Kosrae Shoreline Management Plan

Repositioning for resilience

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is a federally-owned agency that implements technical cooperation programmes on behalf of the German Government and other donors. This Study was undertaken under the SPC/GIZ regional programme Coping with Climate change in the Pacific Island Region.

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Much community and infrastructure development on Kosrae over the last 60 years has occurred within the coastal margins. Most of the coastline on Kosrae, where this development has occurred, is prone to coastal hazards including long-term shoreline change and episodic coastal inundation (particularly during times of high (king) tides, large swell and very occasionally due to typhoon events.

The effects of ongoing and future climate change and sea-level rise will increasingly exacerbate the impact that these coastal hazards have on infrastructure, the five village communities and residential homes over this century, as well as potentially adversely impacting on the protective functions provided by the coastal ecosystem found on Kosrae (reef system, seagrass beds, mangrove strands, wetland areas and the coastal berm).

Over the next one to two generations, and beyond, climate change will make the progressive impacts of coastal hazards such as erosion, wave overwashing and flooding on existing property, infrastructure and communities on Kosrae much more significant than it already is. Where high tide flooding occurs at present, sea level rise will result in the frequency of such flooding events increasing. For example within one generation present-day high tide flooding will occur over four times more frequently than it does today, and within two generations about 10 times more frequently.

Adapting to these future impacts will require a different approach to development on Kosrae than has been practiced over the last 2 to 3 generations. Fundamental this will mean a much greater emphasis on *preventative* measures that remove exposure to the hazard, rather than a primary focus on *impact reduction* (e.g. through for example continuing to build seawalls).

The approaches to achieve effective adaptation, and as an outcome resilient communities and infrastructure, all build on existing approaches in Kosrae and that would be used in an effective policy for reducing current coastal hazard-related risks and achieving safe and resilient development.

The following principles are key for successful adaptation and reduction of present and future coastal hazard risks to Kosrae communities and infrastructure over the next few generations:

1. The continued careful management of Kosre’s natural environment and resources is fundamental for effective and sustained protection from coastal hazards and long term adaptation.
2. A primary focus on <u>where</u> to build.
3. A focus also on <u>how</u> to build.
4. Recognising that in most situations a reliance on impact reduction measures such as coastal defences are not a long-term option for achieving resilient infrastructure and communities on Kosrae.
5. Effective adaptation needs to start now.

Based on these principals the following key strategies have been developed for Kosrae to implement as a means of increasing the resilience of Kosrae’s communities and associated infrastructure to the impacts of coastal-related hazards and exacerbating effects of climate change:

Strategy 1: Continued development and strengthening of the community awareness and outreach activities with a focus on an effective natural coastal defence and Kosrae-relevant climate change impacts and adaptation options.

Strategy 2: Amendment of the KIRMA Regulations for Development Projects to incorporate climate change considerations and strengthening of regulation implementation to support successful long-term risk reduction and adaptation

Strategy 3: Over the next one (by 2030s) to two generations (by 2050s), the primary coastal road network and associated infrastructure currently located on the beach/storm berm is developed inland away from long-term erosion and coastal inundation risk.

Strategy 4: Ensure new development (property, infrastructure) is located away from areas at risk from present and future coastal hazards.

Strategy 5: A programme of encouraging existing residential property to be repositioned away from areas at risk from present and future hazards as it is replaced or renovated.

Strategy 6: Incorporate a grant component in to the housing loan programme to help encourage new property to be constructed in areas not exposed to coastal, river floor or landslide hazards.

Strategy 7: Commence community and state discussions to develop a relocation strategy identifying potential approaches to support relocation from areas exposed to coastal hazards where no alternative relocatable land is available.

Strategy 8: A strategic approach is adopted for the ongoing provision of coastal defences only where it is a sustainable long-term option or where a transitional approach to protecting areas over the short to medium term to enable repositioning strategies to be implemented.

By the 2050s (2 generations time) Kosrae needs to have made significant progress in implementing an adaptation strategy that has enabled the majority of existing critical infrastructure and property to be repositioned away from the beach/storm berm areas, reclaimed areas of mangrove and low-lying wetland swamp to slightly higher land around the base of the volcanic part of the island.

Without such a change in development direction, Kosrae will find it ever more difficult and expensive in attempting to protect and maintain infrastructure and property in its current location, and more importantly will be in a very poor state to respond to the much more significant impacts of climate change that will occur over the latter half of this century and beyond.

1 Introduction

1.1 Background

Much community and infrastructure development on Kosrae over the last 60 years has occurred within the coastal margins. Most of the coastline on Kosrae, where this development has occurred, is prone to coastal hazards such as long-term shoreline change and episodic coastal inundation (particularly during times of high (king) tides, large swell and very occasionally due to typhoon events.

The effects of ongoing and future climate change and sea-level rise will increasingly exacerbate the impact that these coastal hazards have on infrastructure, the five village communities and residential homes over this century, as well as potentially adversely impacting on the protective functions provided by the coastal ecosystem found on Kosrae (reef system, seagrass beds, mangrove strands, wetland areas and the coastal berm).

In 2000 the Development Review Commission (now Kosrae Island Resource Management Authority) developed a shoreline management plan (DRC, 2000) which set out to:

- Inform potential areas of future coastal erosion and inundation hazard risks to aid planning for future development
- Identify opportunities for maintaining and enhancing the natural coastal protection
- Assess a range of strategic coastal management options, in terms of limiting the future impacts of coastal erosion, flooding and storm damage on the people and developed infrastructure, for the entire coastline of Kosrae.
- Establish necessary monitoring and data collection to enable a better understanding of the effects of natural coastal processes on the coastline of Kosrae, and to help understand the potential impacts of future risks such as those posed by climate change.

The strategy summarised a range of short and long-term recommendations to assist in reducing coastal hazard risks to the natural environment, communities and infrastructure. Whilst many of the recommendations are still valid, and are built on within this revision of the Shoreline Management Plan, there is a need to update to:

- Account for more recent data, information and development/infrastructure changes.
- Increase focus on long-term adaptive management planning and prioritisation for critical infrastructure over the next one to two generations.
- Guide and support future municipal and community/individual development decision-making and implementation of village/municipal-level integrated adaptation activities.

Figure 1-1: Map showing locations of municipal boundaries, roads, villages and place names on Kosrae.

1.2 Building resilient coastal communities on Kosrae

1.2.1 Past development pathway

Infrastructure, land and property of Kosrae is currently impacted by coastal flooding and erosion largely due to the development choices that have occurred since the end of the Second Work War. The pattern of development (Figure 1-2 and Figure 1-3) that has occurred over the past 2 to 3 generations has resulted in the majority of property and infrastructure having been built on:

- Land that is low-lying and prone to coastal flooding
- Reclaimed areas in mangrove or swamp areas, or over reef flat sand deposits (in the case of Utwe and Lelu villages)
- Land that that is too close to the shoreline to accommodate both natural and human-induced shoreline change. Much has occurred on the narrow storm or beach berm that separates the fringing reef from the low-lying mangrove or swamp areas (Figure 1-3)

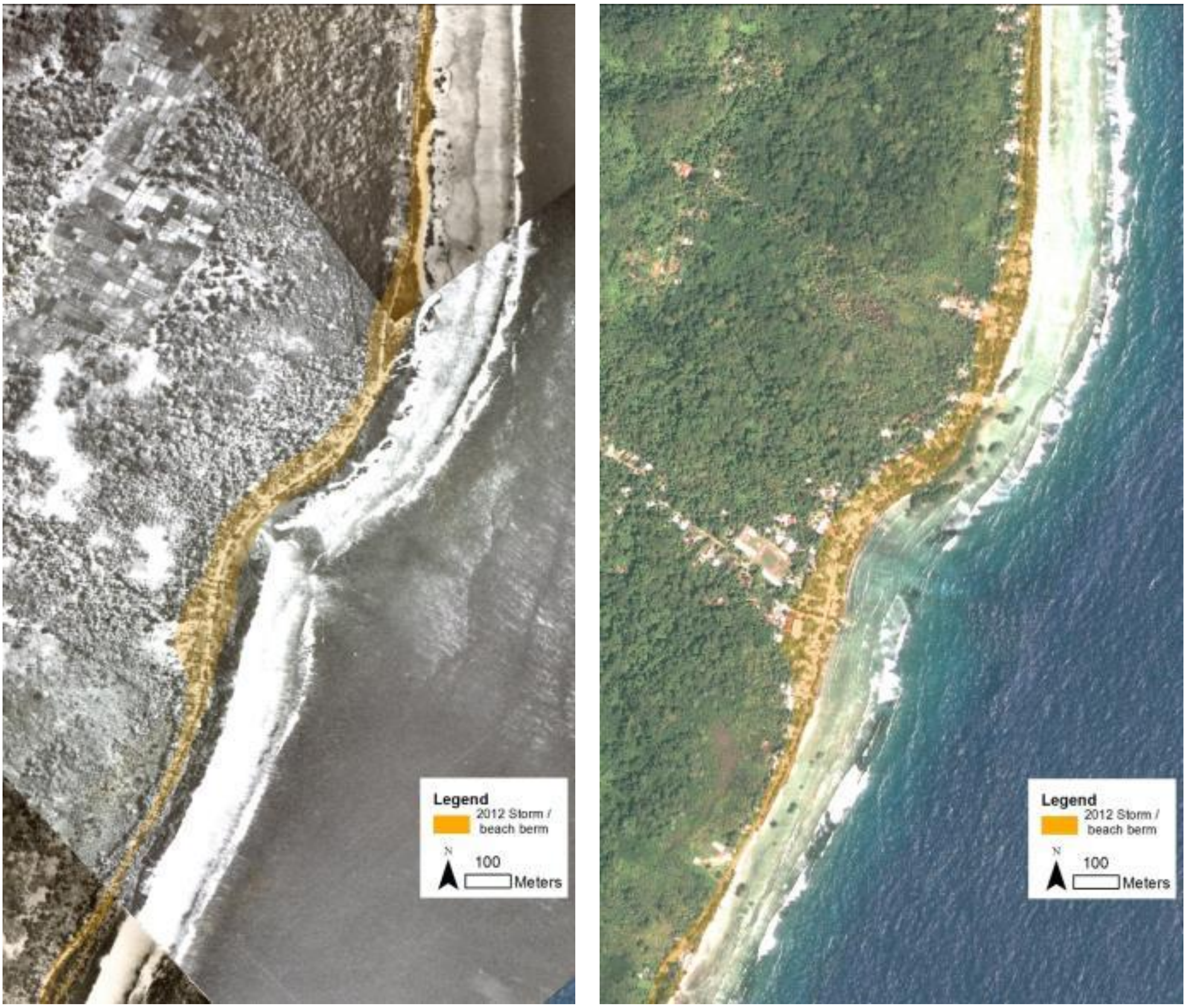

Figure 1-2: Development between 1944 and 2012 in Malem. Much of the development has taken place on the narrow storm berm between the shoreline and the low-lying wetlands.

Furthermore the susceptibility of Kosrae's coastline and the communities located there to the effects of coastal hazards has been significantly exacerbated by human-related activities over the last 2 to 3 generations. These human-impacts are linked to an increasing population over much of the last century, development needs and changing construction practices, and include:

- Removal of sand and coral rubble from the reef flat (particularly along the eastern coast between Finaunpes and Mosral).
- Beach sand mining – the removal of sand and cobbles from the beach primarily for construction aggregates.
- Dredging of the reef flat in front of Tafunsak village.

- Altering the position of stream outlets or changing swamp drainage patterns ad flows.

Building inappropriate seawalls and land reclamation that has exacerbated erosion elsewhere or resulted in further development in high risk areas.

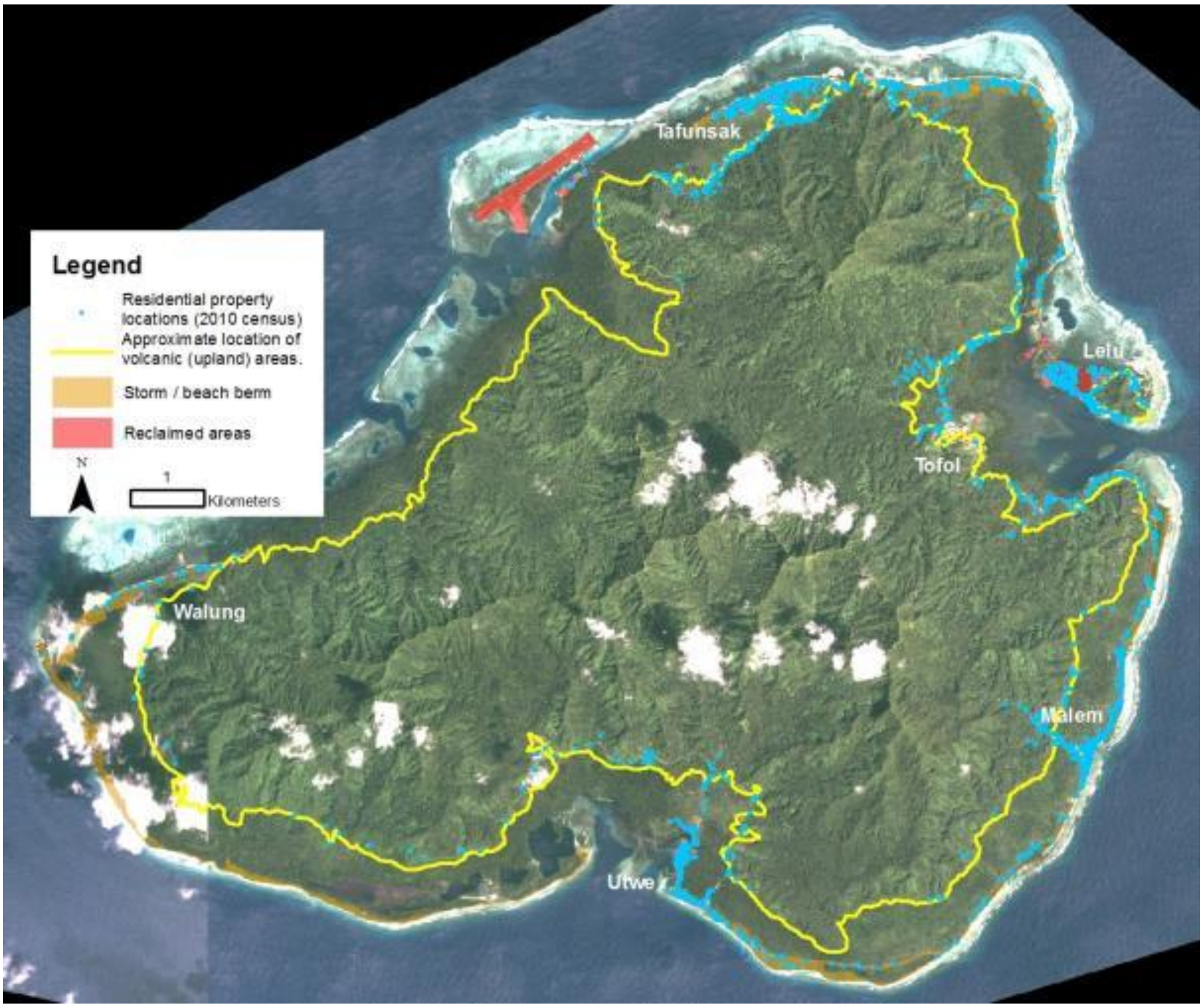

Figure 1-3: Location of residential development. Based on data from the 2010 census.

