planning future shoreline scenarios. Erosion threatens groundwater and agro-forestry resources. A better understanding of erosion will improve management of this problem.

   d. Groundwater resources and hydrologic processes are poorly understood. Improving water security will require improving knowledge and monitoring of potential groundwater resources.

   e. Establishment of monitoring stations in Pohnpei – monitoring of groundwater, surface water, salt intrusion, soil resources, alien vegetation, and others is needed.

9. Specific Next Steps – The Pohnpei population and government agencies need improved understanding of climate risk. Pohnpei could advance the cause of climate risk management with a vigorous public education program. At the same time, community groups, NGOs, teachers, landowners and other partners and stakeholders can begin planning locally applicable adaptation steps and policies.

Chuuk State – The main population center of Chuuk State is the Chuuk Lagoon, a large archipelago with mountainous islands surrounded by a string of islets on a barrier reef. The two major geographical divisions of the Chuuk Lagoon are Faichuuk, the western islands, and Namoneas, the eastern islands. On July 2, 2002, heavy rains from Tropical Storm Chataan caused more than thirty landslides that killed forty-seven people and injured dozens others in the state's deadliest weather disaster. The landslides occurred throughout the day, some within just minutes of one other. Most of the roads and transportation systems are poor or in disrepair. Potholes in the coastal road of the business district of Chuuk are often filled with either saltwater at high tide or runoff that cannot drain due to the low elevation.

Chuuk State, population 53,106, also includes several additional sparsely populated outer-island groups, including the Mortlock Islands to the southeast, the Hall Islands (Pafeng) to the north, Namonuito Atoll to the northwest, and the Pattiw Region to west. The Pattiw Region is of particular interest in that it contains some of the most traditional islands in the Pacific which are culturally related to the outer islands of Yap. The Pattiw Region includes the islands of Pollap, Tamatam, Poluwat, and Houk.

The tidal surges of 2007 and 2008 caused significant damage to coastal infrastructure, food resources, and housing. It is apparent that investment in Chuuk already scheduled to refurbish the main road and buried infrastructure is committed and planned for immediate ground-breaking. Unfortunately, the pace of climate change has already made some design elements of these large infrastructure projects out of date.

Chuuk is the most populous state. The central business district of the main island is in severe disrepair. This is a prime opportunity to establish new climate proofing practices. In the short term these would consist of:

- Start a climate change education project for the people of Chuuk Atoll. Focus on community groups and allow ideas for climate risk management and adaptation to emerge from community discussions.
- Add extra height to the new road. At least 30 cm would be good, better would be 1 m.
- Ensure adequate drainage on and adjacent to the new road. Drainage must accommodate extreme tidal inundation, heavy rainfall and simultaneous rainfall and tidal events.
- Repair the seawalls along the lagoon shore. Build substantial revetments with large stone. Incorporate \ docking facilities and parks for public recreation.
- Begin planning for a new business district in the hills behind the coast. Incorporate housing within walking distance of the new businesses. Utilize smart growth principles.
- Invest in a major search for water resources. Potable water in Chuuk can be available from every tap in every building. Develop a "Chuuk Water Management Plan."
- Plan now and stage resources for a major food and water airlift and boat delivery operation associated with either the next tide surge or El Niño drought within the next two years.

Investigators in the current study find that:

1. The Chuuk coastal zone is vulnerable to negative impacts stemming from rising sea level. Drought threatens the entire state. Atoll islets were damaged by the overwash and groundwater intrusion of 2007 and 2008. El Niño conditions produce drought and threaten food and water security in Chuuk.

    a. Development of a corps of food and water specialists centered in Chuuk that work with atoll islets to increase food and water security is needed.

    b. Monitoring stations can be established on all Chuuk atolls. Data collection on meteorology, groundwater, sea level, and agro-forestry usage and ecosystem changes is needed.

    c. Water security is a significant problem on Chuuk. Community water supplies remain nonpotable. As sea level rises in coming decades, salt intrusion by overwash, as well as by incursion through the groundwater system will increase. Additionally, if global climate model projections prove accurate, El Niño conditions in the Pacific will increase leading to greater frequency and intensification of drought. These circumstances will likely impact water availability. Hence, climate change places Chuuk water security at risk. The above compounds the existing problem from pollutants that enter the water system.

    d. Part of climate risk management on Chuuk will be to increase self-sufficiency (sustainability) by providing as many necessary resources as possible from local sources. This includes water and food. Hence, improving water and food security is a critical step in managing climate risk in the state.

    e. Upland drinking water resources developed from groundwater will improve climate risk mitigation. Sustainable yield and other long-term use parameters must be defined.

f. Water delivery infrastructure will need to be upgraded to incorporate a design element that mitigates climate impacts. This would include raising infrastructure above the elevation of overwash plus 1 m, at a minimum.

g. Development of an island-wide "Chuuk Water Management Plan" in partnership with a knowledgeable water research agency such as the U.S. Geological Survey is needed.

2. Food – Agricultural resources in the coastal zone are vulnerable to future overwash. Steps to manage the climate risk to food include:

   a. Generally raising the elevation at which food is grown can decrease vulnerability to negative climate impacts and increase food security.

      i. Raising the elevation of food production may range from simple steps such as increasing soil thickness with composting efforts to:

      ii. Delineating and developing upland food production sites at elevations at least 1 m above the maximum overwash elevation from December 2008.

   b. Food is raised in historically freshwater coastal settings. As sea level rises these will increasingly experience salt intrusion. Building gated culverts that can be closed during extreme tide events will protect crop lands from marine inundation and "buy time" before they have to be abandoned.

   c. Steps to manage salt intrusion include "cement taro" patches. These are poured cement slabs with low retaining walls within which soil is developed and taro cultivated. Overwash that breach the walls become permanently trapped saltwater; this problem can be anticipated and mitigated in the design of the taro cultivation.

   d. Cement crop cultivation may provide protection for other food types as well.

   e. Climate risk management includes decreasing dependence on external food sources. Chuuk can manage risk by targeting self-sustainable food production as a high-priority statewide goal. The state has the necessary high land to successfully achieve this if adequate steps are defined and funded. Encouraging local food production and consumption is a key step in this. Government can play an important role in providing incentives, market infrastructure, and economic policies in this regard. But, the desire to enact this step must come from the local communities.

3. Building – The maximum overwash elevation of the recent tide surges is likely to be reached in future events. Generally, designing structures such that overwash may run beneath the structure increases community resilience. Buildings with their lowest horizontal structural component set above the maximum elevation of the December 2008 overwash plus 1 m will be less prone to damage and more resilient to recovery. The maximum overwash elevation, plus 1 m, represents a base flood elevation for new construction and for renovation of existing buildings. Building codes establishing this would increase community resilience and improve climate risk management.

4. Invasive Species – The spread of invasive plant species on Chuuk is out of control. Invasive species are a major threat to food security. Invasive species decrease biodiversity, lead to forest ecosystem collapse (a problem that has already happened in some watersheds), directly attack food agriculture, fail to protect soil from erosion on steep slopes, and generally decrease the ecosystem services provided by a healthy forest. Controlling invasive species will be a significant element in successful climate risk management on Chuuk.

a. Programs to control invasive species are a key activity in managing climate risk.

b. Invasive species management is a Pacific-wide problem. Successful control efforts can consist of funding Chuuk staff to attend workshops and conferences as part of professional development to learn the latest techniques in this issue and to participate in global discussions on the problem.

