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Federated States of Micronesia (FSM) International Waters Ridge to Reef Project

Tofol Watershed Catchment Geological Assessment from Ridge to Reef, Kosrae State, FSM

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Tofol Watershed Catchment
Geological Assessment from Ridge to Reef, Kosrae State, FSM

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ABBREVIATIONS

FSM	Federated States of Micronesia
GEF	Global Environment Facility
GMSL	Global Mean Sea Level
GPS	Global Positioning System
IW	International Waters
KIRMA	Kosrae Island Resource Management Authority
LMPA	Lelu Marine Protected Area
PA	Protected Area
R2R	Ridge to Reef
SPC	Pacific Community
UN	United Nations

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Finally, we thank KIRMA's Andy George and Faith Siba for their advice, supervision, and coordination of this project.

1. INTRODUCTION

The Pacific Ridge to Reef (R2R) Programme is a multi -country, multi -GEF agency programmatic initiative guiding the coordinated investment of US$90 million in GEF grant funding across multiple focal areas of biodiversity conservation, land degradation, climate change adaptation and mitigation, sustainable land management, sustainable forest management, and international waters in Pacific Small Island Developing States (SIDS).

Operating across 14 Pacific Island countries, the programme aims to deliver tangible and quantifiable local and global environmental benefits by focusing on cross-cutting approaches to water, land and coastal management with linkages across GEF focal areas including: biodiversity, land degradation, international waters, sustainable forest management, climate mitigation and adaptation and capacity development. The programme is implemented by United Nations Development Programme (UNDP), the United Nations Food & Agriculture Organization (FAO) & the United Nations Environment Programme (UNEP).

Executed regionally by the Pacific Community (SPC) through the Regional Ridge to Reef International Waters Project (Regional IW R2R), the R2R programme is supported by the Regional Programme Coordination Unit (RPCU) in areas of science-based planning, human capital development, policy and strategic planning, results-based management, and knowledge sharing. The Regional IW R2R Project is one of 15 child projects under the Programme, and provides the primary programme coordination vehicle for the 14 other child projects – the national R2R System for Transparent Allocation of Resources (STAR) Projects under the Pacific R2R Programme.

The Regional Project aims to test the mainstreaming of ‘ridge-to-reef’ (R2R), climate resilient approaches to integrated land, water, forest and coastal management in the Pacific Island countries (PICs) through strategic planning, capacity building and piloted local actions to sustain livelihoods and preserve ecosystem services.

The FSM International Waters Ridge to Reef Project (FSM IW R2R) was designed to strengthen synergies between government, communities, and the private sector. The FSM IW R2R Project is implemented in partnership with the Department of Environment, Climate Change and Emergency Management (National Government) and The Kosrae Conservation and Safety Organization.

The project demonstration area is located in Lelu Municipality, extending from Mutunneneah to Tofol, the administrative centre of Kosrae. The three rivers in this area are the Tofol, Srungansralu and Innem rivers. The watersheds of these three rivers receive rainfall from the Mahkontowe Conservation Area.

Kosrae is a tropical island located at 5.3^{o} north and 163^{o} east. The population of Kosrae is 6732 according to projections by the 2020 census. The total area of the island is roughly 110 km^{2}.

Kosrae was formed by the eruption of an undersea volcano approximately 2 million years ago. It is the youngest island among the 607 islands of FSM. Being geologically younger than the other islands, it has different geography from the other FSM states. Having experienced only about 1 million years of weathering and erosion, Kosrae retains steep slopes and narrow ridges. The highest point on Kosrae is Mount Finkol, elevation 624 m. Approximately 1000 years ago, a lowering of sea level exposed reef flats near the island, creating coastal plains about 500 m wide. Kosrae has a fringing reef, which averages 200 m offshore. This reef allows for a shallow and narrow lagoon between the reef and land.

This demonstration project involved two assessments of the watershed and its three rivers:

- A biological assessment of the flora and fauna by Mr. Carlos Cianchini
- A hydrologic and geologic study of the water, rocks, and sediments by Dr. Nick Zoa

For the hydrologic and geologic assessment, the Tofol, Srungansralu and Innem rivers and their tributaries were mapped using GPS coordinates. The rock, clay and soil types found within the watershed were documented and studied, along with the natural and anthropogenic erosional features created along these rivers. Visual assessments of the water quality and turbidity under various weather conditions were made, including during and after torrential rains, which occurred on 17 April.

The results of these assessments are contained in the accompanying report.

2. METHODOLOGY

The Tofol, Srungansralu and Innem rivers and their estuaries were surveyed on foot and by kayak. The table below summarises the areas surveyed.

Table 1: River type, dates of survey and brief descriptions of the sample area

River	Date of survey	Comments	Cianchini	Zoa
Tofol	March 21, 2021	Upper and middle section, fauna search	√	
	March 28, 2021	Upper, middle, and lower sections by foot	√	√
	March 30, 2021	Brief examination of a landslide by foot	√	√
	April 2, 2021	Estuary by kayak	√	√
	April 5&17, 2021	Checked turbidity beneath bridges		√
Srungansralu	March 30, 2021	Upper, middle, and lower sections by foot	√	√
	April 1, 2021	Upper section of S.Srungansralu by foot	√	√
	April 2, 2021	Estuary by kayak	√	√
	April 5&17, 2021	Checked turbidity beneath bridges		√
	April 8, 2021	Channel and dis-used crab farms by foot	√	√
	April 10, 2021	Estuary, channel, and crab farms by kayak		√
Innem	April 2, 2020	Upper section by foot		√
	March 31, 2021	Middle and lower sections by foot	√	√
	April 2, 2021	Estuary by kayak	√	√
	April 5&17, 2021	Checked turbidity beneath bridges		√
	April (?), 2021	Estuary by kayak	√	

A GPS application which was accurate within 10 m was used to determine locations of river channels by plotting GPS points on a satellite view of Google Earth (Map #2).