1.2.2 A different pathway for the future

The consequences of climate change, such as sea level rise and changes in weather patterns will not cause new problems and impacts on Kosrae. Over the next one to two generations, and beyond, climate change will make the progressive impacts of coastal hazards such as erosion, wave overwashing and flooding on existing property, infrastructure and communities on Kosrae much more significant than it already is.

Reducing the present risks to the people and infrastructure of Kosrae posed by existing natural climate variability will be the most effective way in reducing the coastal hazard impacts posed by future climate changes

Figure 1-4: Examples of human impacts that have caused or exacerbated the potential for coastal erosion and inundation impacts on Kosrae. Top left: removal of coral rubble from the reef flat; Top right: Sand mining; Middle left: Dredge pits at Tafunsak; Middle right: Erosion at Walung caused by the cutting of a drainage channel at Leap; Bottom left: Erosion at the Sandy Beach Hotel caused by the seawall; Bottom right: Erosion and coastal change at Finfokoa caused by the reclamation at the old Pheonix Resort and recent house construction.

However, adapting to these future impacts will require a different approach to development on Kosrae than has been practiced over the last 2 to 3 generations. Fundamental this will mean a much greater emphasis on *preventative* measures that remove exposure to the hazard, rather than a primary focus on *impact reduction* (e.g. through for example continuing to build seawalls).

The approaches to achieve effective adaptation, and as an outcome resilient communities and infrastructure, all build on existing approaches in Kosrae and that would be used in an effective policy for reducing current coastal hazard-related risks and achieving safe and resilient development.

The following principles are key for successful adaptation and reduction of present and future coastal hazard risks to Kosrae communities and infrastructure over the next few generations:

1. The continued careful management of Kosre’s natural environment and resources is fundamental for effective and sustained protection from coastal hazards and long term adaptation.
    - Recognising that the coastal ecosystem on Kosrae is the most effective coastal defense protecting the island from the effects of coastal hazards.
    - Understanding that the enormous value of this natural protection is dependent on the health and the natural interactions between the various ecosystems including the watershed, wetlands and swamp forests, mangroves, coastal berm and beach, reef flat and seagrass, and surrounding fringing coral reef.
    - Limiting human impacts on the functioning of this natural protection is essential to Kosrae’s efforts to address both climate change and existing coastal hazards.
2. A primary focus on <u>where</u> to build:
    - Ensuring new development (property, infrastructure) is located away from areas at risk from present and future coastal hazards.
    - Over the next one to two generations[1] a sustained programme of encouraging existing development and infrastructure to be relocated away from areas at risk from present and future hazards as it is replaced or renovated.
    - Strengthening investment criteria and the Development Review Permit process to limit new development in areas at risk from present and future coastal hazards.
    - Developing incentive mechanisms to encourage development/redevelopment away from areas at risk from present and future coastal hazards.
3. A focus also on <u>how</u> to build:
    - Ensuring that new infrastructure and buildings are designed to incorporate weather and climate extremes including the future effects of climate change (climate proofing) over the proposed design life of the structure.
    - Incorporating appropriate climate-proofing guidance in to existing policy and legislation.
4. Recognising that in most situations a reliance on impact reduction measures such as coastal defences are not a long-term option for achieving resilient infrastructure and communities on Kosrae:

[1] One generation is defined as the next 20 to 25 years (2030s) and two generations as the next 40 to 50 years (2050s).

- Given the levels of sea-level rise likely to be experienced in the latter part of this century, seawalls will not be capable of dealing with the types of coastal change and flooding that will occur.
- Over the foreseeable future, Kosrae has substantial financial commitment to ensure that existing coastal defences are maintained and upgraded to provide a sufficient standard of protection to enable longer-term or sustainable risk-reduction initiatives to be implemented.
- Coastal defences built to protect communities often result in an increased sense of security and ongoing intensification of development with the problem becoming ever more complex.

5. Effective adaptation needs to start now:
    - Starts with effectively addressing existing coastal hazard problems and issues to existing communities, villages and infrastructure and builds on the many good examples of things already occurring on Kosrae.
    - Plan for change rather than waiting for damaging events to happen and reacting.
    - Adopts an adaptive management approach focusing on change on Kosrae over the next one and two generations to:
        - Address current and immediate future coastal hazard issues
        - Position Kosrae to effectively cope with the much more significant coastal hazard impacts that will occur beyond this time over the latter part of this century and beyond.
    - Takes advantage of international adaptation financial support available now that may not be as accessible in the future as the effects of climate change increase for all nations.
    - Adopts whole of population responsibility. Adapting to climate change requires changes in the way all sectors behave and to be effective needs to be implemented as a partnership by all (community, Municipality, State and National Governments).

There is no one “solution” to solving all the coastal hazard issues that Kosrae faces now and in to the future. Rather it will involve a “mix” of inter-related activities, the composition of which will vary both from location to location on Kosrae and over time.

1.3 Shoreline management progress since 2000

Many of these principles lay behind the development of the first version of the Shoreline Management Plan in 2000. Since the plan was produced, a number of activities have progressed that are aiding reducing the impacts that coastal hazards have on people, communities and infrastructure on Kosrae or on better understanding these hazards to enable better incorporation of managing theme in decision-making and development-related legislation. A review of progress against the various recommendations made in 2000 is summarised in Appendix A with some key areas of progress outlined below:

- The continued emphasis on educational activities within both the Kosrae Island Resource Management Authority (KIRMA) and Kosrae Conservation and Safety Organisation (KCOS) that is focussing on both catchment and coastal-related aspects.
- An increasing number of residential properties being built inland and increased awareness about the need to move back from the shoreline.
- Incidences of housing loan applications being refused where dwellings are proposed in areas at risk from shoreline change or inundation.
- Construction/upgrading of a number of seawalls identified as being required in the Shoreline Management Plan.
- Installation of an automatic sea-level gauge within Lelu Harbour (since November 2011) and via a temporary gauge at Okat Dock (which will be left in place for one year and then moved to Walung and then to Utwe). This allows sea-levels to be accurately related to land levels.
- Incorporation of the need to consider climate change and climate change adaptation in to infrastructure projects within the Kosrae State Code and in Kosrae Island Resource Management Authority Regulations for Development Projects (currently under review).
- Continuation of beach profile recording since 1995 to accurately monitor ongoing shoreline change at key locations around the Kosrae coast.

However, there are also some worrying developments and activities recently occurred, or continuing to occur, that are not in keeping with sound coastal hazard risk management and, in the longer term will lead to maladaptation and the risk to development on Kosrae increasing. These include:

- Continued reclamation of mangrove and over shoreline areas, with fill levels with little freeboard above present day high (king) tide levels.
- Recent, use of “low cost” solutions in response to urgent need to protect sections of the paved road. This includes dumped concrete rubble at Finfoko in Tafunsak and Pal in Malem, large concrete filled bags at Mosral in Malem, and a previous proposal to use old bitumen drums, left from the re-sealing of the airport runway, filled with concrete for seawall construction.
- Proposed donor support for shore protection activities without considering such activities within a wider strategic and sustainable approach to coastal hazard risk reduction.
- The extension of the road across the wetland/mangrove area and along the shoreline at Leap in Walung (with the intention to continue the reclamation and road development to the church at Insiaf), rather than continuing it around the edge of the volcanic part of the island.

Figure 1-5: Recent examples of poor development activities that will lead to further coastal hazard-related problems and are not sustainable or effective in the long-term. Top left: Low-lying reclamation for a new laundromat at Tafuyat, Lelu Harbour; Top right: Concrete bag seawall to protect the road at Mosral, Malem; Bottom left: Dumped concrete rubble to attempt to protect the road at Pal, Malem; Bottom right: Access road construction through the mangrove and along the foreshore at Leap, Walung.

2 Current and foreseeable coastal hazard issues

Over the last century changes in the position of the shoreline around Kosrae shows considerable variability. Some sections such as along the eastern Malem coastline and at Finfokoa in Lelu has resulted in large shifts in the shoreline position, other sections have been relatively stable. A summary of the key processes driving coastal change and flooding on Kosrae are summarised in Appendix B and potential climate change and sea-level rise in Appendix C. Where changes have occurred these are due to both natural long-term processes and the effects of human activities on Kosrae's shoreline and reef flat (Section 1.2.1). Many of these natural processes and the impacts of past human activities are still ongoing resulting in the patterns of change that have occurred over the past indicative of the main changes that are likely to occur over the foreseeable future. The following areas (Figure 2-1 to Figure 2-5), either due to ongoing significant movement of the shoreline or the proximity of key infrastructure to the shoreline, are likely to be where the main challenges associated with coastal change are likely to occur over the foreseeable future:

- Lelu: Finfokoa and Pukushruk - Despite the large changes that have occurred in shoreline position at Finfokoa over the last half century, foreseeable future changes in shoreline position are likely to be relatively more modest. However, continued retreat of the coastline along the central section at Pukushruk could increase the exposure of the road to damage over time. Similarly the proximity of the road to the shoreline at Putukte suggests it will be susceptible to damage during large waves and high tides.

- Malem – The length of road exposed at Pal and Mosral will continue to increase with damage from erosion and wave overwashing. At Mosral if the concrete (tideflex) outlet continues to deteriorate reducing its effectiveness as a "groyne", the coastline to the north of the Mosral River could retreat more rapidly. A pattern of ongoing slow shoreline retreat is likely along much of the Malem coast, particularly at Yeseng, Kuplu and from Yewak to Tenwak. At Yewak/Pilyuul, where the Pilyuul River would have originally discharged before being deflected north, there is a risk that ongoing retreat will increasingly expose the road to damage in the forseeable future.

- Utwe – The Impuspusa coastline is relatively stable but does experience episodic storm damage which potentially over time could increase the potential for damage to the road where it runs close to the current shoreline.

- Tafunsak – The position of the shoreline at Finfoko is relatively stable but the proximity of the road to the shoreline does make it susceptible to storm-related damage. At the western end of the seawall at Tafunsak, a slow rate of downdrift erosion has been occurring which is now beginning to undermine the road. At Wiya, the shoreline has moved little in the past but again the location of the road makes it susceptible to storm damage and any associated landward movement of the shoreline

- Walung - Between Insiaf and Leap the shoreline has retreated primarily due to long-term sand mining activities and the cutting of a drainage channel through the beach berm in 1976 (and recently blocked up by the construction of the new seawall). A slow rate of retreat is likely to continue to both the east and west of the new seawall.

Flooding of land from the sea tends to occur episodically due to three types of events (large swell events, typhoon events and high tide flooding).

Large swell events (such as affected the Tafunsak coastline in December 2008) and cyclone events, whilst extremely destructive when they do occur, are relatively infrequent events. Their frequency of occurrence is not likely to change noticeably due to climate change, at least over the next few generations.

Rather it is flooding that is caused by high tides, either due to high tides alone or when waves coincide with high tide conditions that are likely to cause the most significant impacts on Kosrae's communities. Where high tide flooding occurs at present, sea level rise will result in the frequency of such flooding events increasing. For example within one generation present-day high tide flooding will occur over four times more frequently than it does at present, and within two generations about 10 times more frequently (see Appendix C). The main locations (Figure 2-1 to Figure 2-5) where high tide levels cause inundation problems to property or infrastructure tends to be where land has been reclaimed in the harbour areas or within the mangroves sheltered from waves:

- Lelu Island – Much of the reclaimed areas on Lelu Island have land levels that are barely above present day high tide levels. Flooding of land during December and January commonly occurs adjacent to the canal sections in Lelu.
- Pukusruk – Landward of the road, many properties are built on reclaimed land in to the mangrove with levels barely above high tides.
- Utwe village – Much of Utwe village lies on reclaimed land on top of a sand spit. Again the level of the land is barely above present day high tide levels.
- Walung – The section of coast between Insiaf and Pilyuul (old elementary school) is largely sheltered from waves with the level of the coastal berm barely above high tide levels.
- Tafunsak – The communities at Malsu, Yekula, Finfukul and Sialat that are located on land that is lower than the crest of the beach berm / coastal road, and overwashing of the seawall at Finfukul on to the road.