5. Roads – New roads in Chuuk that are adjacent to tidally influenced environments, such as mangrove ecosystems and lagoon shorelines, will best avoid climate impacts if they are designed so that their surface elevation lies above the maximum overwash elevation plus 1 m.

   a. New projects adjacent to tidal environments can also utilize coastal strand forest and mangrove stands to dissipate overwash energy, promote sediment deposition and to stabilize shorelines and embankments.

   b. Projects that run over budget with "climate-proofing" design features, may choose to implement a maintenance plan that sets these elements as future goals to be achieved on a schedule corresponding to resurfacing (or other activities) as a practical alternative. Plans to raise roads approximately 30 cm now, and again every decade thereafter, for instance, may provide important mitigation.

6. Coastal Erosion – Erosion is a problem only where human use of the coastal zone is threatened. This suggests that managing human behavior provides an adaptation alternative that addresses the foundation of the problem.

   a. There is widespread beach loss on Chuuk. Continuing to follow the current trend of armoring the Chuuk coast will provide mitigation for only a few decades and at the expense of coastal ecosystems, tourism ambience, public access to the ocean, and likely cause an increase in coastal population density in the area of greatest hazard. A program of widespread armoring will be expensive, and invite scrutiny from funding sources preferring to see a more long-term approach. As sea-level rise proceeds, existing armoring will cease to offer protection and a strategic retreat program will need implementation at greater expense, on an accelerated schedule and with greater social disruption, than if implemented now.

   b. Coastal armoring is most effective where it is employed to protect valuable infrastructure (e.g., airport, causeway, business district, port facilities, etc.). Some coastal locations on Chuuk are protected by armoring with an apparent value that exceeds the adjacent land. In other areas, coastal defense can be achieved by utilizing ecosystem services (strand forests). Utilizing erosion hotspots as guideposts to retreat from the coast can prove to be an effective policy.

   c. Planned expenditures for new armoring may provide better climate risk management if reprogrammed to emphasize the long-term systemic nature of the problem rather than the short-term solution of armoring. Systemic solutions include employing ecosystem services, new building codes, sand nourishment from carefully considered borrow sites and elsewhere and other human behavior-changing options. Reprogrammed funds could also assist redevelopment planning and programs, and other human management, rather than erosion management policies.

   d. Armoring plays an important role in the central business district of Chuuk. However, the engineering is poor and in many places the armor units are failing. These can be replaced to protect the new road and the new road and the immediately adjacent corridor can be raised to reduce climate risk.

7. Coastal Zone Management Policy - The Chuuk business district and significant residential development lie in the coastal zone. Because Chuuk is viewed as a well-developed location within the FSM, population growth will be strong, especially as atoll islets lose sustainability due to food and water problems.

   The Chuuk region is vulnerable to climate change and has experienced drought related to El Niño and marine inundation related to La Niña conditions of high sea level. As found elsewhere in the FSM, Chuuk has no specialized coastal zone management program. Implementation of a base flood elevation to buildings, a construction set-back, a ratified land use plan with required update on a regular basis and other modern elements of a coastal policy would improve the management of climate risk in the state. The most effective climate risk management will emerge from discussions with local communities and non-governmental organizations. A bottom-up, community-based adaptation approach is better than a top-down approach that may not win support at the local level. Elements of coastal zone management that employ setbacks, building codes, sand and gravel mining guidelines, a system of environmental review on all projects, and that emphasize community hazard resiliency and environmental conservation will be most effective if they can emerge from community stakeholders.

   a. Before new coastal zone management policy can be devised, a state-wide climate education effort can be enacted. Community groups, landowners, decision-making bodies, agency staff, the general public, and the education system can all be included. Once a public discussion on climate change has begun , new management policies, such as coastal zone management policy, can be envisioned and discussed to enable local acceptance.

   b. Strategic retreat from the coast, ecosystem services, sustainable traditional and local practices, environmental protection and other behavior management tools can be major principles underlying new coastal zone management policy.

   c. Sea level is going rise throughout the 21st and 22nd centuries. Roads, buildings, the energy grid and other human development in the coastal zone will come under increasing stress from marine inundation. Now is the time to identify an upland area for future development, with supportive new government policies, that encourage the population to relocate, over a period of time, to this new area. Chuuk has several inland settings which have appropriate attributes. Incorporating smart growth design elements in this new community offers improvements to the quality of life of island residents and visitors.

8. Data Gaps – A lack of understanding, and gaps in data, make certain management goals especially difficult to achieve. These include:

   a. LiDAR mapping for the Chuuk coastal zone and hinterlands. Detailed mapping of the lowest lying areas, and the steepest slopes, will assist in identifying areas with greatest climate risk, locations where relocation can be most successful and where landslides may be a potential problem.

   b. Groundwater processes are poorly understood. This includes processes of seawater inundation, over pumping, wetland vulnerability to salinization, and improving water security and infrastructure island-wide. The first step to providing effective mitigation and climate risk management is to define the problem based on in-depth understanding of physical, biological and chemical environmental processes.

c. Knowledge of the detailed pattern of coastal erosion rates among atoll communities will be useful in defining community vulnerability and in planning future shoreline scenarios. Erosion threatens groundwater and agro-forestry resources. A better understanding of erosion will improve management of this problem.

d. Groundwater resources and hydrologic processes are poorly understood. Improving water security will require improving knowledge and monitoring of potential groundwater resources.

e. Monitoring stations can be established in Chuuk. Monitoring of groundwater, surface water, salt intrusion, soil resources, alien vegetation and other parameters is needed.

9. Specific Next Steps – The Chuuk population and government agencies need improved understanding of climate risk. Chuuk could advance the cause of climate risk management with a vigorous public education program. Concurrently, community groups, NGOs, teachers, landowners, and other partners and stakeholders can begin planning locally applicable adaptation steps and policies.

Yap State – Yap's indigenous cultures and traditions are still strong compared to neighboring islands. Yap consists of four islands with unusual geology of non-volcanic origin. The four are very close together and joined within a common coral reef and entirely formed from uplift of the Philippine Plate. The land is mostly rolling hills densely covered with vegetation. Mangrove swamps line much of the shore although beaches are common in some areas. An outer barrier reef surrounds the islands, enclosing a lagoon between the fringing reef attached to the islands and the outer barrier.

Colonia is the capital of the State of Yap. It administers both Yap proper and 14 atolls reaching to the east and south for some 800 km, namely Eauripik, Elato, Fais, Faraulep, Gaferut, Ifalik, Lamotrek, Ngulu, Olimarao, Piagailoe (West Fayu), Pikelot, Sorol, Ulithi, and Woleai atolls, as well as the island of Satawal. The 2009 state-wide population was 11,780. The state has a total land area of 102 km^2.

The tidal surges of 2007 and 2008 caused significant damage to coastal infrastructure, food resources and housing. Yap is well developed and has a generally high quality of life. Nonetheless, water on the main islands is nonpotable and this is a major issue that has not been resolved despite several decades of effort. The central business district of Yap is built around a harbor, the shoreline of which is armored by well designed and engineered walls and revetments. However, the top elevation of most of this coastal protection is only 30-60 cm above high tide. By mid-century or earlier, these protections will need upward extension to protect the critical roads, fuel depots, buildings and freight handling facilities lining the harbor. Over the next decade, climate risk management can focus on the following issues:

- Start a climate change education project for the people of Yap Atoll. Focus on community groups and allow ideas for climate risk management and adaptation to emerge from community discussions.
- Add extra height to new roads. At least 1 ft (m?) would be good, better would be 2 ft. (m?). Marine inundation would be buffered by replanting of coastal mangrove forests and addition of drainage culverts with gates that can be lowered during high water events.
- Raise the seawalls along the harbor shore. Build substantial revetments with large stone to protect critical infrastructure not already protected. Incorporate boat docking facilities and parks for public recreation.
- Begin planning for new residential districts in the hills behind Colonia. Incorporate housing within walking distance of existing businesses. Utilize smart growth principles. Expect population growth from atoll islets as climate risk grows.