In order to determine the geologic and tectonic history of the area, the points where there was exposed undisturbed bedrock were documented. This task was made difficult by thick overburden (vegetation) which permeated this watershed. Most of the observations were made by examining the stream beds and the stream banks. Deposits of gravel, sand, silt, and mud were used to estimate the watershed's source materials and to evaluate the effects of erosion. For this report on the upper section of the Innem river, field notes and photographs of previous surveys from April 2020 (collected by the principal researcher) were also used.

3. RESULTS

Tofol, Srugansralu and Innem rivers (Table 1, Table 2, and Table 3 respectively) were surveyed for the soil types, erosional features, and visual turbidity of water along the different locations. Notably, there are three branches of the Srungansralu river, which will be referred to in this report as the South Srungansralu, the North Srungansralu and the Srungansralu Channel. The survey field notes are found in Appendix B.

Table 2: Tofol river location coordinates, elevation, and description.

Location coordinates	Elevation (metres)	Descriptions
5.3185°N 163.0055°E	50 m	The river flowed through an undeveloped forest where the river meandered and cut into clay banks, some of which sedimentary bedding dipped 45 degrees to the southwest. The inner turns of the Tofol river were filled with cobbles and boulders of basalt. In calm eddies, volcanic sand and clay pebbles accumulated. Water observed to be clear (low turbidity).
5.3166°N, 163.004°9E	70 m	No large trees were observed, and the river valleys broadened. Turbidity of water was moderate due to disturbed clay in riverbed.
5.3246°N, 163.0082°E	10 m	Boulders dumped to form riprap for prevention of erosion. Slightly silted water was observed but clearly visible riverbeds. Further downstream, sliding event occurred frequently due to riverbanks made of soft clay.

Table 3: Srugansralu river location coordinates, elevation, and description

Location coordinates	Elevation (metres)	Descriptions
5.3239°N 163.0062°E (South Srugansralu)	10 m	This is the South Srungansralu, a fast-flowing creek. Water was observed to be low in turbidity, 1 m wide and had basalt ledges. Banks of creeks were mostly clay and calm eddies had clay and basalt pebbles.
5.3227°N 163.0051°E (South Srugansralu)	38 m	Sand and gravel created swirlholes in basalt boulders situated mid-stream. During periods where there is no rain, low turbidity was observed. South Srungansralu estimated to carry 2 – 3 times more water and observed to be visually less turbid than North Srugansarlu.
5.3252°N 163.0050°E (North Srugansralu)	18m	Soils and streambed comprised of very soft clay.
5.3275°N 163.0055°E (North Srugansralu)	4m	Exposed to houses and agriculture plots where water drains into from muddy farms and piggeries. High tide and brackish water flowed into channel with debris and silt from tidal flats.
5.3287°N 163.0114°E (Combined North and South Srugansralu estuary)	1.7m	Riverbanks in this area were an alluvial plane with thick deposits of soft clay silt.
5.3292°N 163.0080°E (Srugansralu Channel)	2.9m	Srugansralu Channel was heavily silted where some water from Innem river flowed into the eastern crab enclosure which then flowed into the Channel on the south side.

Table 4: Innem river location coordinates, elevation, and description

Location coordinates	Elevation (metres)	Descriptions
5.3280°N 162.9980°E	17.9m	Water appeared clear, outer banks of river consisted of orange clay. Inner banks have clay and basalt pebbles and cobbles including occasional red clay cobbles which originating from a higher elevation.
5.3306°N 163.0089°E	8m	Moderately clear water even though proximity to main road and bridges.

Tofol River outflow into Lelu Harbor

4. DISCUSSION

Data was collected in the three rivers that discharge from the Tofol Watershed into the Lelu Marine Protected Area (LMPA) of Lelu Harbor. These rivers are the Tofol, the Srugansralu and the Innem rivers.

All three rivers originate at high altitude in undisturbed, undeveloped forests in the centre of Kosrae. Below these primary forests, each river passes through developed areas where it accumulates sediment, pollution, and garbage. By the time these rivers reach Kosrae's paved roads, they have slowed considerably as they enter the mangrove and freshwater swamp east of the main road.

The Tofol river was found to be clean and clear in undeveloped areas at high elevation. A dam on this river provides tap water to the Tofol community. The primary causes of water quality degradation are the easily eroded clay banks and riverbed. From the legislature to the radio station, human activity produces some turbidity. Near the mangroves, inflow from tides brings coral silt from Lelu Harbor.

The Srungansralu river is divided into three parts: The South Srungansralu, the North Srungansralu and the Srungansralu Channel.

The upper section of the South Srungansralu is an undisturbed mountain stream which drains a heavily forested valley with no human development. The water in this stream was clear, clean, and cold. Although this creek is not as large as the Tofol river, it could be an alternative water supply if the Tofol river were not available.

The study found that although the North Srungansralu started at a spring that was clean enough for cooking and cleaning, 500 meters downstream, it was a muddy, brackish, polluted estuary due to runoff from homes and agriculture and tides flowing through a silt-filled marsh. The Srungansralu Channel was built to provide drainage for a former crab farm.

Of the three rivers in the Tofol watershed, the Innem river was the largest by volume and length and was also the healthiest.

The mangrove ecosystem that the three rivers share was included as a Conservation Target in "A Blueprint for Conserving the Biodiversity of the FSM". Other protected areas within the LMPA are:

- The Awane Protected Area
- The Blue Hole
- The Weok Protected Area

These three Protected Areas are indicated on Map no. 3.

The following discussion subtopics of the hydrology and geologic survey of these three rivers were presented from south to north, starting with the Tofol river, then the Srungansralu and finally the Innem.