However, in the longer term, the potential rate of sea-level rise toward the second half of this century will result in increasingly more frequent damage to much of the infrastructure and property located along all parts of the coastal storm/beach berm and reclaimed areas (Figure 1-3). It will be increasingly difficult to maintain infrastructure and residential property located in these areas without substantial and continuous investment (for example raising reclaimed land levels in Lelu and Utwe villages).

Figure 2-1: Potential areas of inundation and erosion concern in Lelu Municipality over the next one to two generations.

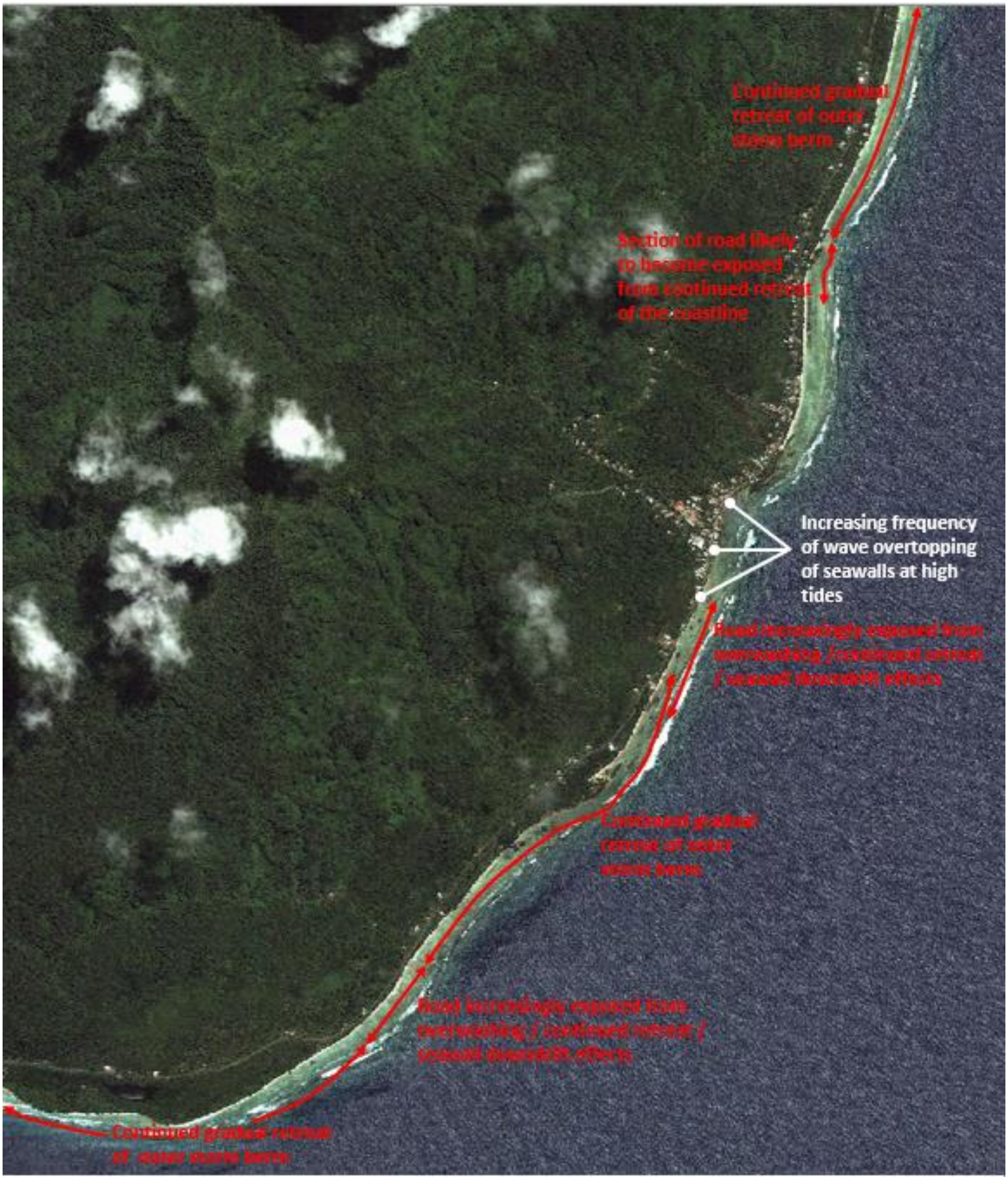

Figure 2-2: Potential areas of inundation and erosion concern in Malem Municipality over the next one to two generations.

Figure 2-3: Potential areas of inundation and erosion concern in Utwe Municipality over the next one to two generations.

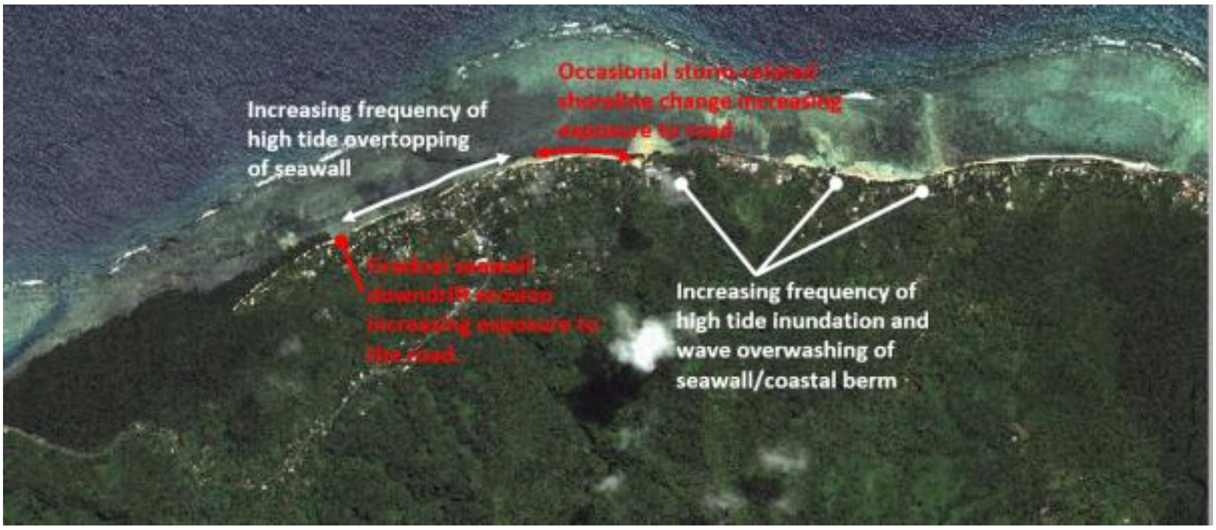

Figure 2-4: Potential areas of inundation and erosion concern in Tafunsak Municipality over the next one to two generations.

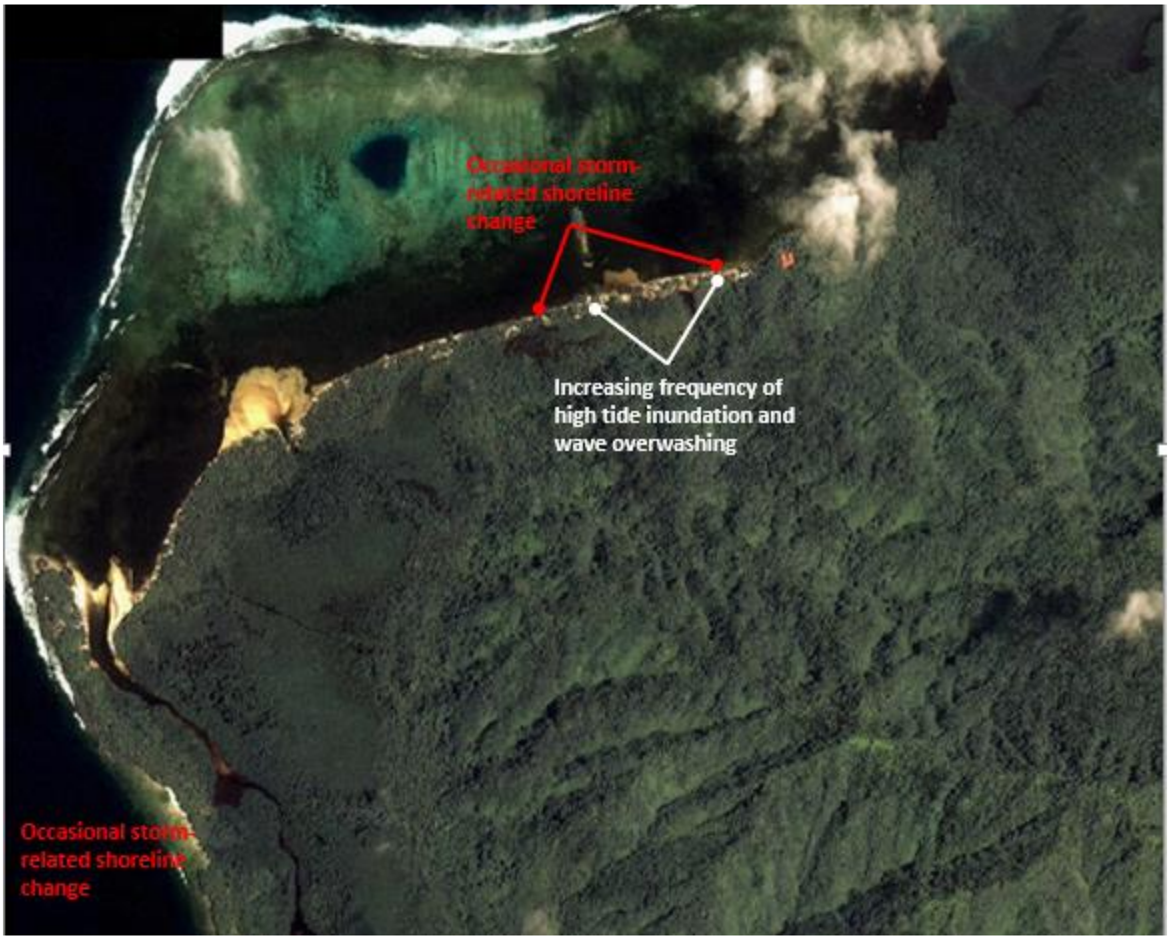

Figure 2-5: Potential areas of inundation and erosion concern in Walung over the next one to two generations.

3 Adaptation foundations: The careful management of the natural coastal environment

The foundations for effective adaptation is built on the careful management of the natural coastal environment, and the resources found there. This is the single most important coastal protection activity on Kosrae and one that is fundamental for minimising the potential impacts of present and future coastal hazard impacts.

A healthy coastal environment on Kosrae is the most effective coastal defense available. This natural coastal defence includes the watersheds, wetlands and swamp forests, mangroves, beaches, reef flat, and the coral reef (Figure 3-1 and Table 3-1). The effectiveness of this natural coastal defence, and its resilience to the effects of climate change and sea-level rise, is dependent upon the health of, and the natural interactions between, each of these environments.

Figure 3-1: The best coastal defence on Kosrae. Awareness poster developed in 1999 by the Development Review Commission (now KIRMA).

Table 3-1: Coast protection functions of Kosrae's natural environment and key impacts on this coast protection function.

Environmental feature	Key coastal protection functions	Key activities on Kosrae that impact on the coastal protection function of the natural environment
Coral reef, reef flat and seagrass	▪ Direct protection from waves ▪ Source of sediment, (coral rubble, skeletal remains of reef biota), that feeds Kosrae's beaches. ▪ The primary factor controlling wave energy reaching the shoreline and influencing how beach and shoreline mangrove areas change.	▪ Detrimental fishing practices (chlorox, poison leaf). ▪ Overfishing of herbaceous reef fish ▪ Excessive pollution from pig pens and septic tanks located too close to the coast or streams. ▪ Pollution or excessive sedimentation from commercial activities or dredging. ▪ Land practices increasing freshwater and sediment discharge. ▪ Removal of reef flat sand and coral rubble.
Beach and backshore	▪ Natural adaptable buffer providing direct protection to land behind from waves and coastal flooding.	▪ Sand mining and removal or reef flat coral rubble. ▪ Vegetation removal from behind the beach ▪ Development that is too close to the shoreline (encroachment within the backshore buffer zone) ▪ Land reclamation or seawalls that impact on the natural beach processes.
Mangroves	▪ Direct protection from waves (reef flat and harbour areas). ▪ Trapping sediments and nutrients washed off the land before it reaches seagrass and coral reef environments.	▪ Harvesting large areas of seaward fringe mangroves ▪ Land activities that result in pollution, increased river flows or sediment input. ▪ Land filling, roads through, or reclaiming mangroves areas.
Wetland areas and rivers	▪ Controls flow of fresh water from land to reef environments during periods of heavy rain. ▪ Trapping sediments and nutrients washed off the land before it reaches the seagrass and coral reef environments.	▪ Drainage of wetlands. ▪ Alterations to natural drainage pathways through wetlands (e.g. due to farm roads, insufficient culverts). ▪ Alterations to river or stream outlets at the coast. ▪ Land filling or reclaiming large areas of wetland.
Catchment watersheds	▪ Regulates flow of rainfall and sediment run-off to wetland and coastal areas	▪ Clearing of steep sloping land or land too close to rivers and streams ▪ Development of land above the Japanese line[2]. ▪ Construction of roads with steep slopes

Limiting detrimental human impacts on the functioning of this natural protection is essential to Kosrae's efforts to address both climate change and existing coastal hazards. The mechanisms for supporting this are well developed and mainstreamed in Kosrae through the community awareness activities of both KIRMA and Kosrae Conservation and Safety Organisation (KCOS) and the development review process.