- Invest in a major search for water resources. Potable water in Yap can be available from every tap in every building. Develop a "Yap Water Management Plan."
- Plan now and stage resources for a major food and water airlift and boat delivery operation associated with either the next tide surge or El Niño drought within the next two years.

Investigators in the current study find that:

1. The Yap coastal zone is vulnerable to negative impacts stemming from rising sea level. Drought threatens the entire state. Atoll islets were damaged by the overwash and groundwater intrusion of 2007 and 2008. El Niño conditions produce drought and threaten food and water security in Yap.

   a. Develop a corps of food and water specialists centered in Yap that work with atoll islets to increase food and water security.

   b. Establish monitoring stations on all Yap atolls. Collect data on meteorology, groundwater, sea level, and agro forestry usage and ecosystem changes.

   c. Water security is a significant problem on Yap. Community water supplies remain nonpotable. As sea level rises in coming decades, salt intrusion by overwash, as well as by incursion through the groundwater system will increase. Additionally, if global climate model projections prove accurate, El Niño conditions in the Pacific will increase leading to greater frequency and intensification of drought. These circumstances will likely impact water availability. Hence, climate change puts Yap water security at risk. The above compounds the existing problem from pollutants that enter the water system.

   d. Part of climate risk management on Yap will be to increase self sufficiency (sustainability) by providing as many necessary resources as possible from local sources. This includes water and food. Hence, improving water and food security is a critical step in managing climate risk in the state.

   e. Upland drinking water resources developed from groundwater will improve climate risk mitigation. Sustainable yield and other long-term use parameters must be defined.

   f. Water delivery infrastructure will need to be upgraded to incorporate a design element that mitigates climate impacts. This would include raising infrastructure above the elevation of overwash plus 1 m, at a minimum.

   g. Develop an island-wide "Yap Water Management Plan" in partnership with a knowledgeable water research agency such as the U.S. Geological Survey.

2. Food - Agricultural resources in the coastal zone are vulnerable to future overwash. Steps to manage the climate risk to food include:

   a. Generally raising the elevation at which food is grown can decrease vulnerability to negative climate impacts and increase food security.

      i. Raising the elevation of food production may range from simple steps such as increasing soil thickness with composting efforts, to;

      ii. delineating and developing upland food production sites at elevations at least 1 m above the maximum overwash elevation on December, 2008.

b. Food is raised in historically freshwater coastal settings. As sea level rises these will increasingly experience salt intrusion. Building gated culverts that can be closed during extreme tide events will protect crop lands from marine inundation and "buy time" before they have to be abandoned.

c. Steps to manage salt intrusion include "cement taro" patches. These are poured cement slabs with low retaining walls within which soil is developed and taro cultivated. Overwash that breaches the walls becomes permanently trapped saltwater, this problem can be anticipated and mitigated in the design of the taro cultivation;

d. Cement crop cultivation may provide protection for other food types as well.

e. Climate risk management includes decreasing dependence on external food sources. Yap can \ manage risk by targeting self-sustainable food production as a high-priority statewide goal. The state has the necessary high land to successfully achieve this if adequate steps are defined and funded. Encouraging local food production and consumption is a key step in this. Government can play an important role in providing incentives, market infrastructure and economic policies in this regard. But, the desire to enact this step must come from the local communities.

3. Building - The maximum overwash elevation of the recent tidal surges is likely to be reached in future events. Generally, designing structures such that overwash may run beneath the structure increases community resilience. Buildings with their lowest horizontal structural component set above the maximum elevation of the December, 2008 overwash plus 1 m will be less prone to damage and more resilient to recovery. The maximum overwash elevation, plus 1 m, represents a base flood elevation for new construction and for renovation of existing buildings. Building codes establishing this base flood elevation would increase community resilience and improve climate risk management.

4. Invasive Species – The spread of invasive plant species on Yap is out of control. Invasive species are a major threat to food security. They decrease biodiversity, lead to forest ecosystem collapse - a problem that has already happened in some watersheds, directly attack food agriculture, fail to protect soil from erosion on steep slopes, and generally decrease the ecosystem services provided by a healthy forest. Controlling invasive species will be a significant element in successful climate risk management on Yap.

   a. Programs to control invasive species are a key activity in managing climate risk.

   b. Invasive species management is a Pacific-wide problem. Successful control efforts can consist of funding Yap staff to attend workshops and conferences as part of professional development to learn the latest techniques in this issue and to participate in global discussions on the problem.

5. Water - Water security is a significant problem on Yap. Community water remain nonpotable. As sea level rises in coming decades, salt intrusion by overwash as well as by incursion through the groundwater system will increase. Additionally, if global climate model projections prove accurate, El Niño conditions in the Pacific will increase leading to greater frequency and intensification of drought. These circumstances will likely impact water availability. Hence, climate change puts Yap water security at risk. The above compounds the existing problem from pollutants that enter the water system.

a. Part of climate risk management on Yap will be to increase self sufficiency (sustainability) by providing as many potable water resources as possible from local sources. A drinking water research effort can be initiated with the goal of increasing water security.

b. Upland drinking water resources developed from groundwater will improve water reliability. Sustainable yield and other long-term use parameters must be defined.

c. Water delivery infrastructure needs to be upgraded to improve potability. This can incorporate a design element that mitigates climate impacts.

d. Develop an island-wide "Yap Water Management Plan" in partnership with a knowledgeable water research agency such as the U.S. Geological Survey.

6. Roads – New roads in Yap that are adjacent to tidally influenced environments, such as mangrove ecosystems and shorelines, will best withstand climate impacts if they are designed so that their surface elevation lies above the maximum overwash elevation plus 1 m.

   a. New projects adjacent to tidal environments can also utilize coastal strand forest and mangrove stands to dissipate overwash energy, promote sediment deposition and to stabilize shorelines and embankments.

   b. Projects that run over budget with these design features may choose to implement a maintenance plan that sets these elements as future goals to be achieved on a schedule corresponding to resurfacing (or other activities) as a practical alternative. Plans to raise roads approximately 30 cm now, and again every decade thereafter, for instance, may provide important mitigation.

7. Erosion – Erosion is a problem only where human use of the coastal zone is threatened. This suggests that managing human behavior provides an adaptation alternative that addresses the foundation of the problem.

   a. There is widespread beach loss on Yap. Continuing to follow the current trend of armoring the Yap coast where there is no threat to critical infrastructure will provide mitigation for only a few years and at the expense of coastal ecosystems, tourism ambience, public access to the ocean, and likely cause an increase in coastal population density in the area of greatest hazard. A program of armoring will be expensive and invite scrutiny from funding sources preferring to see a more long-term approach. As sea-level rise proceeds, existing armoring will cease to offer protection and a strategic retreat program will need implementation at greater expense, on an accelerated schedule and with greater social disruption, than if implemented now.

   b. Coastal armoring is most effective where it is employed to protect valuable infrastructure (e.g., port facilities, main roads, etc.). Some coastal locations on Yap are protected by armoring with an apparent value that exceeds the adjacent land. In other areas, coastal defense can be achieved by utilizing ecosystem services (strand forests). Utilizing erosion hotspots as guideposts to retreat from the coast can prove to be an effective policy.

   c. Planned expenditures for new armoring may provide better climate risk management if reprogrammed to emphasize the long-term systemic nature of the problem rather than the short-term solution of armoring. Systemic solutions include employing ecosystem services, new building codes, sand nourishment from carefully considered borrow sites, and other human behavior-changing options. Reprogrammed funds could also assist redevelopment planning and programs, and other human management, rather than erosion management policies.

d. Armoring plays an important role in the central port district of Yap; his can be upgraded to protect facilities.