4.1 Tofol River

Tofol river was found to be slightly silted but clear enough to see pebbles on the riverbed due to the observation of no construction, no buildings, and no agricultural activity upstream. Other observations of note were river water had a milky quality where a vehicle scrap yard and septic fields were in close vicinity. However, due to the incoming high tide, the milky quality observed may have been due to coral silt entering the river channel.

Basalt cobbles and easily eroded clay bank

Clay pebbles in an eddy

Landslide of 29 March 2021 near KIRMA

Riprap adjacent to legislature parking lot

Fish seen from the bridge below government offices

Septic ponds near the radio station

Brackish water near the outflow to Lelu Harbor

Figure 1: Tofol river notable observations

4.2 Srungansralu River

The Srungansralu river is separated into the North, South and the Channel. The South Srungansralu has the largest water flow of the three branches because it drains the largest watershed. It originates from the forests west of Tofol's administrative centre and flows parallel to the Tofol River. Near the legislature, the South Srungansralu River is only about 100 m north of the Tofol River. The South Srungansralu passes below the hospital, goes under the main road, flows past Kosrae's High School, and joins the North Srungansralu before flowing into the mangrove swamp.

It was suggested that there are bedded clays dipping to the southwest as also observed in Tofol river. This suggested that an uplift occurred to the northeast in the distant past. Tilted clay beds could be found in Innem that were similar to Tofol riverbanks as well.

Downstream from the primary forest, the South Srungansralu flows through a grassy meadow where sand and gravel have created swirlholes in the basalt boulders in mid-stream. During times of heavy rain, silt from the hospital construction site contaminates this stream and is carried to the alluvial marsh downstream.

From the last bridge over the South Srungansralu

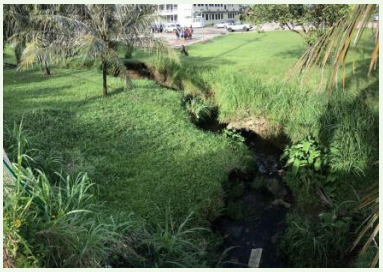
(5.3242N 163.0064E)

Small cascade over basalt

Swirlholes in a basalt boulder

Grassy fields below the primary forest

Inside the primary forest



South Srungansralu ditch next to high school

View from the hospital construction site: South Srungansralu River in foreground, Tofol River in background

Dipping clay beds behind hospital construction site

Figure 2: Srungansralu river notable observations

During the survey it was discovered that local landowners pump water from a spring located along the North Srungansralu river for cooking and cleaning. This highlights the importance of regular monitoring of water as the livelihoods of the nearby communities rely greatly on the river. North Srungansralu River is joined by the faster flowing South Srungansralu River which empties from a ditch between the road and a high school. The combined North and South Srungansralu flow into a brackish estuary. The surrounding forest was littered with garbage and furniture disposed of from the nearby high school also noting that during high tide, the marshlands were flooded.

Mues's spring and electric pump

Freshwater swamp with taro

North Srungansralu below the farms

Stream choked with vegetation

Below junction of North and South Srungansralu

Srungansralu tidal marsh behind gymnasium

Figure 3: North Srungansralu River observations

The observations in Table 2 indicate that the Srungansralu River is at a lower elevation than Innem River. Geologic data suggests that with enough time, Srungansralu River will eventually capture the Innem River.

Small spring at the start of the channel

(5.3292N 163.0080E)

View of the channel from the main road

A residence by the channel next to the main road

Location of former crab farm enclosures

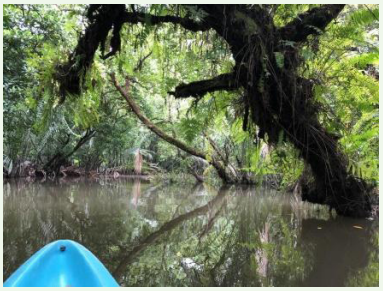
Western sluice gate with channel to the right

The western sluice viewed from the channel

The eastern sluice viewed from inside the enclosure

Exploring upstream from the gymnasium

The salt marsh of the Srungansralu



The exit of the Srungansralu River into Lelu Harbor

Figure 4: Srungansralu Channel observations

4.3 Innem River

The Innem river was accessible by foot, and a farm road along the north side of the river allowed access to homes and farms. Clay deposits form the walls of the Innem Valley. Innem river consists of dendritic streams and creeks flowing down steep ravines through undeveloped forests.

Unlike the North Srugansralu on the south side of the Innem Valley, the Innem river remained clean and clear down to the bridge on the main road. This is due to five reasons:

1. The Innem drains a larger part of the watershed, therefore it has more water.
2. The Innem was at a slightly higher elevation than the Srungansralu, so it remained a fast-flowing stream all the way to the main road.
3. There is little farming upstream. No ditches have been dug to drain the farmlands.
4. The houses were at least 200 m from the river.
5. The banks of the Innem are forested or covered with vegetation; whereas the Srungansralu has tidal mud flats on both banks.

Road cut showing clay walls of the Innem Valley

At 5.3280N 162.9980E, the Innem river is 10m wide.

Vertical clay riverbanks

Clay from riverbank

Meandering Innem river in primary forest

Red clay cobble

A shrimp with long claws

Calm section near road

Calm section near road

East from the main road

Large ficus below the bridge

Clear water below the bridge

Figure 5: Innem River observations

4.4 Hydrological and Geologic Relationship of Tofol, Innem and Srungansralu Rivers and Estuaries.

Tofol, Srungansralu and Innem Rivers exit into Lelu Harbor at these coordinates:

Table 5: Coordinates in which the Tofol, Srungansralu and Innem Rivers exit into Lelu Harbor

Name of River	Coordinates rivers discharge into Lelu Harbor
Tofol	5.3279°N 163.0158°E
Srungansralu	5.3292°N 163.0146°E
Innem	5.3306°N 163.0141°E

Mapping data showed that the headwaters of Tofol, Srungansralu and Innem rivers were more than 2000 m apart. However, these rivers exited through the mangrove swamp into Lelu Harbor at three points, which were only approximately 400 m apart. This is typical of a watershed which captures precipitation from a bowl-shaped valley whose rivers all flow towards a single common low point.