[2] The Japanese Line is an important land tenure legacy where almost the entire interior of the island came under government control. The Japanese Line, and its designation of public ownership of the lands of the interior of Kosrae remain today.

Strategy 1: Continued development and strengthening of the community awareness and outreach activities with a focus on an effective natural coastal defence and Kosrae-relevant climate change impacts and adaptation options.

Continuing the community awareness and outreach activities conducted by KIRMA and KCOS is critical if Kosrae's communities are to reduce the ongoing impacts of coastal hazards on their communities and respond effectively to the longer-term exacerbating impacts of climate change and sea-level rise. Many of the current coastal hazard-related issues are in a significant part due to past, and in some cases ongoing, human-related activities that have impacted on the effectiveness of the natural coastal protection provided by the coastal system on Kosrae. Future awareness and outreach activities should continue to focus on reducing and minimising human impacts on the effectiveness and protection provided by the natural coastal defences:

- Impacts of sand mining and coral rubble removal.
- Importance of naturally vegetated buffer zones between the shoreline/edge of mangroves/rivers and streams and land development.
- Avoiding developing areas prone to current or future coastal hazards over the lifetime of the development. Key messages should incorporate recommendations to avoid development:
  - seaward of the paved section of road between Okat and Utwe.
  - within 50 feet of the shore or mangrove vegetation line or top of seawall structures (including no further land reclamation over mangrove or beach areas).
  - located on land less than 3 feet above the high water mark (includes mangroves). For the purpose it is suggested that the elevation of the high water mark is defined as 2 m above land vertical datum on Kosrae. For practical purposes the level of 3 feet above the high water mark is roughly similar to the level of the centre of the coastal road.

  An integral component of this awareness/outreach activity will be to continue to strengthen the relationship with the Housing and Renovation Division of the Department of Resources and Economic Development.
- Continued focus on protecting the natural functions of river and stream catchments and limiting development above the Japanese Line.
- Limitations of sea walls and other coastal defences as a long-term effective adaptation option.

Strategy 2: Amendment of the KIRMA *Regulations for Development Projects* to incorporate climate change considerations and strengthening of regulation implementation to support successful long-term risk reduction and adaptation.

The KIRMA *Regulations for Development Projects* are currently being amended to require the design and implementation of public infrastructure such as road and building to incorporate climate change adaptation measures consistent with the FSM National Climate Change Policy of 2009. Further changes have been suggested to strengthen the consideration of the effects of natural change, impacts of extreme weather and climate events, and climate change on a proposed development activity and to better incorporate risk-reduction and adaptation considerations in to the development permitting process.

In strengthening the implementation of the development permit process to contribute to sustained adaptation and reduction of present and future coastal hazard risks to Kosrae communities it is recommended that development projects be permitted only by exception in the following locations:

- seaward of the paved section of road between Okat and Utwe, or
- within 50 feet of the shore or mangrove vegetation line or top of seawall structures (including no further land reclamation over mangrove or beach areas).
- Located on land less than 3 feet above the high water mark (includes mangroves). For the purpose it is suggested that the elevation of the high water mark is defined as 2 m above land vertical datum on Kosrae. For practical purposes the level of 3 feet above the high water mark is roughly similar to the level of the centre of the coastal road.

4 Repositioning: An adaptation pathway for development on Kosrae

4.1 Introduction

Over the next one to two generations ensuring new development (property, infrastructure) is located away from the narrow coastal berm and low-lying areas where there is both current and future risk of being impacted by shoreline change, inundation and the exacerbating effects of sea-level rise is critical if Kosrae is to build communities resilient to the future effects of climate change.

Also critical is a sustained effort to encouraging existing development and infrastructure to be repositioned away from areas at risk from present and future hazards. Such repositioning does not need to happen immediately but rather conducted in a structured way over time as buildings and infrastructure are replaced or significantly upgraded.

By the 2050s (2 generations time) Kosrae needs to have made significant progress in implementing an adaptation strategy that enables the majority of existing critical infrastructure and property to be repositioned away from the beach/storm berm areas, reclaimed areas of mangrove and low-lying wetland swamp to slightly higher land around the base of the volcanic part of the island (Figure 4-1).

Figure 4-1: Potential primary and secondary sealed road network on Kosrae by the 2050s. Note: Parts of the secondary road network (current coastal road) may become impassable due to ongoing shoreline change and breaching.

Without such a change in development direction, Kosrae will find it ever more difficult and expensive in attempting to protect and maintain infrastructure and property in its current location, and more importantly will be in a very poor state to respond to the much more significant impacts of climate change that will occur over the latter half of this century and beyond.

4.2 Resilient infrastructure

4.2.1 Strategy overview

The coastal (paved) road network is a major piece of critical infrastructure on Kosrae providing the only connection between the main villages and to the airport and port.

Much of the coastal road is located on the narrow storm/beach berm between Tafunsak and Utwe. With the exception of the section around Tofol much of the roads is at risk from shoreline change and wave overwashing. To date the response to the most critically at risk sections has been to build seawalls, typically rock revetments which provide varying degrees of protection. At present further sections, notably at Pal and Mosral, are now critically threatened. In the forseeable future, both ongoing coastal change and the exacerbating effects of sea-level rise and climate change, will result in further sections of road increasingly becoming exposed (for example at Yewak/Pilyuul and Pukusruk) and more frequently overwashed leading to an ever increasing risk of damage and breaching. Given the elevation of much of the existing coastal road relative to future sea levels and its location on the narrow beach/storm berm continued reliance on seawall protection of all sections of the present paved coastal road will become progressively less effective, more expensive and ultimately unlikely to be a sustainable option.

The road network also plays a fundamental role in directing where other infrastructure (Kosrae Utility Authority and FSM Telecom) and residential development has occurred and will occur. The majority of residential property developed over the last two to three generations is located alongside the main paved sections of road. Likewise the power distribution network that runs north from Tofol to the airport and port at Okat, and to the south to Utwe is located next to the road upon the narrow beach/storm berm. Airport and port operations in particular are extremely vulnerable should damage occur to any part of the power distribution system between Tofol and Okat (a back-up route between Mutunnenea and Sialat for part of the route is largely in place but with a small gap due to a lack of access agreement with one landowner).

Continuing to maintain the coastal road between Tafunsak and Okat in its present location upon the narrow beach/storm berm as the only link between each of the villages will make responding to the impacts of climate change and the development of long-term resilient infrastructure and communities much more difficult on Kosrae.

Strategy 3: Over the next one to two generations the primary coastal road network and associated infrastructure currently located on the beach/storm berm is developed inland away from long-term erosion and coastal inundation risk.

The priority focus of road development activities on Kosrae urgently needs to change from any further extension/completion of the circumferential road between Okat and Walung to addressing the current and potential vulnerabilities of the existing coastal road particularly between Utwe and Malem (where there is presently a real risk of a breach occurring of the road) and from Finpukal to Tafunsak.

Starting now, but implemented over the next 25 to 50 years, a phased approach to repositioning the road away from the shoreline is key to enhancing the resilience of the coast to the effects of future climate change, reducing and removing the risks to Kosrae's essential infrastructure, and to encouraging and enabling the relocation of residential properties and village communities back from areas at risk from present and future coastal hazards.

The present-day practice (as seen in the development of the section between Utwe and Walung) of constructing the inland road around the perimeter of the lower slopes of the volcanic part of the island and above the freshwater swamp or mangrove areas provides a suitable long-term response as long as levels of new and upgraded inland roads are at least 6 feet (2 m) above present day high tide levels (above the 4 m contour). This would ensure:

- Road levels are above any future high tide levels for at least the next one hundred years.
- The majority of the road network is located well back from the shoreline and protected by the full extent of the natural coastal protection (reef, reef flat, beach and beach/storm berm, swamp and/or mangrove forest).

Furthermore with Kosrae's already high rainfall amounts and intensities, and with rainfall intensities likely to increase in the future due to climate change:

- Road slopes need to be minimized as far as possible.
- Construction activities that increase landslipping risk, e.g. cutting into the hillside should be minimized.
- Adequate culverts and bridges are installed, taking account of revised design rainfall amounts and drainage guidelines that have been developed[3] to minimize changes to drainage patterns and to cope with periods of heavy rainfall.

In the development/upgrade of sections of inland road the following assumptions have been made:

- A 60 feet standard easement is assumed.

[3] Developed as part of the ADB funded *Climate proofing: A Risk-based Approach to Adaptation* and Pacific Adaptation to Climate Change projects.

- An integrated infrastructure approach is adopted which includes relocation of power distribution, and any water or telecom service infrastructure. For this indicative costing it is assumed that new power lines will be installed along all new/upgraded sections of road.
- Existing sections of inland farm roads require widening to obtain a roadway width of 30 ft., require construction of roadway drainage structures and resurfacing to sub-base course level.
- Upgrade to Hot Mix Asphalt (HMA) pavement includes base course preparation on top of the sub-base and 2" thick asphalt pavement. It is assumed that all aggregates included sand are imported.
- Indicative costs from the Department of Transport and Infrastructure and Kosrae Utility Authority are as follows:
  - New road development to full width, all drainage infrastructure and to sub-base wearing course: $600k per mile ($372.82 per metre)
  - Sub-standard road upgrade to full width, all drainage infrastructure and to sub-base wearing course: at least $300k per mile ($186.41 per metre)
  - Upgrade sub-base wearing course to Hot Mix Asphalt pavement: $520k per mile ($323.11 per metre)
  - Power line network: $30k per mile ($18.64 per metre)

In addition roads will cost somewhere in the order of 2 - 5% of the construction cost on an annualized basis to maintain at their as constructed standard over their design life (Richard Creed, Pers Comm).

The prioritized redevelopment of the coastal road is summarized in Figure 4-2 and outlined below.

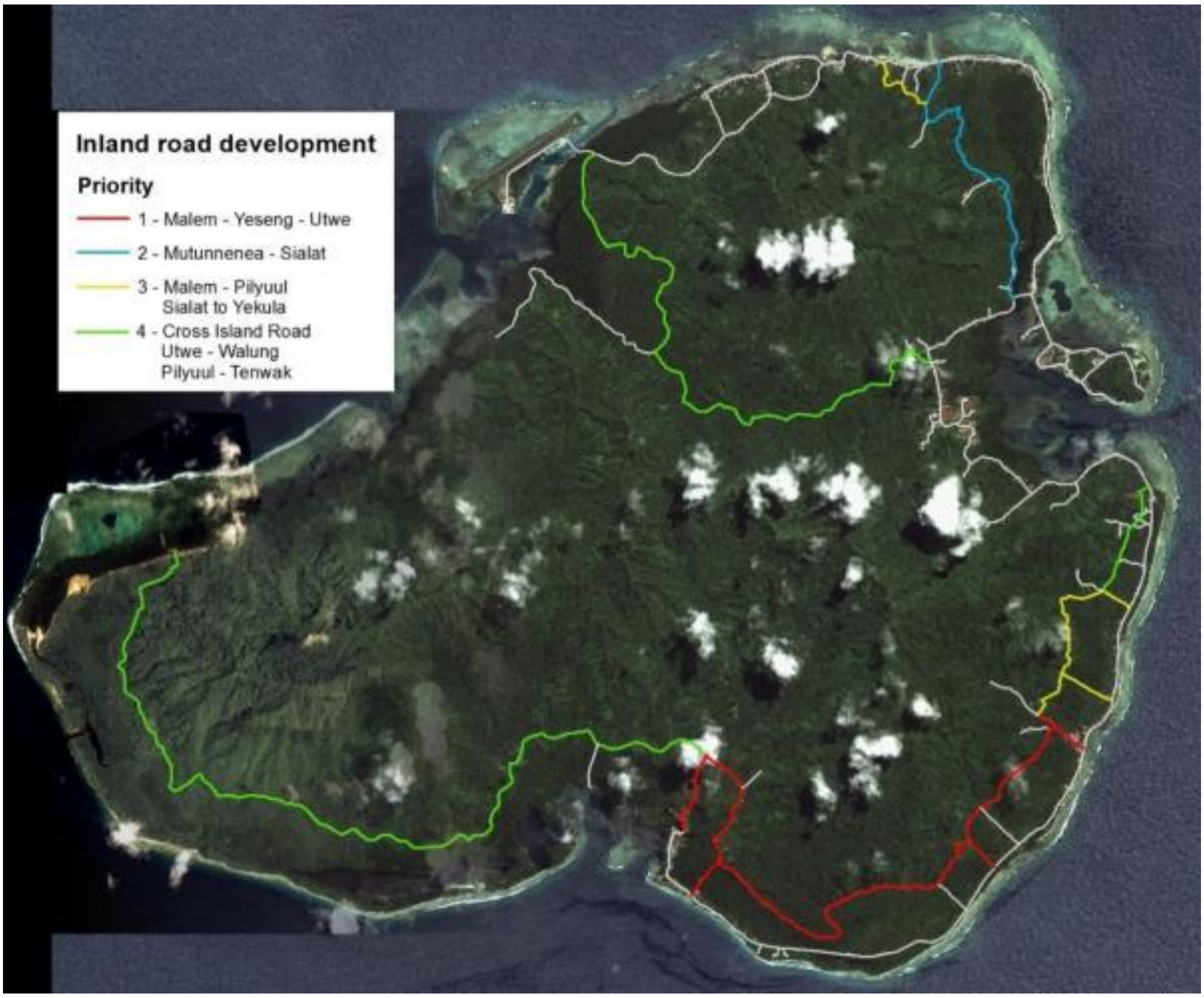

Figure 4-2: Priority section of the development of the inland road on Kosrae.