8. Coastal Zone Management Policy - The Yap business district and significant residential development lie in the coastal zone. Because Yap is viewed as a well-developed location within the FSM, population growth will be strong, especially as atoll islets lose sustainability due to food and water problems.

   The Yap region is vulnerable to climate change and has experienced drought related to El Niño and marine inundation related to La Niña conditions of high sea level. As found elsewhere in the FSM, Yap has no specialized coastal zone management program. Implementation of a base flood elevation to buildings, a construction set-back, a ratified land use plan with required update on a regular basis, and other modern elements of a coastal policy would improve the management of climate risk in the state. The most effective climate risk management will emerge from discussions with local communities and non-governmental organizations. A bottom-up, community-based adaptation approach is better than a top-down approach that may not win support at the local level. Elements of coastal zone management that employ setbacks, building codes, sand and gravel mining guidelines, a system of environmental review on all projects, and that emphasize community hazard resiliency and environment conservation will be most effective if they can emerge from community stakeholders.

e. Before new coastal zone management policy can be devised, a state-wide climate education effort can be enacted. Community groups, landowners, decision-making bodies, agency staff, the general public, and the education system can all be included. Once a public discussion on climate change has begun, new management policies, such as coastal zone management policy, can be envisioned and discussed to enable local acceptance.

f. Strategic retreat from the coast, ecosystem services, sustainable traditional and local practices, environmental protection and other behavior management tools will be the major principles underlying new coastal zone management policy.

g. Sea level is going rise throughout the 21st and 22nd centuries. Roads, buildings, the energy grid, and other human development in the coastal zone will come under increasing stress from marine inundation. Now is the time to identify an upland area for future development, with supportive new government policies, that encourages the population to relocate, over a period of time, to this new area. Yap has several inland settings which have appropriate attributes. Incorporating smart growth design elements in this new community offers improvements to the quality of life of island residents and visitors.

9. Data Gaps – A lack of understanding, and gaps in data, make certain management goals especially difficult to achieve. These include:

f. LiDAR mapping for the Yap coastal zone and hinterlands. Detailed mapping of the lowest lying areas, and the steepest slopes, will assist in identifying the areas with greatest climate risk, locations where relocation can be most successful and where landslides may be a potential problem.

g. Groundwater processes are poorly understood. This includes processes of seawater inundation, over pumping, wetland vulnerability to salinization, and improving water security and infrastructure island-wide. The first step to providing effective mitigation and climate risk management is to define the problem based on in-depth understanding of physical, biological and chemical environmental processes.

h. Knowledge of the detailed pattern of coastal erosion rates among atoll communities will be useful in defining community vulnerability and in planning future shoreline scenarios. Erosion threatens groundwater and agro-forestry resources. A better understanding of erosion can improve management of this problem.

i. Groundwater resources and hydrologic processes are poorly understood. Improving water security will require improving knowledge and monitoring of potential groundwater resources.

j. Monitoring stations can be established in Yap. Monitoring of groundwater, surface water, salt intrusion, soil resources, alien vegetation and other parameters is needed.

10. Specific Next Steps – The Yap population and government agencies need improved understanding of climate risk. Yap could advance the cause of climate risk management with a vigorous public education program. At the same time, community groups, NGOs, teachers, landowners, and other partners and stakeholders can begin planning locally applicable adaptation steps and policies.

APPENDIX 6 - Study Itinerary, Meetings and Field Visits

- April, 14-16, 2009: Majuro, Republic of the Marshall Islands, "Climate Change and the Micronesia Challenge: Ways Forward in Collaboration and Adaptation"
- April, 17, 2009: tour of Enemanit and Bikirin islands, Majuro Atoll
- April, 18, 2009: tour of Majuro and Laura islands, Majuro Atoll
- April, 19-23, 2009: Kosrae
  - April 19, 2009: travel and tour of Kosrae problem sites
  - April 20, 2009: meetings with Kosrae Island Resource Management Agency (KIRMA), Department of Public Works, Office of the Governor, FSM Office of Emergency and Environmental Management (OEEM)
  - April 21, 2009: tour of Kosrae problem sites
  - April 22, 2009: tour of Kosrae problem sites
  - April 23, 2009: tour of Kosrae problem sites, and travel to Pohnpei
- April 23-25, 2009: Pohnpei
  - April 23, 2009: travel
  - April 24, 2009: tour of Pohnpei problem sites and meeting with FSM Office of Emergency and Environmental Management (OEEM), Pohnpei Office of Historic Preservation and Pohnpei Environmental Protection Agency
  - April 25, 2009: meeting with FSM Office of Emergency and Environmental Management (OEEM), tour of problem sites, and travel to Chuuk

- April 25-30, 2009: Chuuk
  - April 25, 2009: travel and tour of Chuuk problem sites
  - April 26, 2009: tour of Chuuk problem sites
  - April 27, 2009: tour of Chuuk problem sites and meeting with FSM Second National Communication Coordinator - Office of Emergency and Environmental Management (OEEM), Chuuk Environmental Protection Agency
  - April 28, 2009: day visit to Taa Island - Satowan Atoll, tour of problem sites, meeting with Taa Village Council, Chuuk Environmental Protection Agency, and FSM Second National Communication Coordinator
  - April 29, 2009: day visit to Houk Island, tour of problem sites, meeting with Houk Village Council, Chuuk Environmental Protection Agency, and FSM Second National Communication Coordinator
  - April 30, 2009: meeting with Chuuk Environmental Protection Agency, and FSM Second National Communication Coordinator and travel to Yap
- April 30-May 6, 2009: Ya
  - April 30, 2009: travel
  - May 1, 2009: tour of Yap Island, meeting with Office of Planning and Budget/Disaster Coordination, FSM Second National Communication Coordinator, Margie Falanruw (Forester), Mathius Kuaumaar (Taro farmer), Joe Falalay (resident)
  - May 2, 2009: travel and tour of Mogmog and Fassarai islands, Ulithi Atoll and meetings with village councils
  - May 3, 2009: tour of Falalap Island and community meeting
  - May 4, 2009: travel and tour of Woleai Atoll and islands of Falalop, Falalus, Wottegai, and Seliap and meeting with village councils
  - May 5, 2009: travel and meeting with Yap Governors office
  - May 6, 2009: return to Honolulu

APPENDIX 7 - Field Elevation Measurements

This appendix provides tables and location photos of global positioning system (GPS) measurements of elevations on all islands visited in the course of this study.