The freshwater from the Tofol meets the incoming salt water somewhere behind the radio station, depending on the height of the tide. The Srungansralu is a tidal estuary from the mud flats west of the main road all the way to Lelu Harbor. Freshwater from the Innem flowed clean and clear to 5.3300°°N 163.0131E. From this point, incoming tides bring saltwater.

Each river flows through a brackish swamp whose banks are heavily overgrown with mangroves and other salt-tolerant plants. The soils were found to be mostly fine silt derived from the clays upstream, and the banks of the Innem river were mixed with sand and silt. The Innem river also has gravel bars of clay and basalt pebbles.

Of the three rivers, the Innem is the longest, as it drains the largest part of the watershed and carries the most water. For this reason, the banks of the Innem are sandy and gravel bars are present within the mangrove swamp. The Innem's fresh water almost reaches the harbour. The Tofol, the steepest river, remained clean and clear until it reached tidal inflow in the flats behind the radio station. The Srungansralu River is the lowest in elevation, and had relatively the slowest river flow, was observed to be the most turbid and had the highest level of anthropogenic effects.

Between the Innem and Srungansralu rivers, there are two 2-acre enclosures with 3 m berms, which were formerly used for crab farming. The western enclosure is densely forested and creates a barrier between the Innem and Srungansralu rivers. The eastern enclosure has a disused intake

portal through which about 5% of the Innem passes enroute to a human-constructed channel, which empties into the Srungansralu. Except for this connection, all three rivers remain separate and distinct, although at some points their meanders bring them as close as 50 m from each other.

Entrance to the Innem river

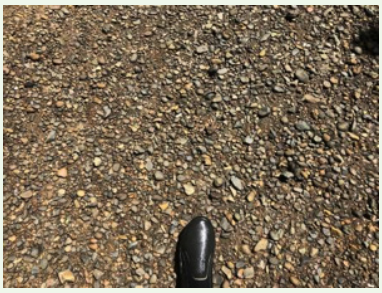
Inside the mangrove swamp

Sandy bank on the Innem

Silt deposits on the riverbank

Vegetation and garbage

Clear water in the Innem



Clay and basalt pebbles in the Innem river

Intake of the Innem into the former crab farm enclosure

View down into the eastern crab farm enclosure

The muddy Srungansralu outflow into Lelu Harbor

Behind the gymnasium on the Srungansralu

Tofol River outflow into Lelu Harbor

Figure 6: Observations of hydrological and geologic relationship of Tofol, Innem and Srungansralu rivers and estuaries

4.5 Lelu Harbor

One of the goals of this study was to determine the impact of the sedimentation, pollution, and garbage which the Tofol, Srungansralu and Innem rivers discharge into the LMPA. To assess the impact of these discharges, additional observations of the Lelu Harbor area were made.

On 17 April 2021, Kosrae received several hours of heavy rain. At flood stage, all three rivers of the Tofol Watershed carried heavy loads of sediment into Lelu Harbor, turning the water brown in colour. Additional sediments were discharged via the Tafeyat River and the Mutunneneah channel. During low tide after the heavy rainfall, a sediment plume was visible outside Lelu Harbor in the open sea. By snorkelling, it was verified that the underwater visibility in the harbor and at the Weok Protected Area (PA) remained extremely poor for the next week, indicating that much of the sediments discharged during flooding remained in the LMPA.

These heavy sediment discharges adversely affected Kosrae's coral reefs, the Blue Hole and the Weok PA. Clay particles from the Tofol Watershed remain suspended inside Lelu Harbor long enough to settle on the coral in the Weok PA and on the coral reefs at the mouth of Lelu Harbor. These microscopic particles clog the mouths of the coral polyps, reduce the corals' nutrient intake, and suffocate the coral. The blanketing of the coral with silt reduced the sunlight required for the zooxanthellae to undergo photosynthesis, thus starving the corals.

Another negative impact of heavy sediment discharged from the Tofol Watershed was the silting-in of Lelu Harbor. Satellite photos of the LMPA taken on 29 January 2005 and on 18 July 2020 that were published on Google Earth were compared. These photographs showed substantial expansion of mangroves near the Lelu Causeway. The expansion of the mangroves occurred because the water near the Lelu Causeway was shallower in the present day than it was 15 years ago. During the past 15 years, Global Mean Sea Level had risen at a rate of 3.5 mm/year. If the mangrove forests near the Lelu Causeway were expanding, then Lelu Harbor was silting-in faster than the sea was rising. It was estimated that the rate of in-fill of the Lelu Harbor by sediment discharge was greater than 3.5 mm/year.