4.2.2 Priority section 1: Malem to Yeseng to Utwe

Upgrading the inland road between Malem and Utwe is considered the highest priority due to the risks posed due to wave overwashing and potential breaching of existing sections at Pal and Mosral. There is a very real present day risk that road access to Utwe could be cut off. The natural storm berm to the south of Malem also tends to be lower in elevation (than other areas such as north of Malem and the Pukusruk coast) resulting in the road being more prone to wave overwashing where it is exposed.

At Pal despite rock protection being extended south from Malem and further concrete rubble being dumped along the most exposed section a significant investment is required to provide adequate protection of this section in the short to medium term (see Section 3.2). At present there is a very real risk of the road being breached or damage to the power line, which is located to the seaward edge of the road. Over the next 25 years further sections of the road to the south of Pal will become progressively exposed as the shoreline continues to retreat back.

At Mosral the concrete bags that have been placed along the most exposed section to the south of the Mosral River outlet similarly do not offer an adequate standard of protection with there still being a significant present-day risk of the road being damaged. There is already signs that this section of wall is exacerbating further the rate of retreat of the shoreline to the immediate south. Over the next 25 years further sections of road to the south of Mosral to where the road bends inland at Kuplu, will become progressively exposed as the shoreline continues to retreat back. The road may also become more exposed to the north as well, if the tideflex outlet, which acts as a groyne trapping gravel being moved south, deteriorates further.

Should a severe typhoon affect Kosrae during the next 25 years, it is likely that substantial sections of the road from Malem to the south of Pal, at Mosral, and from Hiroshi Point towards Utwe could experience substantial damage irrespective of whether coastal defences are in place or not.

Indicative locations of new and upgraded inland road between Utwe and Malem are shown in Figure 4-3 with indicative costs in Table 4-1.

Table 4-1: Indicative costs for inland road and associated infrastructure development between Utwe and Malem. Costs are shown for upgrading/developing the inland road to both sub-base wearing course and to hot mix asphalt pavement.

Section	Upgrade existing road (m)	New road section (m)	Total to sub-base wearing course ($)	Total to Hot Mix Asphalt Pavement ($)	Power line upgrade/ installation ($)
Inland: Malem to Yeseng		2000	$746,000	$1,392,000	$38,000
Access: Malem	870		$163,000	$444,000	$16,300
Access: Yeseng	500		$94,000	$255,000	$9,400
Inland: Yeseng to Finsrem (Utwe)	2520	2460	$1,387,000	$2,997,000	$92,900
Access: Utwe to Finsrem	600		$355,000	$969,000	$35,500
Inland: Finsrem to Finkol	1900		$112,000	$306,000	$11,200
Access: Utwe to Finkol	1140		$213,000	$581,000	$21,300
TOTAL	**7530**	**4460**	**$3,070,000**	**$6,944,000**	**$224,600**

Figure 4-3: Indicative inland road between Utwe and Malem showing the requirements of new and upgraded sections of road.

4.2.3 Priority section 2: Mutunnenea to Sialat

The section of coastal road between Mutunnenea and Wiya is a further major section of coastal road located on a narrow storm berm, and on the northern coast a wider beach berm. Also located adjacent to the road is the only power and telephone line to Tafunsak and to the port and airport.

Currently the only section of road at critical risk to wave overwashing and damage at Finaunpes has been protected by a variety of seawalls culminating in the rock revetment installed in 1998. Between Finaunpes and Sialat the shoreline has generally been accreting over the last few decades (with severely eroded section at Sandy Beach due to the above seawall now stabilized by the beach control breakwater and beach nourishment scheme installed in 2001). This section of coast has a wide natural buffer, although narrowing towards Sialat, with minimal development between the road and the shoreline. Unless there is a significant change in the sedimentary regime along this section of coast this natural buffer should continue to provide adequate protection to the road.

Between Finfokoa and Putukte the road is generally well back from the shoreline at the northern end with much less of a buffer at the southern end. Whilst the shoreline appears to have moved little over the last few decades at Putukte, the proximity of the road to the shoreline does put it at significant risk. However, it is north of the Mormon Church where over the next 25 years coastal retreat will progressively increase exposure and risk of damage to the road. Any coastal defences, unless very carefully designed, on much of the Pukusruk coast will cause exacerbated erosion on adjacent sections.

From Putukte to Finpukal, the storm berm (and road) is lower and, despite being sheltered from the largest of waves, overwashing of the existing road at high tides will become an increasing issue as sea levels rise, irrespective of whether further coastal defences are built.

Landward of the road from Finpukal to Finaunpes most property is located on reclaimed land over the edge of the mangrove on land levels with little freeboard above high tide levels. Between Finaunpes and Sialat, property located on the low-lying land behind the beach berm is prone to occasional inundation when large swell events from the north overwash the berm (such as occurred in December 2008) and will increasingly experience drainage issues, waterlogging and ponding water due to increasing rainfall and higher sea levels.

The inland road between Mutunnenea and Sialat has been in place for many years (Figure 4-4). It was built as largely single track and when maintained was passable in most vehicles. However, over the last few years the central section has had little maintenance, is now largely overgrown and only passable with a large four-wheel drive. However, progressively it has encouraged an increasing number of residential properties to be located along it, particularly at the southern end. Upgrading the inland road will encourage further development inland away from the exposed storm/beach berm and low-lying areas between Finaunpes and Finpukal.

Figure 4-4: Inland road section between Mutunnenea and Sialat.

The alternative to upgrading the inland road between Mutunnuenea and Sialat would be to develop the cross island road between Innem and Okat. This is the preferred option for Kosrae Utility Authority to provide a secondary power line to Okat harbor and airport. However, the Mutunnenea to Sialat option was generally favoured by all others consulted. Power lines do extend up the existing inland road from both the Mutunnenea and Sialat ends but do not yet join due to an access dispute with a local landowner.

Table 4-2: Indicative costs for inland road and associated infrastructure development between Mutunnenea and Sialat. Costs are shown for upgrading/developing the inland road to both sub-base wearing course and to hot mix asphalt pavement.

Section	Upgrade existing road (m)	New road section (m)	Total to sub-base wearing course ($)	Total to Hot Mix Asphalt Pavement ($)	Total power line upgrade/ installation ($)
Mutunnenea to Sialat	4500		$839,000	$2,293,000	$83,900

4.2.4 Priority section 3a: Sialat to Yekula / Wiya

Between Sialat to Wiya the road is located close to the shoreline, with a number of streams discharging resulting in low-lying, inundation-prone land behind the beach berm. At present coastal inundation only tends to be an issue during episodic swell events (such as occurred in December 2008) or when high tides combine with northerly waves (the low lying areas behind the berm are also prone to flooding due to heavy rainfall events). From Yekula to Wiya the coastal margin is higher in elevation, less prone to overwashing, and relatively stable but with little buffer between the shoreline and road.

The most exposed section between Sialat and Yekula, opposite the channel over the outer reef, was protected by a seawall in 1999. The wall was well constructed in terms of minimizing impacts on adjacent sections of the coast but had no crest protection resulting in the edge of the road still prone to damage due to wave overtopping. The potential for damage to the road along this protected section will increase over time unless some further crest protection is provided.

Table 4-3: Indicative costs for inland road and associated infrastructure development between Sialat and Yekula. Costs are shown for upgrading/developing the inland road to both sub-base wearing course and to hot mix asphalt pavement.

Section	Upgrade existing road (m)	New road section (m)	Total to sub-base wearing course ($)	Total to Hot Mix Asphalt Pavement ($)	Total power line upgrade/ installation ($)
Sialat to Yekula	765	350	$274,000	$634,000	$21,000

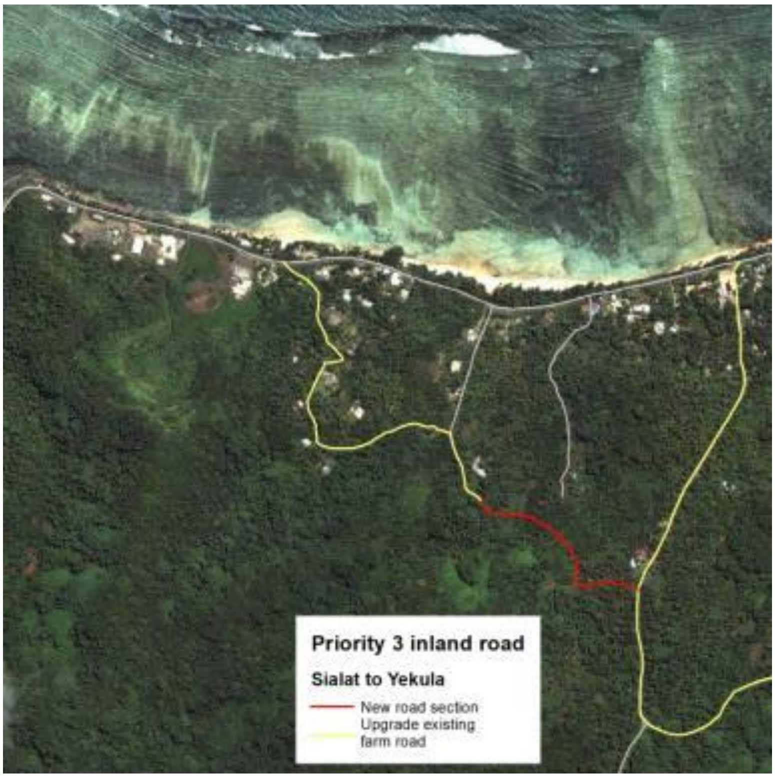

Figure 4-5: Inland road section between Sialat and Yekula.

4.2.5 Priority section 3b: Malem to Pilyuul

The coastal road through Malem village to the north of the Malem River outlet is protected by a rock revetment and buffer of reclaimed land. The revetment has been poorly constructed in places and is overwashed during high tides. However, typhoons aside, the road is not at significant risk at present from damage. To the north of Malem, through Yewak to south Pilyuul, the shoreline position is relatively stable but over the next one to two generations is likely to see a continual slow retreat with the road becoming progressively more exposed to coastal hazards (particularly around the section of coast opposite the shallow reef channel between Yewak and Pilyuul).

Between Malem and Pilyuul there is a relatively high density of residential properties located along the coastal road upon the storm berm, either:

- Seaward of the road and hence at increasing risk from erosion and wave damage, over the next 25 to 50 years
- Landward of the road on lower lying land backing on to the saline/freshwater swamp areas behind the storm berm.

Around Pilyuul the buffer between the shoreline and road increases in width and despite a slow rate of ongoing shoreline retreat the road is less at risk over the forseeable future.

As with developing the inland road between Mutunnenea and Sialat, upgrading the inland between Malem and Pilyuul will encourage further development inland away from the narrow storm berm, which although not critically exposed at present, parts of the road will progressively become so over the next one to two generations. The timing for the upgrade of the inland road development will depend on the ongoing rate of retreat of the section of coast between Yewak and southern Pilyuul, particularly around the location of where the outlet of the Pilyuul River would have historically been. It is suggested that as soon as the buffer between the shoreline vegetation line reduces to less than 10 m (30 feet), planning for the upgrade of the inland road should be prioritized.

As on other sections of the exposed Malem and Lelu coastline, any coastal defences such as seawalls will tend to cause downdrift (exacerbated) erosion on adjacent sections to the south.

Figure 4-6: Inland road section between Malem and Pilyuul.

Table 4-4: Indicative costs for inland road and associated infrastructure development between Malem and Pilyuul. Costs are shown for upgrading/developing the inland road to both sub-base wearing course and to hot mix asphalt pavement.

Section	Upgrade existing road (m)	New road section (m)	Total to sub-base wearing course ($)	Total to Hot Mix Asphalt Pavement ($)	Total power line upgrade/ installation ($)
Inland: Malem to Pilyyul	2500		$467,000	$1,274,000	$46,700
Access: Pilyuul	430		$81,000	$220,000	$8,100
Access: Yewak	760		$142,000	$388,000	$14,200
Total	**3690**		**$690,000**	**$1,882,000**	**$69,000**

4.2.6 Priority section 4: Pilyuul to Tenwak

Between Pilyuul and Tenwak the road, as for most of the coastal road is located on the storm berm. However, along this section there is a relatively wider buffer caused by a more recent storm ridge (likely created during the 1891 cyclone) which has not yet migrated back to join the more "permanent" storm berm. In between the Pilyuul River flows northwards to its outlet at Tenwak.

The need for upgrading this section of the road over the next one to two generations will depend on the pattern of retreat over the next decade or two. If the storm ridge continues to retreat (and the Pilyuul River outlet breaches further south) then the need for repositioning to the base of the volcanic part of the island may increase in priority.

Figure 4-7: Inland road section between Pilyuul and Tenwak.

Table 4-5: Indicative costs for inland road and associated infrastructure development between Pilyuul and Tenwak. Costs are shown for upgrading/developing the inland road to both sub-base wearing course and to hot mix asphalt pavement.

Section	Upgrade existing road (m)	New road section (m)	Total to sub-base wearing course ($)	Total to Hot Mix Asphalt Pavement ($)	Total power line upgrade/ installation ($)
Inland: Pilyyul to Tenwak		1510	$563,000	$1,051,000	$28,200
Access: Tenwak	150		$28,000	$77,000	$2,800
Total	**150**	**1510**	**$591,000**	**$1,128,000**	**$31,000**

4.2.7 Other road sections

Other sections of coastal road

There are a number of other sections of the coastal road where, for example due to the steep volcanic topography extending to the coast, there is little potential to relocate the road further inland. These sections include:

- Tenwak to Mutunlik
- Wiya to Malsu
- Causeway and Lelu Island

Protecting, or upgrading and continuing to protect these sections with coastal defences is the only real option for the forseeable future (Section 0). At Malsu the road and surrounding land is low-lying as it is the outlet of two streams. Both river flooding and overwashing during high tides/large swells will continue to be an issue with their appearing to be limited option to relocate further inland.