Table 7-1. Kosrae. Measurements and descriptions of selected coastal sites on Kosrae, FSM. Beach elevation and horizontal distance is from the toe of the beach to the *beach berm*. Measurements in (parentheses) are the elevation and distance from the toe of the beach to the adjacent *coastal ridge* where present and accessible. Non-beach elevations are the elevation of the feature above the approximate low-tide level. Locations are shown in Figure B. Base image from Google Earth

Way Point	Elevation (m)	Horiz. Dist (m)	Feature/Comments
484	2.28	10.6	E. beach; sand & gravel
485	1.83	18.23	E. beach; gravelly sand
486			Boulders on reef flat (S. coast)
487	2.81	13.01	S. beach; sand & gravel; erosional scarp
488			Revetment
489			End of groin
490			Inundation limit Dec. 2008 overwash
491	2.45		Revetment
492	1.93 (2.37)	16.13 (35.08)	N. beach; sand
493	2.07	10.11	N. beach; sand
494	1.08		Road elevation
495	1.61	14.76	N. beach behind mangroves; sand
496	1.95	14.35	NE. beach; sand & gravel
497			Offshore reef site
498	2.66	12.24	NE. beach; sand & gravel
499	1.85	14.02	NE. beach; sand
500			Reef flat rubble bank
501	2.26	11.76	E. beach; sand & gravel
502	2.02	12.02	E beach; sand & gravel
503	2.31	11.01	SE. beach; sand & gravel, 2 berms
504			Large reef flat block (~4x3x2 m)
505	1.96	8.03	SE. beach; sand & gravel
506	2.21	2.1	E.beach; sand & gravel

Figure B. Kosrae, Federated States of Micronesia (FSM) elevation locations.

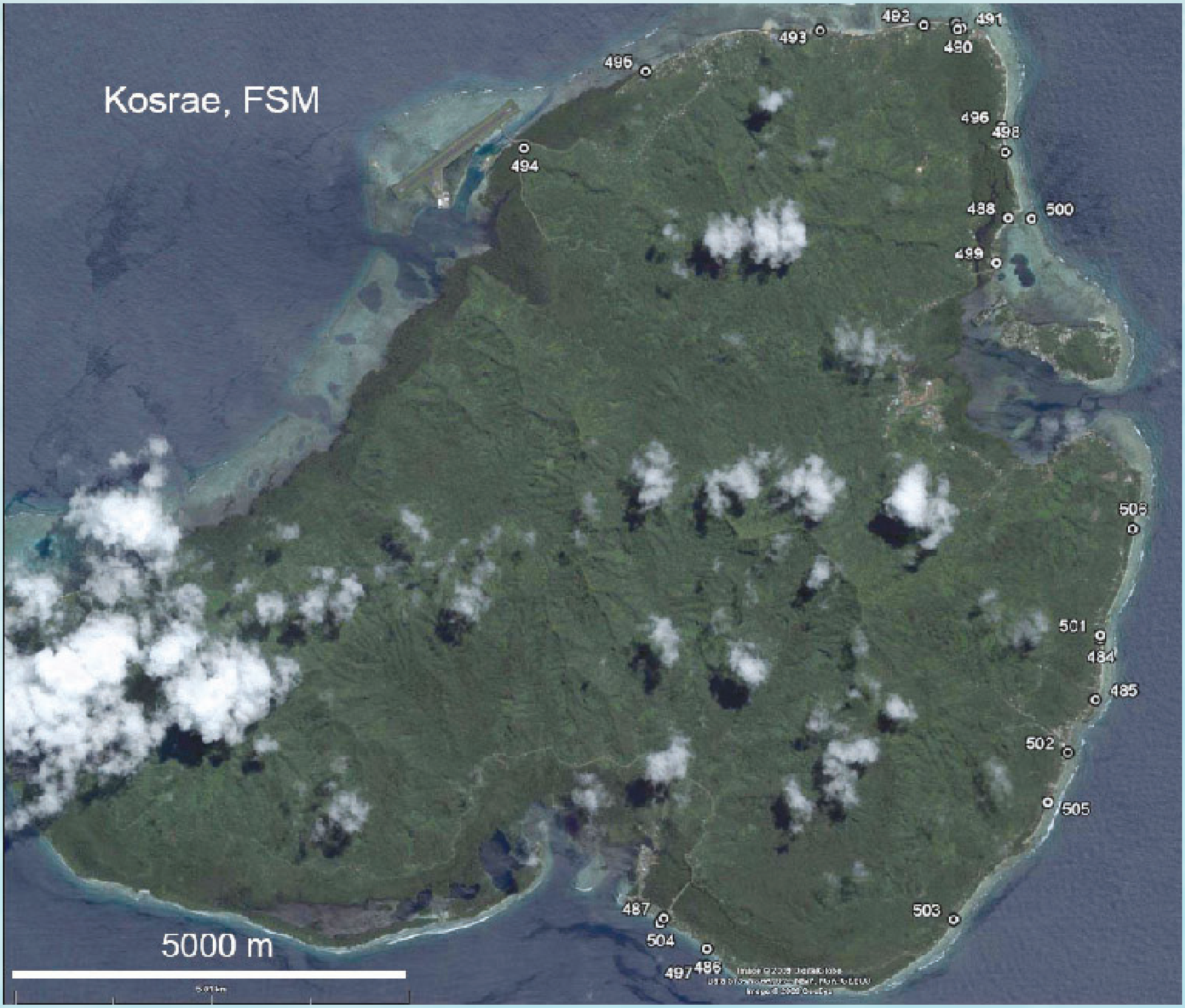


Table 7-2. Taa Islet, Satawan Atoll. Measurements and descriptions of selected coastal sites on Taa Islet, Satawan Atoll, Chuuk, FSM. Beach elevation and horizontal distance is from the toe of the beach to the beach berm. Non-beach elevations are the elevation of the feature above the approximate low-tide level. Locations are shown in Figure C. Base image from Google Earth.

Way Point	Elevation (m)	Horiz Dist (m)	Feature/Comments
515	1.77	8.52	Oceanside beach; sand lower, gravel upper
516	1.94	8.81	Oceanside beach; sand lower, gravel upper
517	1.79	8.18	Oceanside beach; sand lower, gravel upper
518	1.99	9.5	Oceanside beach; sand lower, gravel upper
519	1.78	8.99	Oceanside beach; sand lower, gravel upper
520	1.53	10.09	Lagoon beach; sand with scattered rubble
521	1.19	8.31	Lagoonside beach; low coral seawall
522	1.69	9.56	Lagoonside beach; sand
523	1.49	8.94	Lagoonside beach: sand
526	1.05	4.8	Lagoon bch; mudy/sd w/ grvl, low cral wall
527	1.45		Lagoonside; wall elevation above beach
528			Islet interior swamp taro
529	1.16	7.34	Lagoonside beach; sand with scarp
530			W. end of islet (Taa
531			Reef block (2x1.8x1.2 m)
532	1.25	6.68	Lagoon beach; sand, adjacent to swamp taro
533			Duplicate point
534			E. end of islet to west of Taa
535	1.62	8.77	Lagoonside end of islet; gravel beach
536	1.61	10.33	Lagoonside end of islet; sand beach
537	1.49	5.73	Lagoonside beach; sand and gravel
538	1.55	6.52	Lagoonside beach; sand and gravel
539			W. end of islet to west of Taa

Figure C. Taa Islet, Satawan Atoll, Chuuk, Federated States of Micronesia (FSM) elevation locations.