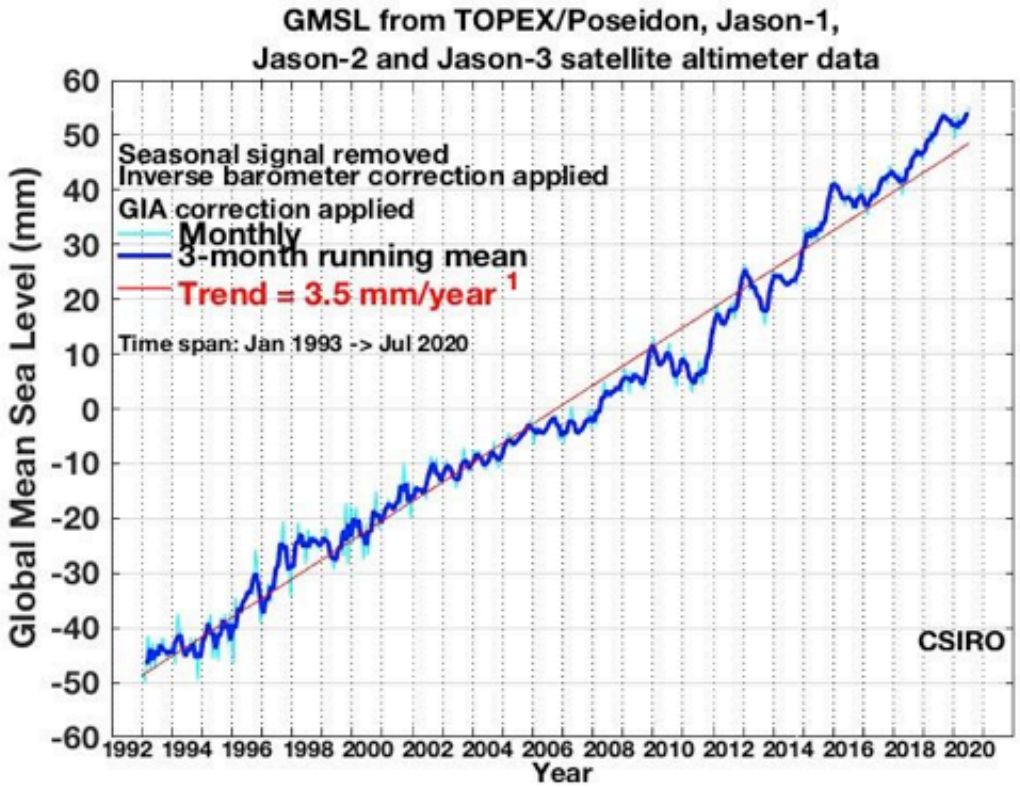


Figure 7: Global Mean Sea Level from the year 1992 to 2019

Figure 8: Aerial photos of the LMPA showing expansion of mangroves near the Lelu Causeway from 2005 to 2020

Figure 9: Aerial photos of the LMPA showing expansion of mangroves near the Lelu Causeway from 2005 to 2020 (zoomed in).

Note that, in addition to the rivers of the Tofol Watershed, there is another influx of freshwater and silt into the LMPA from the Mutunneneah channel, located at the north end of the LMPA, by which the Pukusrik River and several smaller streams bring freshwater into the LMPA. The Mutunneneah channel also carries sediments after heavy rain into Lelu Harbor.

4.6 Climate Change

Kosrae faces one existential environmental hazard: sea level rise caused by global warming.

For the past 30 years, the Global Mean Sea Level (GMSL) has risen at an average rate of 3.5 mm/year. For the next 30 years, the rise of the GMSL is predicted to accelerate to at least 1 cm/year. By the year 2050, the mean sea level of Lelu Harbor will be 30 cm higher than its current level, or higher.

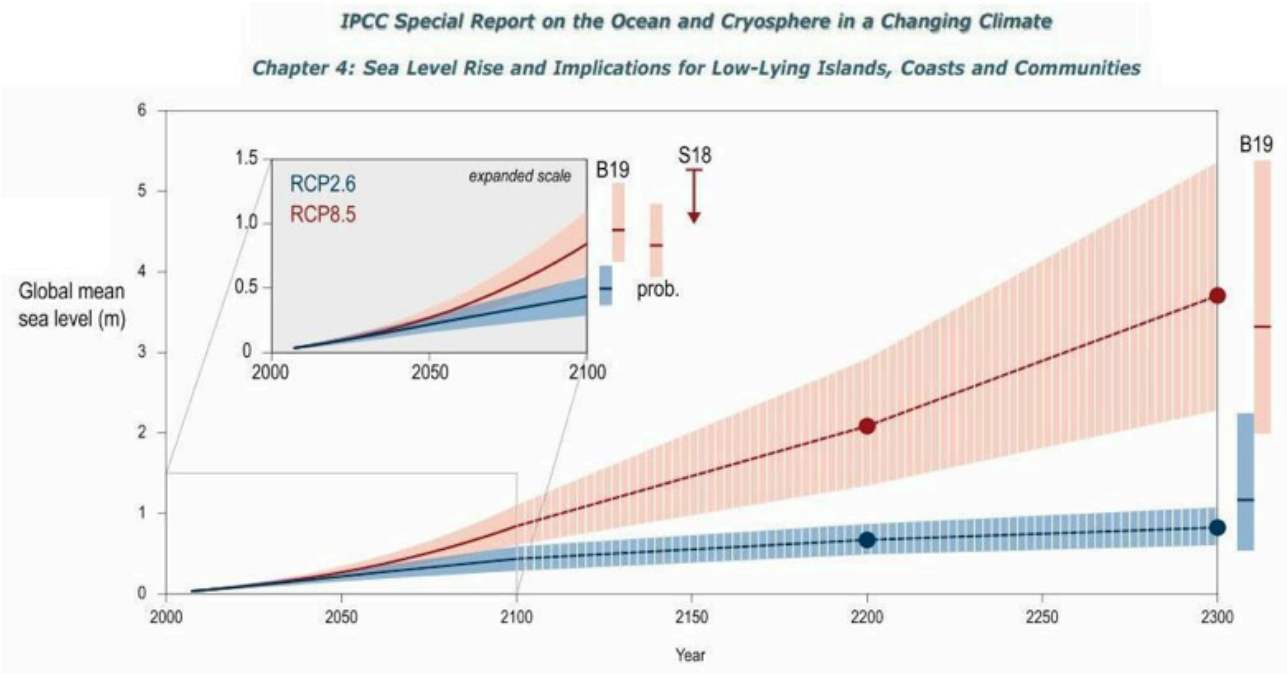


Figure 10: Future global mean sea level projections till the year 2300.