Mutunnenea to Mutunlik

Between Mutunnenea, through Tofol to Mutunlik the road is located well back from the harbor shoreline and unlikely to be significantly affected by sea-level rise or coastal change over the next few generations. Only between the outlet of the Tafuyat River and southern part of Mutunlik, where the road level is low is there a need for continued protection and over time potentially raising the road level if inundation becomes an issue.

Utwe to Walung

The section of road from Utwe to Walung is currently being upgraded with Chinese support. The alignment of the road around the edge of the lower section of the volcanic part of the island is a good example of a road that is well positioned to minimize the impacts of potential coastal hazards and the future effects of sea-level rise. However, extending the road along the coastline at Walung to Insiaf should not be undertaken.

Okat to Yela

This road is currently being upgraded and extended as part of the Pacific Adaptation to Climate Change project which includes incorporating “climate proofing” of culvert size to accommodate increased intensity rainfall and a minimum road surface level (of 3 feet above high tide level) where the road is located directly behind the fringing mangroves.

It is suggested that developing an alternative inland road network as outlined and prioritized in the sections above is a much higher priority than any further upgrading or extension of this section of road.

4.2.8 Other infrastructure: Airport and Okat Harbour

Over the next one to two generations both the airport and port infrastructure are likely to cope with the modest increases in sea-level rise and other climate change effects although maintenance requirements may increase. However, as sea-level rise continues to increase beyond this time, the airport in particular will be increasingly impacted, with an ever increased frequency and magnitude of wave overtopping of the coastal defences surrounding the airport. The airport is one area where a continued focus on upgrading coastal protection (and in the future potentially land levels) will be required as sea levels rise.

4.3 Safe development and relocation of existing property

Strategy 4: Ensure new development (property, infrastructure) is located away from areas at risk from present and future coastal hazards.

Strategy 5: A programme of encouraging existing residential property to be relocated away from areas at risk from present and future hazards as it is replaced or renovated.

Reducing the number of residential properties located on land that is too low lying or too close to the shoreline is critical if Kosrae is to build communities resilient to the future effects of coastal hazards and climate change.

More effective application of the KIRMA Regulations for Development in ensuring new properties are not located in coastal-hazard prone areas is fundamental (see Section 3). This should aim to avoid future development in locations:

- Seaward of the paved section of road between Okat and Utwe.
- Within 50 feet of the shore or mangrove vegetation line or top of seawall structures (including no further land reclamation over mangrove or beach areas).
- Located on land less than 3 feet above the high water mark (includes mangroves). For the purpose it is suggested that the elevation of the high water mark is defined as 2 m above land vertical datum on Kosrae. For practical purposes the level of 3 feet above the high water mark is roughly similar to the level of the centre of the coastal road.

For existing properties relocation does not need to happen immediately, rather it take place in a planned and proactive manner over the next one to two generations as property is replaced or significantly upgraded. It is recommended that no further *ad hoc* coastal defences be permitted to protect existing property.

4.3.1 Incentives for developing in safer locations

Strategy 6: Incorporate a grant component in to the loan programme to help encourage new property to be constructed in areas not exposed to coastal, river floor or landslide hazards.

Whilst the KIRMA *Regulations for Development Projects* provided a regulatory mechanism for controlling future development of residential and commercial property in locations at risk from coastal hazards, there is also opportunity for providing an incentive mechansims for achieving effective adaptation.

A substantial proportion of housing redevelopment or construction of new property is carried out with financial assistance in the form of a loan from the Housing and Renovation Division of the Department of Resources and Economic Development. The Division also administers the two USDA Rural Development loan programmes (Table 4-6).

Table 4-6: Housing loan programmes available on Kosrae.

Programme	Purpose	Annual number of loans	Loan value	Loan duration
Housing loan programme	New residential property construction	30-50	Maximum of $30,000	6 – 20 years
USDA 502	New residential or commercial property construction	Unkown	$8,000 - $80,000 secured against property (state acts as trustee)	10-15 years
USDA 504	Residential property renovation	50-60	$500 - $7,500 not secured	Up to 20 years

At present all new housing loans are reviewed by a number of Government Departments including KIRMA (Development Permit and EIA requirements), Historic and Preservation, Sanitation, Governor's Office (land use rights and to ensure not to be located on Government land) and the Department of Resources and Economic Development (who act as trustee and ensures the property is not located above the Japanese Line or below the high water mark).

Incorporating a grant component in to the loan that does not need to be paid back could provide an incentive to encourage people when building a new house to relocate further inland (assuming that they own accessible land). Given the number of new loans on Kosrae the total the costs may be relatively modest (of the order of $100k - $150k per year for an incentive of $2,000 - $3,000 per loan). The potential for donors to fund the grant programme as adaptation support to Kosrae should be explored.

Strict guidelines would need to be defined and applied over acceptable criteria for recipients of the grant. In addition to meeting all current state clearing house requirements and KIRMA Development Project Regulation requirements, at the very minimum it is suggested the following be included:

- Be located on land levels greater than 3 feet above present high tide levels.
- Not be located on the storm or beach berm, on reclaimed land over the shoreline, mangroves, saline or freshwater swamp areas, or on any other areas affected by coastal erosion or flooding from wave overwashing.
- Not involve clearing of, or construction on, steep land or on land with a potential landslip risk (including access road).
- Not be located in areas prone to river or stream flooding or with current waterlogging or drainage issues.
- Have a buffer of at least 50 feet between land cleared for the property and any coastal, mangrove or river/stream waterway.

4.3.2 Development of a relocation strategy

Strategy 7: Commence community and state discussions to develop a relocation strategy identifying potential approaches to support relocation from areas exposed to coastal hazards where no alternative land is available.

Whilst many families on Kosrae have access to alternative land areas on the volcanic parts of the island away from the coastline, there will be a significant number of landowners where no alternative safe land is available for relocating property. This may not be a significant issue over the next one to two generations but may well be more of a pressing issue over the latter half of this century. Discussing and developing approaches that could work on Kosrae to address such situations and developing the appropriate provisions now in a proactive way, rather than waiting until the situation forces decisions to be made, would provide certainty and security.

Examples of approaches could include land swaps with surplus Government land, opening up small areas of low gradient land above the Japanese line (e.g. between Innem and Okat), or development of a community relocation fund to support the purchase of land.

5 Defending: The future role of coastal defences

On Kosrae, as in many other places, seawalls or other forms of constructed coastal defences are typically seen as the "solution" to coastal erosion and flooding problems.

Unfortunately such approaches[4]:

- Are reactive usually in response to damaging coastal hazard events.
- Rarely the most effective or sustainable option in the long-term, particularly in areas prone to coastal flooding given the levels of sea-level rise likely to be experienced in the latter part of this century.
- Can lead to a false sense of security and often encourage further development behind coastal defences (Figure 5-1). No present seawall on Kosrae will prevent wave overwashing and resulting damage, from severe events such as occurred during the December 2008 swells on the Tafunsak coast or if a major typhoon was to track close to Kosrae.

Figure 5-1: The develop-defend-develop cycle. Seawalls are often built in response to a storm event. This often then leads to a sense of security within the community that they are “protected” often leading to further development on land that is either too low lying or too close to the shoreline. When a further storm occurs, or the coastal defence breaks down and does not provide as much protection as anticipated there is a demand for bigger and better defences. This develop-defend-develop cycle that results typically causes the hazard problem to become more complex over time as the root cause of the problem is ignored, that is that people are residing and infrastructure developing in land that is at risk from coastal hazards.

- Often lead to other environmental damage (such as exacerbated erosion as occurred at Sandy Beach Hotel) and impacts on other community values (such as access to the reef flat).
- Typically result in an expectation that protection provided by such defences will continue to be maintained, leading to ever increasing financial commitment to

[4] Ministry for the Environment (2008). Coastal hazards and climate change. A guidance manual for Local Government in New Zealand. 2nd edition. Revised by Ramsay, D. and Bell, R. Prepared for Ministry for the Environment, New Zealand.

maintain and upgrade such defences, and ever increasing difficulty in implementing more sustainable development options.

- On a retreating coastline such as south of Malem, the effectiveness of such defences is continually being reduced whilst the potential negative impacts caused by the defence often increases.

Where such structures become permanent features there will be longer-term impacts that will affect the ability of Kosrae's coastline to naturally respond to the long-term effects of sea-level rise. Such aspects are rarely considered but are important if Pacific Islands such as Kosrae are to successfully adapt to climate change effects.

For example the reclaimed areas of Lelu Island and Utwe village are two highly developed areas that will face particular challenges due to sea-level rise. The level of the reclaimed land in both villages is barely above present high (king) spring tide levels with some areas already experiencing frequent high tide flooding. Whilst both these areas are protected by seawall structures, these structures will not prevent the ever increasing frequency of flooding of the low-lying land behind them.

Figure 5-2: Low-lying reclaimed areas on Lelu Island (left) and Utwe village (right). Both Lelu and Utwe villages have been built on reclaimed land that is close to present day high spring tide levels. The frequency and severity of high-tide flooding will be an ever-increasing issue as sea-level rise continues. Constructing further seawalls will not prevent more frequently and severe inundation occurring in the future.

As Kosrae has discovered, adequately constructed coastal defences have a high capital cost, typically have a high maintenance requirement, and have a limited lifespan at best probably around 20 to 30 years. Both the State and Municipal Governments on Kosrae have a considerable future financial commitment in ensuring existing coastal defences are maintained and upgraded to provide a satisfactory level of protection to enable longer-term adaptation strategies to be implemented and before any further new coastal defences are planned.

- In a general context, seawalls such as these are an expensive option, typically only ‘buy some time’ and should only be used as a last resort where critical assets are at direct risk and

- There an no other cost effective options to reduce this risk

There is a need to quickly reduce the current risk to critically exposed infrastructure to enable longer-term adaptation strategies to be implemented.

Strategy 8: A strategic approach is adopted for the ongoing provision of coastal defences only where it is a sustainable long-term option or where a transitional approach to protecting areas over the short to medium term to enable repositioning strategies to be implemented.

Such a strategy requires:

- Long-term defences: a priority on protecting sections of road or other critical infrastructure where there is no option to reposition away from coastal hazards.
- Transitional defences:
  - Upgrading sections of existing defences to provide an adequate standard of protection to the road or highly developed areas over the short to medium term (1 to 2 generations) to enable longer-term adaptation strategies to be implemented
  - Limiting any new sections of coastal defences to the areas where the road is critically threatened at present at Pal and Mosral to provide short to medium term (1 to 2 generations) protection to enable longer-term adaptation strategies to be implemented.

The locations where long-term protection will be required and where transitional defences, primarily areas with existing coastal defences which will need to be maintained and where required upgraded to enable the longer term strategies outlined in Sections 4.2 and 4.3 to be implemented, are shown in Figure 5-3.

Figure 5-3: Location of long term and transitional coastal defences.

5.1.1 Long-term protection requirements

Most sections of shoreline where coastal defences are likely to be required over the long-term (beyond 2 generations / the 2050s) to protect infrastructure where there is limited or no other adaptation options available, already have coastal defences in place. Future requirements for these defences are summarised in Table 5-1 and Figure 5-4.

In the majority of cases this will require maintaining the existing defences when damage occurs, upgrading rock armour layers where they are currently inadequate (for example Lelu Causeway), and improving on the wave overtopping performance as sea level rise results in higher volumes and more frequent wave overtopping of existing defences. In the short to medium term (1 to 2 generations) this may require additional crest protection, such as mass concrete upstands / wave return walls at the landward edge of the rock revetment crest.

In the longer term, given the rates of sea-level rise likely to be experienced over the second half of this century, rock revetments may need to be replaced with larger structures, higher crest levels and potentially infrastructure raised behind the protection.

Table 5-1: Current and forseeable future requirements and priorities for sections of coast requiring long term coastal defences.

Location	Approx. length of protection	Current Priority	Details
Okat Airport / Port	5070 m 5550 yds	Low	Continued maintenance and upgrading of the rock armour protection around the airport. In the future this may require further crest protection to reduce any increased frequency of wave overtopping. Maintenance requirements to rock armour may increase as sea-level rise allows larger waves to reach the defence. Continued maintenance of concrete wharf and walls at the port.
Okat access road	620 m 680 yds	Low	Continued maintenance and future upgrading if required to the rock protection along the landward access to the bridge to the airport and dock.
Headland between Malsu and Wiya	290 m 320 yds	Medium	Upgrade of existing rock protection to the road and FSM Telecom tower from Malsu around the corner to Wiya. The revetment armour layer should be at least two rocks thick and at a slope no greater than 1:1. Given the little width of road shoulder or revetment crest, a concrete upstand may be required at the crest between the road edge and the rock armour.
Wiya	290 m 320 yds	Low	New rock revetment to protect the road between Wiya and Yekula. The revetment armour layer should be two rocks thick, at a preferred slope of 1:3, with a crest width of three rocks wide at the shoulder of the road.
Lelu Causeway (seaward)	650 m 715 yds	Medium	Upgrade armour protection of the causeway with single layer of rock armour at a 1:1 slope. A secondary layer may be required in the future as well as further crest protection such as a concrete upstand.
Lelu Causeway (Harbour – Lelu Island to Marine Resources)	245 m 270 yds	Medium	Upgrade armour protection of the causeway with single layer of rock armour at a 1:1 slope.
Lelu Causeway (Harbour –Marine Resources to Finpukal)	310 m 340 yds	Medium	Upgrade armour protection of the causeway with single layer of rock armour at a 1:1 slope.
Tafuyat	225 m 245 yds	Medium	Upgrade existing rock protection if high tide wave overtopping becomes too frequent with concrete wave upstand between revetment crest and road.
Leyot to Mutunlik	800 m 875 yds	Medium	Upgrade existing rock protection with a second armour layer. If high tide wave overtopping becomes too frequent install concrete wave upstand between revetment crest and road.