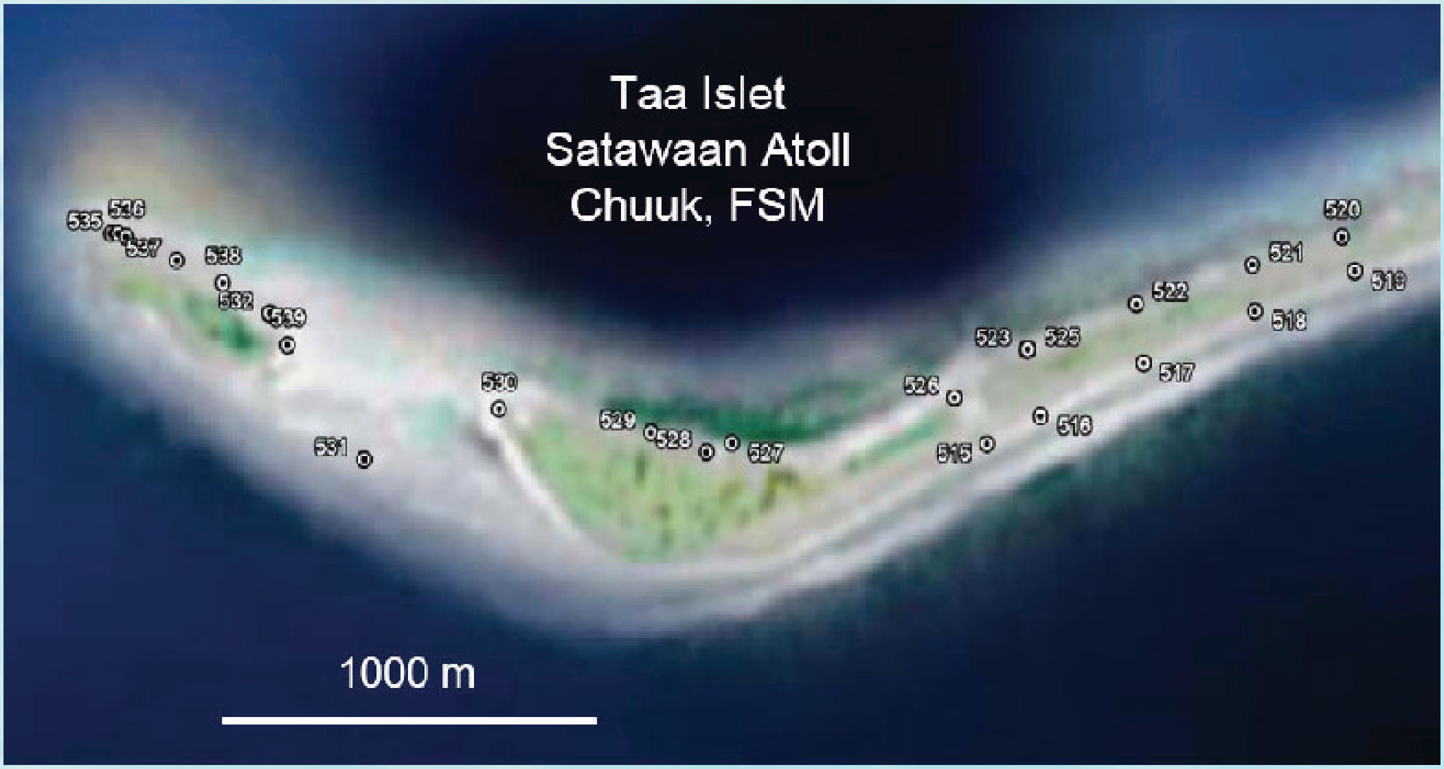


Table 7-3. Houk Islet, Pulusak Atoll. Measurements and descriptions of selected coastal sites on Houk Islet, Pulusak Atoll, Chuuk, Federated States of Micronesia (FSM).Beach elevation and horizontal distance is from the toe of the beach to the beach berm. Measurements in (parentheses) are the elevation and distance from the toe of the beach to the adjacent coastal ridge where present and accessible. Non-beach elevations are the elevation of the feature above the approximate low-tide level. Locations are shown in Figure D. Base image from Google Earth.

Way Point	Elevation (m)	Horiz Dist (m)	Feature/Comments
541	1.85	12.62	SW. beach near runway; sand with multiple berms
542	1.61	5.45	S. Beach; sand and gravel with sand cap
543	1.51	8.24	S. beach; sand with scattered gravel
544	1.23	6.81	SE. beach; sand lower, gravel upper
545	1.99	8.09	SE. beach; gravel with sand
546	2.31	8.69	SE. beach; gravel with prominent ridge
547	2.25	8.62	E. beach; gravel with sand
548	2.17	8.53	E. beach; gravel with sand
549	1.51	8.64	SW. beach; sand with some gravel
550	3.64	19.23	N. beach; sand lower, gravel upper
551	2.49	9.11	N. beach; gravel with sand, beachrock
552			N. end of interior lake
555	1.38 (2.36)	9.07 (21.07)	E. beach; pebbly sand
556	0.90 (2.26)	7.61 (16.23)	E. beach; coarse sand, seagrass offshore
557	1.28 (3.61)	9.68 (26.47)	E. beach; sand, broad plain
558			duplicate point
559	1.60 (3.15)	12.13 (24.04)	E. beach; sand, broad plain
560	1.62 9.7		E. beach; sand with gravel, broad plain
561	1.35 9.7		SE. beach; sand with broad plain

Figure D. Houk Islet, Pulusak Atoll, Chuuk, Federated States of Micronesia (FSM) elevation locations.

Table 7-4. Yap Main Islands. Measurements and descriptions of selected coastal sites on the Yap Main Islands, Federated States of Micronesia (FSM). Beach elevation and horizontal distance is from the toe of the beach to the beach berm. Non-beach elevations are the elevation of the feature above the approximate low-tide level. Locations are shown in Figure E. Base image from Google Earth.

Way Point	Elevation (m)	Horiz Dist (m)	Feature/Comments
562	1.33		Top of revetment at road, overwashed during storms
563			Greenschist outcrop
564			Post cyclone coral wall, Wanyan Village
565	1.97	14.22	Beach park, sand and scattered pebbles
566			Stream bank
567			Stream bank
568	1.72	16.91	Beach, Maap, Moonrize resort; sand;
603	2.54 (0.59)		Top of vertical wall near reef flat (beach berm behind wall)

Figure E. Yap, Main Islands, Federated States of Micronesia (FSM) elevation locations.