As a result of this rise in sea level, the freshwater and brackish marshes near the mouths of the Srungansralu and Innem rivers will become saltwater estuaries by 2050. The soft, muddy sediments along the banks of these three rivers will erode rapidly and wash into the LMPA where they will add to the in-filling of Lelu Harbor.

Map #4 in this report (produced by KIRMA) indicates (in red) the parts of Kosrae which will be submerged by 2100. This submerged area includes most of the Tofol Watershed east of Kosrae's main paved road, as well as the septic fields and automobile dump east of the high school, near the radio station.

4.7 Cross-Island Road

In recent years, there have been proposals to construct a cross-island road to connect Tofol with Okat via the Innem and Okat valleys as shown in the map below. Based on our survey, a road following this route would have at least five negative effects:

- Construction in the Innem and Okat valleys would release large amounts of sediment into the Innem and Okat rivers, exacerbating the siltation of Lelu Harbor and the LMPA.
- The increase in turbidity of the Innem and Okat rivers would render these rivers unsuitable as water sources for domestic use.
- The clays of the Innem and Okat valleys are a type of smectite clay, which expands when wet and contracts when dry. This clay would not create a stable roadbed.
- The soft clay walls of the Innem and Okay valleys are easily eroded and would be prone to landslides, which would damage and/or bury the road.
- The grade of a road up and over the steep ridge between the Innem and Okat valleys would be at least 15%, which is too steep for ordinary automobile traffic.

The biological and geologic environment of the Tofol Watershed was found to be fragile and the LMPA was found to be vulnerable to siltation. Heavy construction, such as road building, in the Tofol Watershed is not recommended.

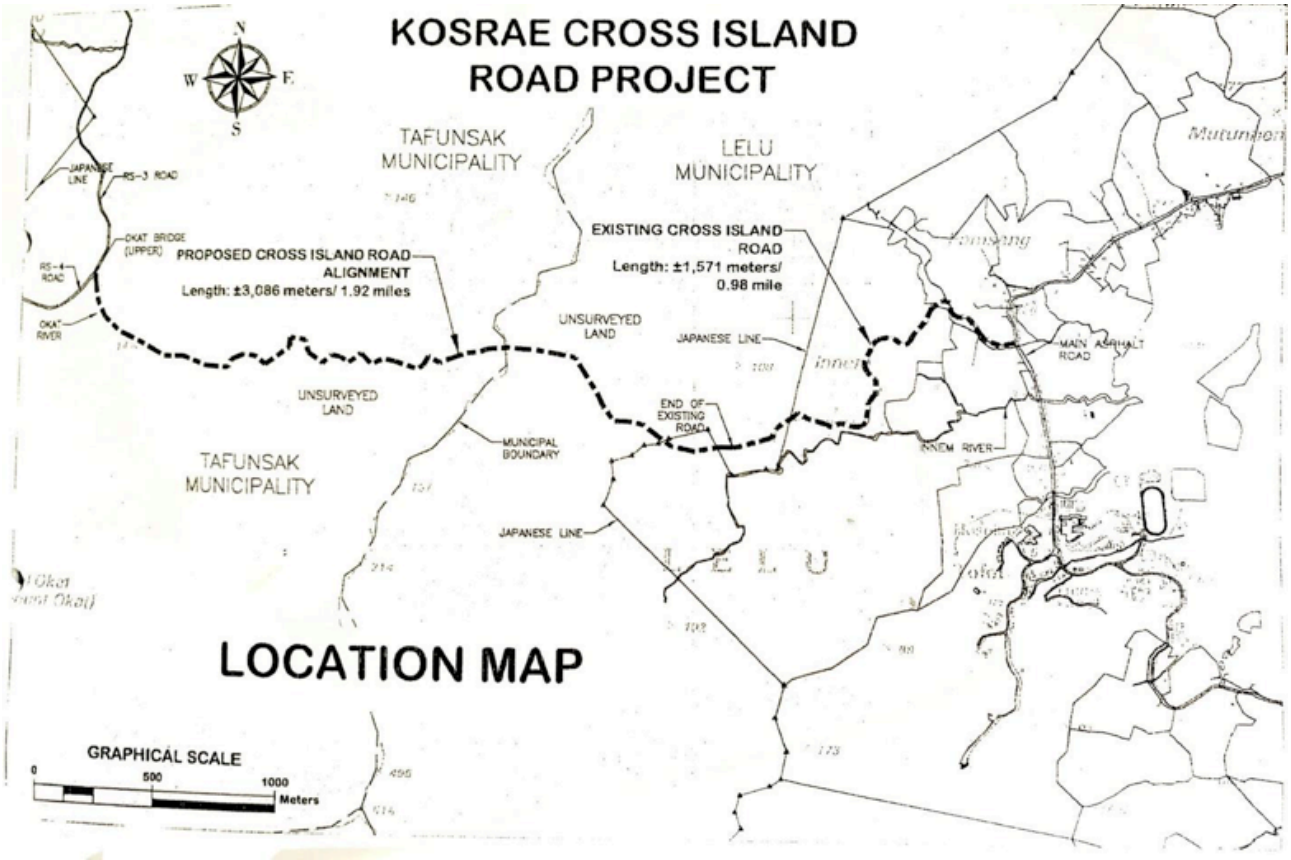


Figure 11: Map of the proposed Kosrae Cross Island Road Project

5. CONCLUSION

The primary threats to the Lelu Marine Protected Area are sedimentation, pollution, and garbage for which this survey has identified three main sources within the Tofol Watershed, mainly along the Srungansralu river.