Only at Wiya is there likely a need for new long-term protection. Around the headland between Wiya and Malsu there is no scope to reposition the road further inland. Whilst between Wiya and Yekula, the road could be moved back slightly future protection would likely still be required.

A current (2013) proposal for Japanese assistance to upgrade a number of coastal defences covers a number of the sections included in Table 5-1 including:

- Upgrading the armour protection along the harbour side of Lelu Causeway
- Headland between Malsu and Wiya and along the Wiya shoreline.

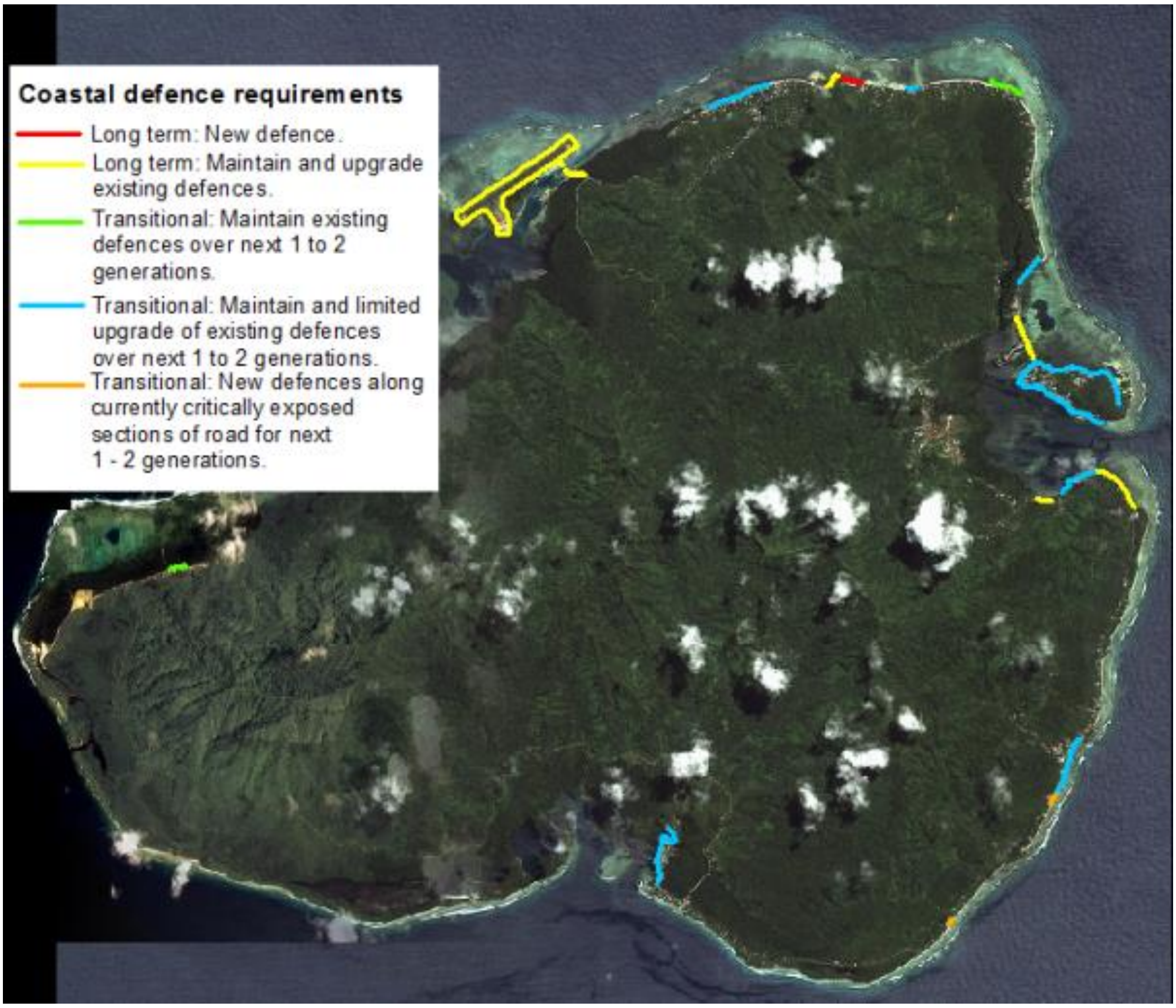

Figure 5-4: Summary of coastal defence requirements over the forseeable future.

5.1.2 Transitional protection requirements

Future requirements for defences required over the short to medium term (1 to 2 generations) to enable longer-term adaptation strategies to be implemented are summarised in Table 5-2 and Figure 5-4. Again many of these defences are already in place and the financial commitment to maintain and in many cases upgrade them to provide an adequate level of protection over the next one to generations will be considerable. In the longer-term, over the second half of this century, the rate of sea level rise will mean that these coastal defences either:

- Become increasingly in-effective: particularly where the impacts are due to increasingly more frequent high tide flooding (such as the reclaimed areas upon which Lelu and Utwe villages are located).
- Become too expensive to maintain, upgrade or replace to continue to provide a suitable standard of protection.

Table 5-2: Current and forseeable future requirements and priorities for transitional coastal defences.

Location	Approx. length of protection	Current Priority	Details
Tafunsak village	880 m 970 yds	Medium	Maintain existing rock armour defence. Potential upgrades include: ▪ Reconfiguring western end of defence to alleviate downdrift erosion impacts. For example short breakwater with beach nourishment behind (similar to Sandy Beach). ▪ Extending the revetment across the outlet of Infal Mutunte (now relocated to Malsu) to prevent high tide and swell inundation through the opening in the defence. ▪ Constructing a concrete wave upstand at the landward edge of the revetment crest to improve the performance in reducing wave overtopping during large swell events.
Finfukul	160 m 175 yds	Medium	Maintain existing rock armour defence Constructing a concrete wave upstand at the landward edge of the revetment crest to protect edge of the road and improve the performance in reducing wave overtopping.
Finaunpes	525 m 575 yds	Low	Maintain current rock revetment and breakwater.
Pacific Treelodge / Putuk	425 m 465 yds	Medium	Replacement when required of the concrete mattress revetment with a sloping rock revetment to the same slope as the existing revetment. Replace vertical concrete wall with sloping rock revetment. The revetment should be founded on the reef flat and located at the crest of the beach. The beach should be reinstated on the seaward side of the structure. Any mangroves should be retained.
North Lelu Island	1560 m 1710 yds	Medium	Upgrading of sections of largely coral rock wall protection as required with a sloping rock revetment at a 1:1 slope and crest above the level of the road (as is currently in place along various sections). The emphasis should be on maintaining the current line of land with no further reclamation occurring. Any mangroves fronting the defences should be retained.
South Lelu Island	2210 m 2420 yds	Medium	Upgrading of sections of largely coral rock wall protection as required with a sloping rock revetment at a 1:1 slope and crest above the level of the road (as is currently in place along various sections). The emphasis should be on maintaining the current line of land with no further reclamation occurring.
Muntunlik	615 m 675 yds	Low	Upgrading of sections of largely coral rock wall protection as required with a sloping rock revetment at a 1:1 slope and crest above the land level. The emphasis should be on maintaining the current line of land with no further reclamation occurring.
Malem village (North)	340 m 370 yds	High	Reconstruct existing poorly constructed rock revetment to provide a consistent revetment profile with a 1:3 slope, average rock size of 0.66 m (2 feet), double layer or armour and crest of three rocks wide. Future upgrade to include mass concrete wave upstand wall at landward edge of revetment crest if wave overtopping frequency increases with sea-level rise.
Malem village (Kotfwa)	500 m 550 yds	High	Northern section: Upgrade existing single layer rock armour revetment to two layers, maintaining the 1:3 slope, average rock size of 0.66 m (2 feet),with a revetment crest of 3 rocks wide. Southern section: Reconstruct existing poorly constructed rock revetment to provide a consistent revetment profile with a 1:3

Location	Approx. length of protection	Current Priority	Details
			slope, double layer or armour and crest of three rocks wide. Future upgrade to include mass concrete wave upstand wall at landward edge of revetment crest if wave overtopping frequency increases with sea-level rise.
Pal	160 m 175 yds	High	New rock revetment from the southern end of the exiting rock armour along the section where the road is critically exposed. Existing dumped concrete rubble will need to be removed. The revetment should be to the same profile as the upgraded sections to the north with a 1:3 slope, double layer of rock armour, average rock size of 0.66 m (2 feet), and a crest 3 rocks wide. Given the proximity of the road a mass concrete wave upstand wall at the landward edge of revetment crest may also be required to ensure wave overtopping is minimised, either now or sometime in the future. The new revetment will need to extend behind the existing shoreline at the southern end to prevent outflanking and further downdrift erosion. However, further retreat of the shoreline will occur at the southern end and some form of additional low reef flat breakwater may also be required to 'stabilise' the shoreline at the southern end of the revetment to prevent further exposure of the road.
Mosral	110 m 120 yds	High	New rock revetment from the outlet of Infal Mosral tideflex structure along the section where the road is critically exposed. The existing mass concrete bags can be retained with the revetment constructed seaward of them. The revetment should be at a 1:2 to 1:3 slope, double layer of rock armour, average rock size of 0.66 m (2 feet), and a crest 3 rocks wide. Given the relatively low- level of the road a mass concrete wave upstand wall at the landward edge of revetment crest may also be required to ensure wave overtopping is minimised, either now or sometime in the future. Outflanking and further downdrift erosion will occur at the southern end of the revetment and some form of additional low reef flat breakwater may also be required to 'stabilise' the shoreline at the southern end of the revetment to prevent further exposure of the road.
Utwe village	1015 m 1110 yds	Medium	Upgrading of sections of largely coral rock wall protection as required with a sloping rock revetment at a 1:1 slope and crest above the land level. The emphasis should be on maintaining the current line of land with no further reclamation occurring.
Walung (Insiaf)	230 m 250 yds	Medium	Maintain existing rock armour revetment

The highest priority for defences remains the upgrade of the defences at Malem village, extension of protection to the south along the critically exposed section of road at Pal and at Mosral. These section should be the priority focus for any further coastal defence work in the immediate future. Further details of these defences are provided in Appendix D.

6 Monitoring adaptation progress

The measures outlined above are intended to provide a strategic approach to long-term reduction of coastal hazard risks to infrastructure and communities on Kosrae as a means to effectively adapt to the physical changes that climate change and sea-level rise will cause to Kosrae's present coastal margins

Such risks to the communities in Kosrae will change with time. Some activities or decisions will increase such risks, other activities will reduce them. An important aspect to help inform decision-making is to monitor and assess how such risks are changing over time and whether the relevant decisions that have previously been made have been effective in helping reduce coastal hazard related risks.

Outlined below is an initial attempt at developing a set of quantifiable measures, based on the strategies outlined above, that could be used to assess how the risks associated with coastal hazards change over time and how well Kosrae is progressing in addressing these changing risks. It is by no means a complete list and may well require further refinement in the future. By carrying out an assessment of the relevant factors that will increase or decrease risk on say an annual basis, the progress that Kosrae makes in reducing their risks to coastal hazards can be monitored.

1. Number of community awareness and outreach activities implemented with a focus on reducing and minimising human impacts on the natural coastal defences over the last 2 years.
2. Number of sand mining incidents report to/investigated by KIRMA over the last 2 years.
3. KIRMA regulations updated to better incorporate risk reduction and adaptation considerations in to the development review progress.
4. Total number of developments (farm roads, properties) above the Japanese Line.
5. Total length of new inland primary road constructed.
6. Total number of residential property located seaward of the circumferential road in Lelu, Malem, Utwe and Tafunsak.
7. Total number of residential property located on the beach berm in Walung
8. Total number of property located below or seaward of the 4 m contour
9. Relocation strategy developed.
10. Total number of long-term coastal defence recommendations implemented
11. Total number of transitional coastal defence recommendations implemented
12. Total number of seawall structures built without KIRMA permit / outwith requirements identified in this strategy.

Table 6-1 provides a summary of the situation as of late 2013.

Table 6-1: Summary of indicators as of late 2013 and goal over the next two generations.

Number	Indicator	Required progress direction	2013	By 2050
1	Number of community awareness and outreach activities implemented with a focus on reducing and minimising human impacts on the natural coastal defences over the last 2 years.	↑	?	?
2	Number of sand mining incidents report to/investigated by KIRMA over the last 2 years.	↓	?	0
3	KIRMA regulations updated to better incorporate risk reduction and adaptation considerations in to the development review progress.		No	Yes
4	Total number of developments (farm roads, properties) above the Japanese Line.	↓	?	0
5	Total length of new inland primary road constructed.	↑	0	
6	Total number of residential (2010 census) property located on the beach/storm berm / reclaimed land and seaward of the circumferential road ▪ Lelu ▪ Malem ▪ Utwe ▪ Tafunsak.	↓	 75 48 43 20	 0 0 0 0
7	Total number of residential (2010 census) property located on the beach berm in Walung	↓	29	0
8	Total number of property (2010 census) located below or seaward of the 4 m contour ▪ Lelu ▪ Malem ▪ Utwe ▪ Tafunsak ▪ Walung	↓	 334 222 145 87 32	 0 0 0 0 0
9	Relocation strategy developed.		No	Yes
10	Total number of long-term coastal defence recommendations implemented	↑	0	9
11	Total number of transitional coastal defence recommendations implemented	↑	0	13
12	Total number of seawall structures built without KIRMA permit / outwith requirements identified in this strategy in last 2 years.	↓		0

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Appendix A Summary of progress on the recommendations made in the Shoreline Management Plan in 2000.