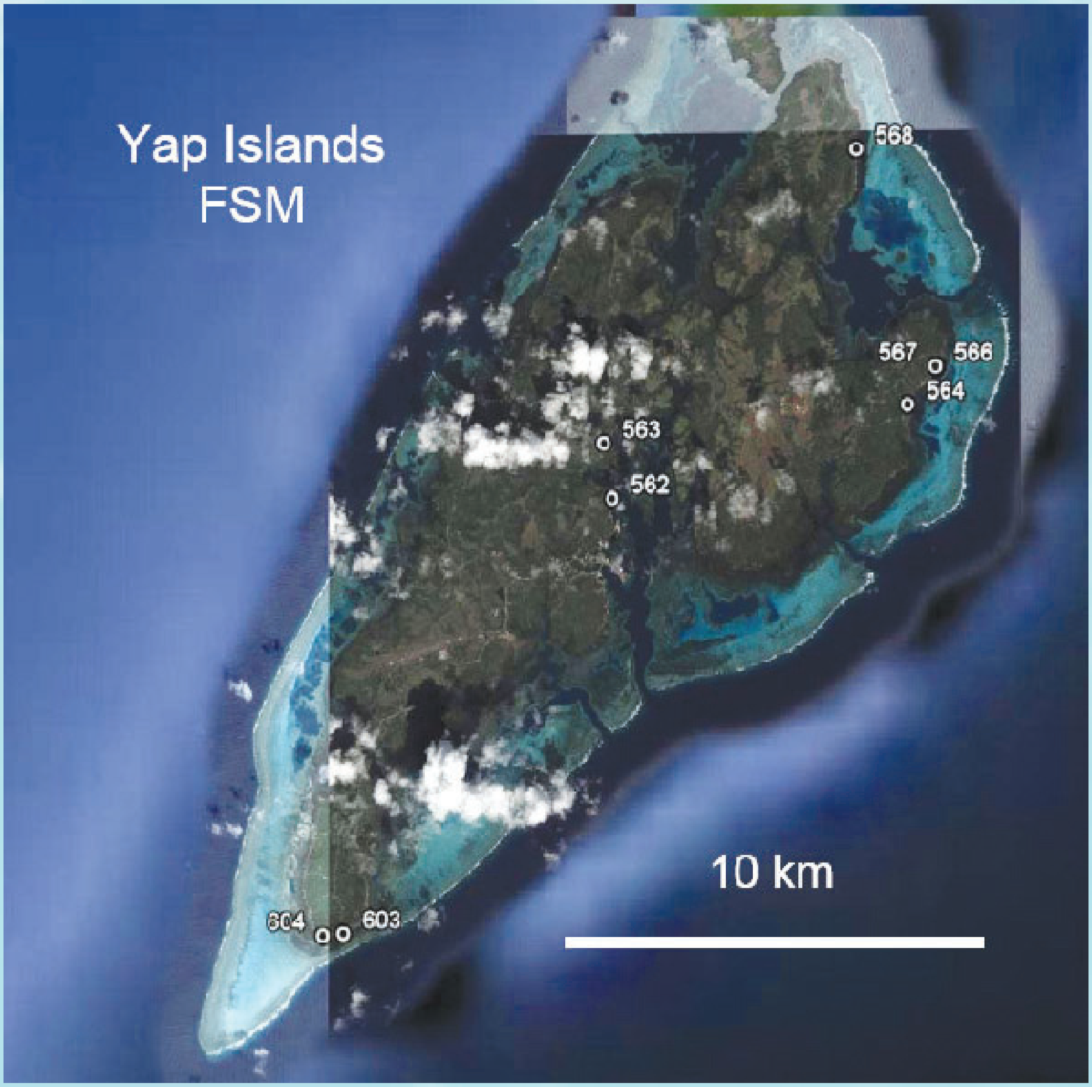


Table 7-5. Ulithi Atoll. Measurements and descriptions of selected coastal sites on Ulithi Atoll, Yap, Federated States of Micronesia (FSM). Beach elevation and horizontal distance is from the toe of the beach to the beach berm. Measurements in (parentheses) are the elevation and distance from the toe of the beach to the adjacent coastal ridge where present and accessible. Non-beach elevations are the elevation of the feature above the approximate low-tide level. Locations are shown in figures F Fassarai Islet, G Mogmog Islet, and H Falalop Islet. Base image from Google Earth.

Way Point	Elevation (m)	Horiz Dist (m)	Feature/Comments
569	1.69?	19.57	W. beach (lagoon), sand and gravel; eroding with beachrock slabs
570	3.61	22.52	W. beach (lagoon); sand and gravel
571	2.44 (5.36)	14.29 (38.51)	E. beach; sand with pebble base
572	2.13	19.14	S. beach (lagoon); coarse sand and pebbles
573	2.65	9.35	S. beach (lagoon); pebbles
574	2.23	14.67	NW. beach; sand and gravel
575	1.64 (2.76)	8.47 (14.81)	N. beach; gravel
576			Boat landing
577	2.69 (4.10)	12.12	W. beach; gravel with sand
578	1.37 (2.51)	7.83 (15.15)	S. beach; gravel with sand
579	2.25	9.01	S. beach; gravel with sand
580	2.18	7.84	SE. beach; gravel
581	2	6.62	E. beach; gravel with sand
582	2.27	15.81	Airstrip revetment (E. coast)
583	3.09	12.59	N. beach; gravel, conglomerate platform
584	1.25 (5.12)	9.46	NW. beach; sand with gravel
585	7.58		Old elevated cemetery by channel
586	1.9 (5.26)	26.96 (61.82) S	W. beach; sand with gravel

Figure F. Fassarai Islet, Ulithi Atoll, Yap, Federated States of Micronesia (FSM) elevation locations.