1. There are currently two major construction sites in Tofol: the hospital's quarantine facility and a project sponsored by the Department of Resource and Economic Affairs near the Tissue Culture Center. Sedimentation barriers below these two construction sites are not well-maintained. During heavy rain, silt from these construction sites washes into the South Srungansralu river.
2. There are many homes, gardens, and piggeries along the North Srungansralu river. Irrigation ditches drain excess fluids and sewage from these areas into the river.
3. The marshes east of the paved road, especially behind the high school, are areas where litter has accumulated in the Srungansralu river.

6. RECOMMENDATIONS

Based on our study, this report recommends three ways to preserve and improve the long-term health of Lelu Harbor and the LMPA:

1. The effects of sedimentation, pollution and garbage discharged from the Tofol Watershed can be alleviated by reducing the impact of construction and agriculture.
   A. Maintain sedimentation barriers.
   B. Avoid or limit heavy construction on hillsides above streams.
   C. Locate piggeries away from streams or flowing water.
   D. Recycle or properly dispose of all non-biodegradable garbage.
2. The Lelu Causeway prevents semidiurnal tidal flushing of Lelu Harbor.
   A. The Lelu Causeway should be replaced with a series of bridges with wide, deep channels between bridge supports. This will allow strong tidal currents to flow in and out of Lelu Harbor, flushing sediment, pollution, and garbage into the open sea.
   B. It has been suggested that opening the channel at Insrefusr will also help to clear the water at Lelu Harbor. According to Coastal Engineer Doug Ramsey, opening the Mutunneneah channel at Insrefusr will have the opposite effect. An opening at Insrefusr will draw in sand from the reef flat and will lead to the clogging of the channel. In *Island of Angels*, Rev. Eldon Buck reports that the channel was temporarily opened in 1905 to facilitate transportation from Tafunsak to Lelu. Without maintenance, the channel naturally silted in and closed.
   C. Rising seas may soon render the Lelu Causeway unusable. It may make sense to replace the causeway sooner rather than later.

3. Preparations for rising seas in 2050 should begin now.

   A. No new construction should be approved east of the paved road.

   B. The septic fields east of the high school should no longer be used. If the septic fields are left fallow for a few decades, they will lose most of their toxicity and not poison the harbour when they flood with rising sea levels.

   C. Damaged vehicles should no longer be abandoned in the area immediately north of the radio station. This will prevent toxic materials from old cars from leaching into Lelu Harbor when sea levels rise.

A century ago, ships stopped at Kosrae to get fresh, clean drinking water from the streams and people caught fish in abundance in Lelu Harbor. Although people lived in the Tofol Watershed, their impact on their environment was minimal. Until the Lelu Causeway was built during the post-war Trust Territory era, Lelu Harbor was a deep, clean nature reserve filled with corals, fish, giant clams, and other wildlife. This healthy environment was maintained by semidiurnal tides which flushed sediments and other natural pollutants out of the harbour into the deep sea.

Kosrae's growing population has put pressure on the surrounding environment. Although there have always been homes and farms along the rivers, demand for food has increased. Constant reuse of farmlands has degraded the soils and stimulated erosion. Small homes built with native materials have been replaced by multi-story concrete buildings. Non-biodegradable products have been introduced to our modern lifestyle. When the causeway was built, people could ride to Lelu in cars and trucks instead of by canoe.

As the population increases, so must the awareness of the impacts to the community. Collaboration between stakeholders and decision makers can help solve the issues presented in this study to improve Kosrae's environment and maintain a healthy quality of life.