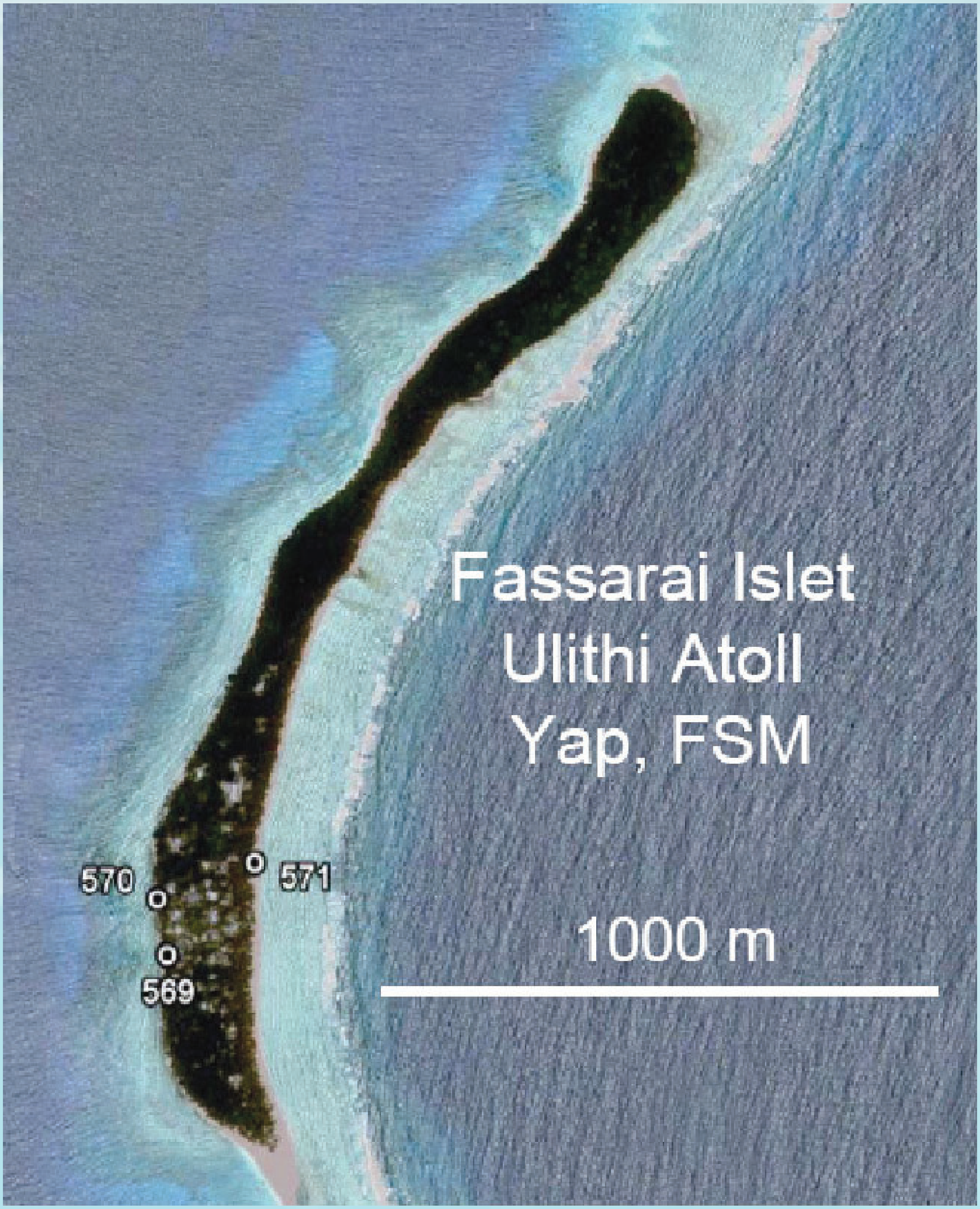


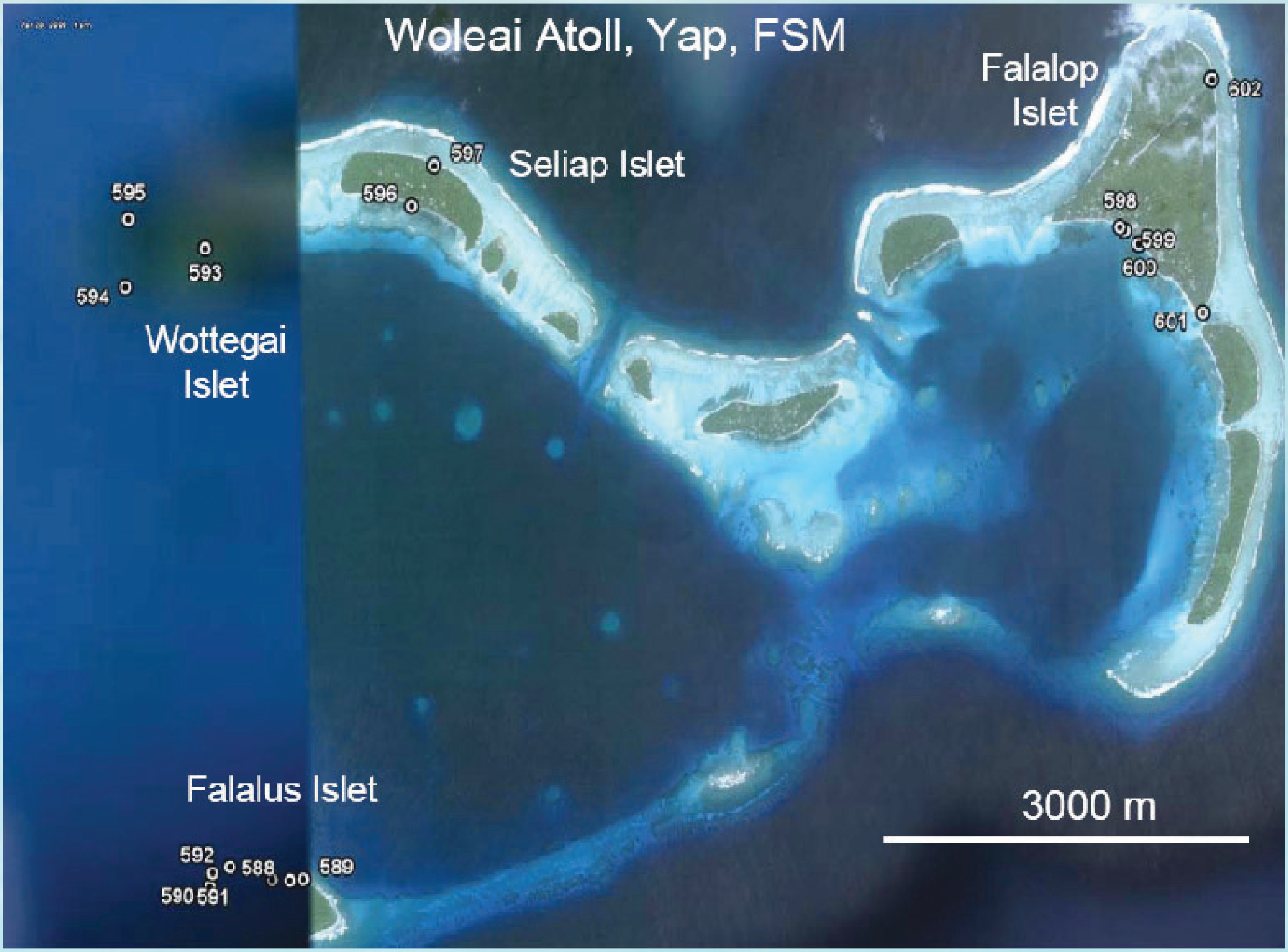
Figure G. Mogmog Islet, Ulithi Atoll, Yap, Federated States of Micronesia (FSM) elevation locations.

Figure H. Falalop Islet, Ulithi Atoll, Yap, Federated States of Micronesia (FSM) elevation locations.

Table 7-6. Woleai Atoll. Measurements and descriptions of selected coastal sites on Woleai Atoll, Yap, Federated States of Micronesia (FSM). Beach elevation and horizontal distance is from the toe of the beach to the beach berm. Measurements in (parentheses) are the elevation and distance from the toe of the beach to the adjacent coastal ridge where present and accessible. Locations are shown in Figure I. Base image from Google Earth.

Way Point	Elevation (m)	Horiz Dist (m)	Feature/Comments
587	1.48	10.62	Lagoonside; gravel ridge
588	1.45	6.99	Lagoonside; gravel ridge
589	1.73	4.56	Lagoonside; gravel ridge, old seawall
590	2.61	4.91	W. end; beach, sand with gravel; erosional scarp and old cemetary
591	2.55	20.76	NW. beach; sand, accretionary ridges
592	1.96	8.76	N. beach; sand, small scarp
593	1.4	7.14	S. beach; sand, collapsing seawall
594	1.42	7.92	W. end beach; sand, erosional, fallen coco trees
595	2.76	9.24	NW. oceanside beach; gravel
596	1.51	9.31	S. beach (lagoonside); sand
597	2.88	12.06	N. beach (oceanside); gravel
598	3.21	36.67	Lagoonside beach; sand, broad plain
599	2.96	46.15	Lagoonside beach; sand, broad plain
600	1.78	17.43	Lagoonside beach; sand, broad plain
601	1.12 (1.50)	11.31 (42.89)	W. end beach; sand, broad plain

Figure I. Woleai Atoll, Yap, Federated States of Micronesia (FSM) elevation locations



END NOTES

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[2]Geologist, U.S. Geological Survey, Pacific Coastal and Marine Geology Science Center, 400 Natural Bridges Drive, Santa Cruz, CA, 95060 U.S.A. ph. (831) 427-4731, fx. (831) 427-4748, brichmond@usgs.gov, www.usgs.gov

[3]The event evolved from a coincidence of unusually high tides (moon near perigee – closest distance to Earth) and a low-pressure system north of Wake, which generated northerly swells in the 4–5 m (~13–16 ft) range from Majuro to Chuuk. Marine inundation caused damage to crops, property, and resources in coastal areas throughout Micronesia. Damage assessments were conducted among islands of Kosrae, Pohnpei, Chuuk, and Yap states focusing on impacts to agricultural crops and groundwater resources.

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[5]Shigetani, M., and members of the Preliminary Damage Assessment Team, 2009 Preliminary Damage Assessment, Federated States of Micronesia: High Tide Event, December 7-12, 2008; USAID, FEMA.

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[73]Ramsay, 2000.

[74]It is not expected that traditional cultures lived on islands without impact, and it is not expected that traditional communities were uniformly sustainable. But it is assumed that a traditional culture that has a high degree of self-reliance also has a strong ethical system, detailed ecosystem knowledge, and a system of community and resource management that is historically successful.

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[92]Ramsay, notes 89 and 90.

[93]Ramsay, notes 89 and 90.

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