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APPENDIX

MAPS

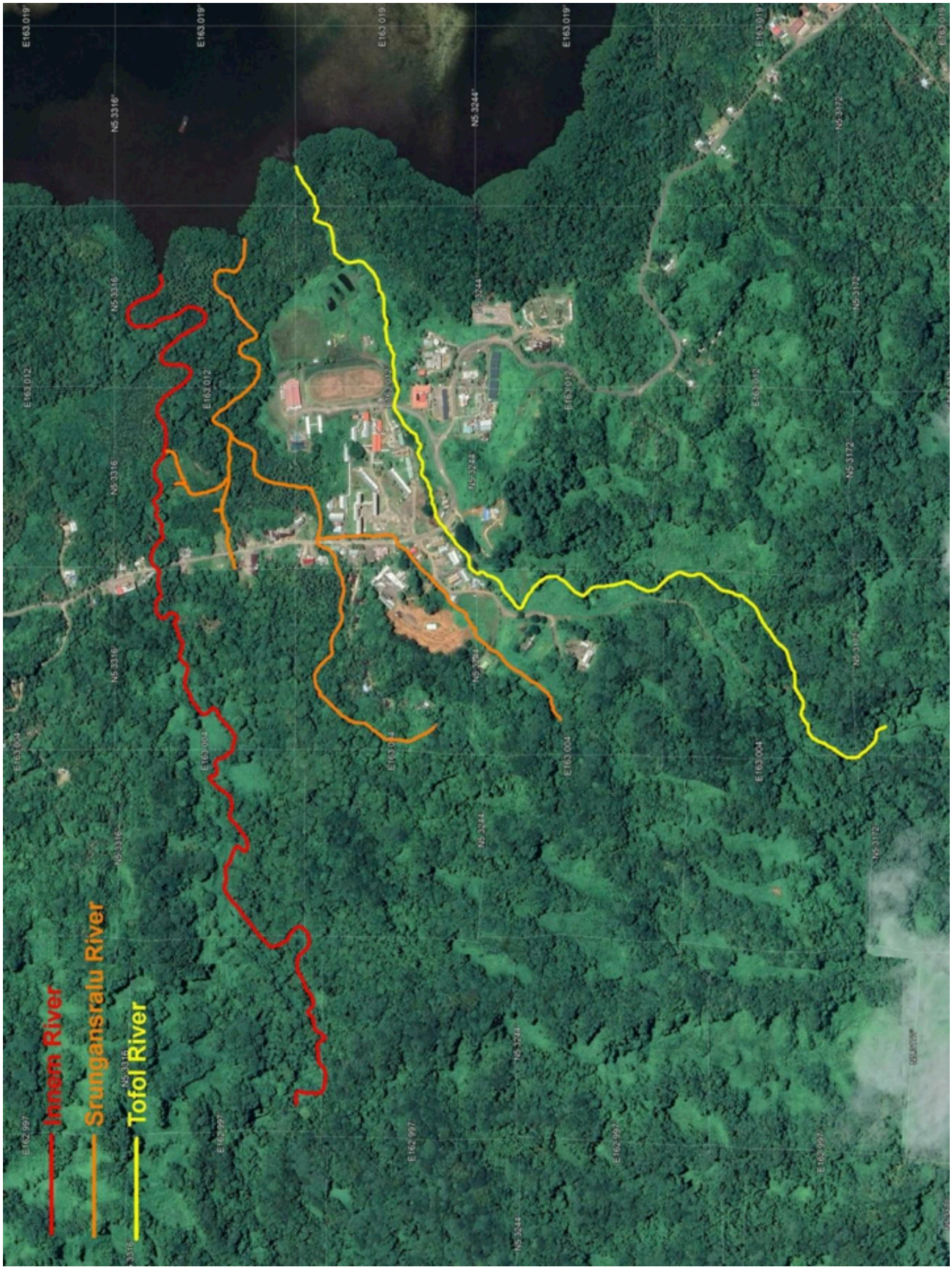
Map #1

Topographic map of Kosrae

Map #2

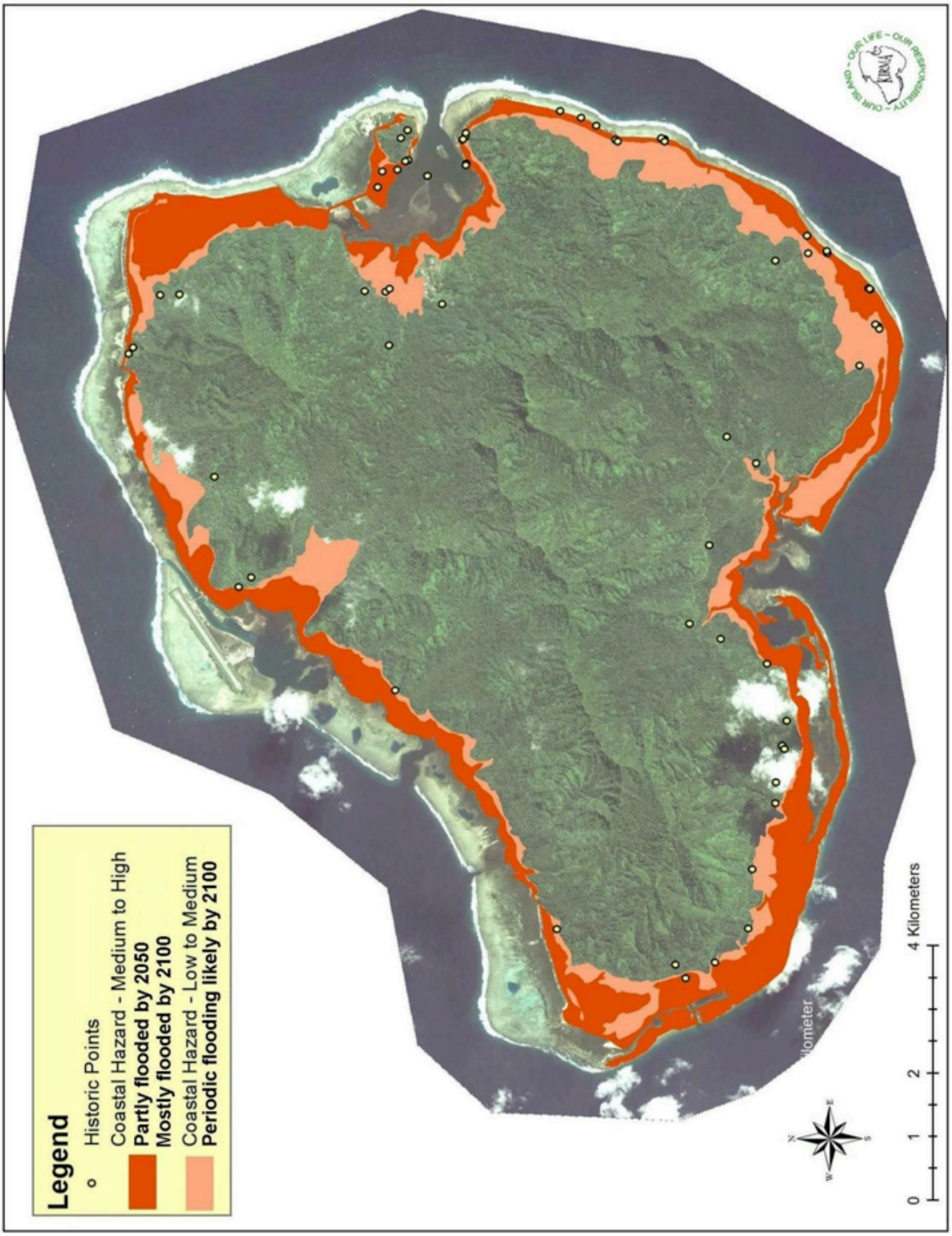
Lelu Marine Protected Areas

Map #3



The three rivers of the Tofol Watershid

Map #4



Effect of Sea Level Rise on Kosrae