Recommendation	Progress	Comments
The natural environment		
Coral reef and reef flat:		
Every effort needs to be directed at continuing to protect the health of Kosrae's living coral reef from land based human impacts.	✓	An ongoing issue
The present practice of not removing coral rubble, shingle and sand from the reef flat be continued and that it be regulated if such activity re-commences.	✓	Rubble and sediment from the reef flat has not been removed
A full Environmental Impact Assessment is carried out by qualified personnel before any further reef flat dredging is permitted. However, it is strongly recommended that no further dredging of any part of the fringing reef flat be conducted.	✓	No further dredging (other than at the ship repair facility) has taken place
Stricter regulation, enforcement, training and education aimed at managing and reducing both residential and industrial sources of pollution will be vital for the long-term health of Kosrae's living reef biota	✓	No significant suggestion that pollution from land-based sources is
Beaches and the shoreline:		
A long-term source of construction sand needs to be developed to meet Kosrae's future development needs. Existing sand resources in the coastal hinterland are extremely limited and increasingly will not meet Kosrae's construction demands	X	Still a pressing issue
Sand mining from the beaches of Kosrae needs to be regulated. However, experience from other small island developing states suggests that this is likely to only be effective once a suitable long-term alternative to beach sand is available.	=	Sand mining from beaches has reduced considerably due to KIRMA awareness effort but still practiced and is still an issue.
Vegetation clearing be discouraged for at least 50m behind the vegetation line at the shoreline. Where possible the planting of typical coastal strand vegetation should be encouraged.	X	Still a pressing issue
Construction of new coastal defenses and land reclamation over the beach be strictly controlled and regulated through the Development Review Process. This is particularly important on the exposed sections of coastline (i.e. those facing the open ocean).	X	Inappropriate reclamation and coastal defences still being constructed.
Mangroves:		
Mangrove replanting, to provide natural coastal protection to the coastline, is a suitable mechanism in the following areas: • **Lelu lagoon**:- potentially from Mitais, all along the northern coastline of Lelu Island, the Causeway and Finpukal • **Lelu Harbor**:- Mutunnenea area (south of the bridge) • **Tafuyat**:- mainly the area where mangroves died off due to the oil spill that occurred sometime in the 1980's.	X	Some mangrove planting attempted in Lelu lagoon but have not established
The area of mangrove replanting should be at least 50 meters wide. This is approximately the width, in a mature mangrove strand, that would effectively dissipate a 1m high wave.	X	
Should a severe storm or typhoon affect the mangrove strands on Kosrae, it is recommended that human activity, such as the removal of felled trees, be discouraged from the damaged areas and immediate surroundings to allow the damaged area to	✓	No typhoons or serious storms have affected Kosrae

Recommendation	Progress	Comments
recover naturally.		
From a coastal protection viewpoint, that harvesting of mangrove timber is discouraged from within 100m of the outer mangrove fringe and from within 50m of major channels.	✓	No significant suggestion that detrimental Mangrove harvesting is occurring
Wetland areas and rivers		
Where it is deemed necessary to develop swamp areas for activities such as agriculture, it is recommended that buffer zones of at least 100m be established around rivers and major drainage channels and along the coastal edge of the swamp.	X	Buffer zones rarely applied.
Further farm roads through wetland swamp areas, particularly between Tenwak and Kuplu, be discouraged	✓	No further roads appear to be constructed
Future culverts and bridges over natural drainage channels and rivers are of sufficient size to have as little influence as possible on the passage of flood flows due to high rainfall events.	✓	New guidance being developed and implemented as part of PACC project
Development or alteration of artificial river or drainage channels outlets is not recommended and should be controlled within the Development Review Permitting Process	=	No further significant river or drainage channel works conducted.
The built environment		
Infrastructure:		
Building further sea walls or other forms of coastal defenses is not a recommended, appropriate or affordable option for the long-term protection of most of the existing infrastructure at risk from coastal hazards	X	Continued
With the current re-negotiation of the Compact Funding, it is recommended that now is an ideal opportunity for the Government of Kosrae to consider a program of developing Kosrae's essential infrastructure inland away from such high risk areas. Within the next 10 to 15 years an inland road will be required between Utwe and Tenwak, and between Mutunnenea and Yekula or Wiya. Over this time, it is recommended that this road be developed as the main road linking the Municipalities	X	No progress on developing inland roads. General conditions of existing inland farm roads has deteriorated.
It is recommended that the existing practice of constructing the inland road around the perimeter of the lower slopes of the volcanic part of the island, above the freshwater swamp areas be continued, taking due care to minimize road slopes, run-off, and ensuring adequate culverts are installed to minimize changes to drainage patterns and to cope with periods of heavy rainfall.	✓	Being applied in the extension of the road from Utwe to Walung and the extension of the road from Okat as part of the PACC project.
In developing the new sections of inland road, priority be given to: • Extend the inland road between Malem village (Mutacsrisr) and Mosral • Developing the road behind Sialat and Finfukul to Yekula or Wiya	X	No progress
Further development of the circumferential road beyond Okat bridge, towards Walung, be constructed around the perimeter of the lower slopes of the volcanic part of the island above freshwater swamp areas, taking due care to minimize road slopes, run-off, and ensuring adequate culverts are installed to minimize changes to drainage patterns and to cope with periods of heavy rainfall	✓	Being incorporated as part of the PACC project
Upgrading and construction of coastal defenses is recommended to protect the existing road at certain key areas where there is little opportunity to develop further inland.	✓	Sea walls have been upgraded or constructed at Finfukal, Tafuyat, Leyot/Mutunlik and Malem
Residential property		

Recommendation	Progress	Comments
Over the next ten to fifteen years, reducing the number of residential properties constructed or located within coastal hazard areas is of the highest priority.	X	No strategic progress made
The Government assist individuals in developing residential property out-with coastal hazard risk areas by gradually developing the existing essential infrastructure (roads, electricity, telecommunications) along an inland route	X	No progress made
Where new development and property construction does occur close to the coastline, a general set-back zone of at least 100 feet from the vegetation line at the coastline be adopted	X	Not applied
The construction of sea walls or other forms of coastal defense to protect individual property is not permitted where there is no existing coastal protection structures. Future construction of sea walls or other forms of low cost coastal defenses is not a recommended option for the protection of residential property out-with certain locations	X	Ad hoc seawall structures still being built
Land owners / housebuilders are advised that no hard structures will be permitted in front of newly built properties that have been located seaward of the circumferential road.	X	Not occurring to any great extent
The DRC continue to work with the Housing Renovation Loan Fund Office (Department of Commerce and Industry) and the Rural Development Office (USDA) to minimize the development of loan-funded housing within coastal hazard areas	✓	Ongoing as part of the housing loan application process
If it is felt that regulation of residential development is required in coastal hazard areas, above the measures that have been incorporated within the Housing Renovation Loan Fund and Rural Development processes, it is recommended that changes be made to the Development Review Process to include all residential housing	=	Strengthening the Development Review regulations is currently being conducted.
Private Sector		
Future tourism, and other major commercial development is controlled within the Development Review Process. It is recommended that the use of Environmental Impact Assessments be continued as a pre-requisite for all major development projects.	✓	Generally being applied.
Through the Development Review Process, it is recommended that no commercial development be permitted in high risk coastal hazard areas (and certainly not within 100 feet of the coastline or on land that could potentially flood).	X	A number of Laundromats have been permitted on reclaimed areas over the shoreline
The risk to develop land with any coastal hazard risk for commercial purposes, must be borne by the Developer. It is recommended that, at the project review stage, it is made clear to the Developer that the construction of coastal defenses will not be permitted during the lifetime of the development to protect the development from storm damage or flooding where no coastal defenses currently exist.	✓	Generally being applied.
It is recommended that the Development Review Process ensures that appropriate technology be utilized to ensure that effluent discharge to the fresh water or marine environment from any proposed commercial development has minimal detrimental or cumulative impact	✓	Generally being applied.
Coastal defences		
The construction of engineered sea walls or other forms of coastal defense, such as breakwaters (wave breakers) are **not** an appropriate coastal management, or cost effective solution, for reducing the risks posed by coastal erosion, flooding and storms around **much** of the coastline of Kosrae.	X	Ad hoc seawall structures still being built and viewed as the preferred solution.

Recommendation	Progress	Comments
Construction or upgrading of coastal defences in locations where such an approach is the most effective long-term strategy for the protection of infrastructure or property.	=	Some upgrading of defences has occurred (e.g. at Leyot).

Appendix B An overview of coastal change on Kosrae.

Types of coastline

Kosrae has a varied coastline the current characteristics of which depends on the width of the reef flat and the relative exposure to tradewind waves and occasional, severe, storm or typhoon waves (Figure B-1). These characteristics have also defined how development has occurred, how vulnerable parts of the coastline are to inundation events, and how the shoreline has changed and will continue to change in the future.

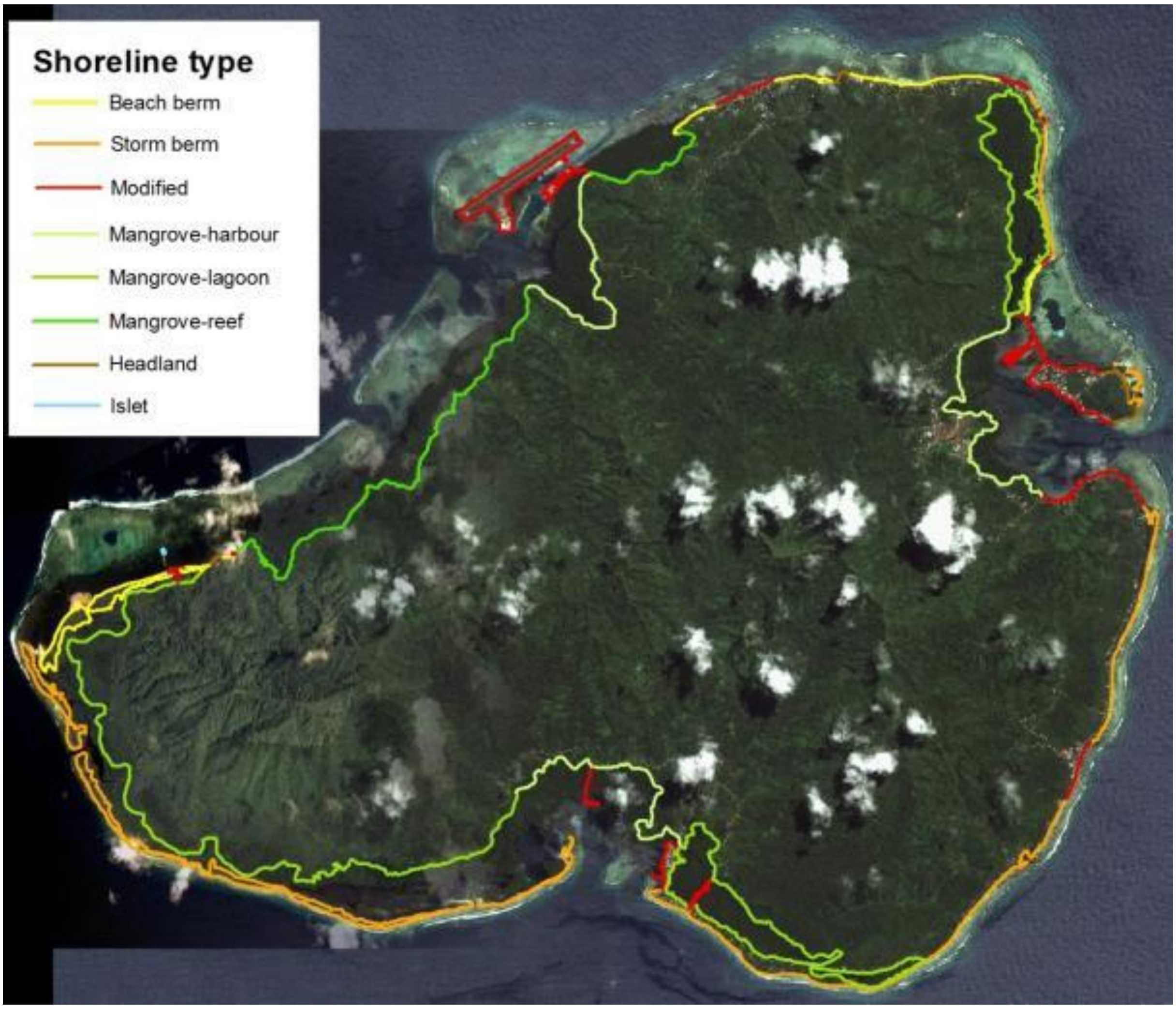

Figure B-1: Basic shoreline types on Kosrae.

Beach berm

This is a dominantly sandy coast found along the north facing Tafunsak and Walung coastlines that are moderately exposed to tradewind-related waves, and along the northern part of Lelu Lagoon (between Putuke to Finpukal).

It is characterised by a wide reef flat with seagrass beds, narrow wave built sand berm upon which the coastal road and most development has occurred, with low lying infill swamp or farmland behind the berm to the volcanic part of the island. At Walung, and between Putuke and Finpukal, mangrove occurs between the narrow beach berm and the volcanic uplands (Figure B-2).

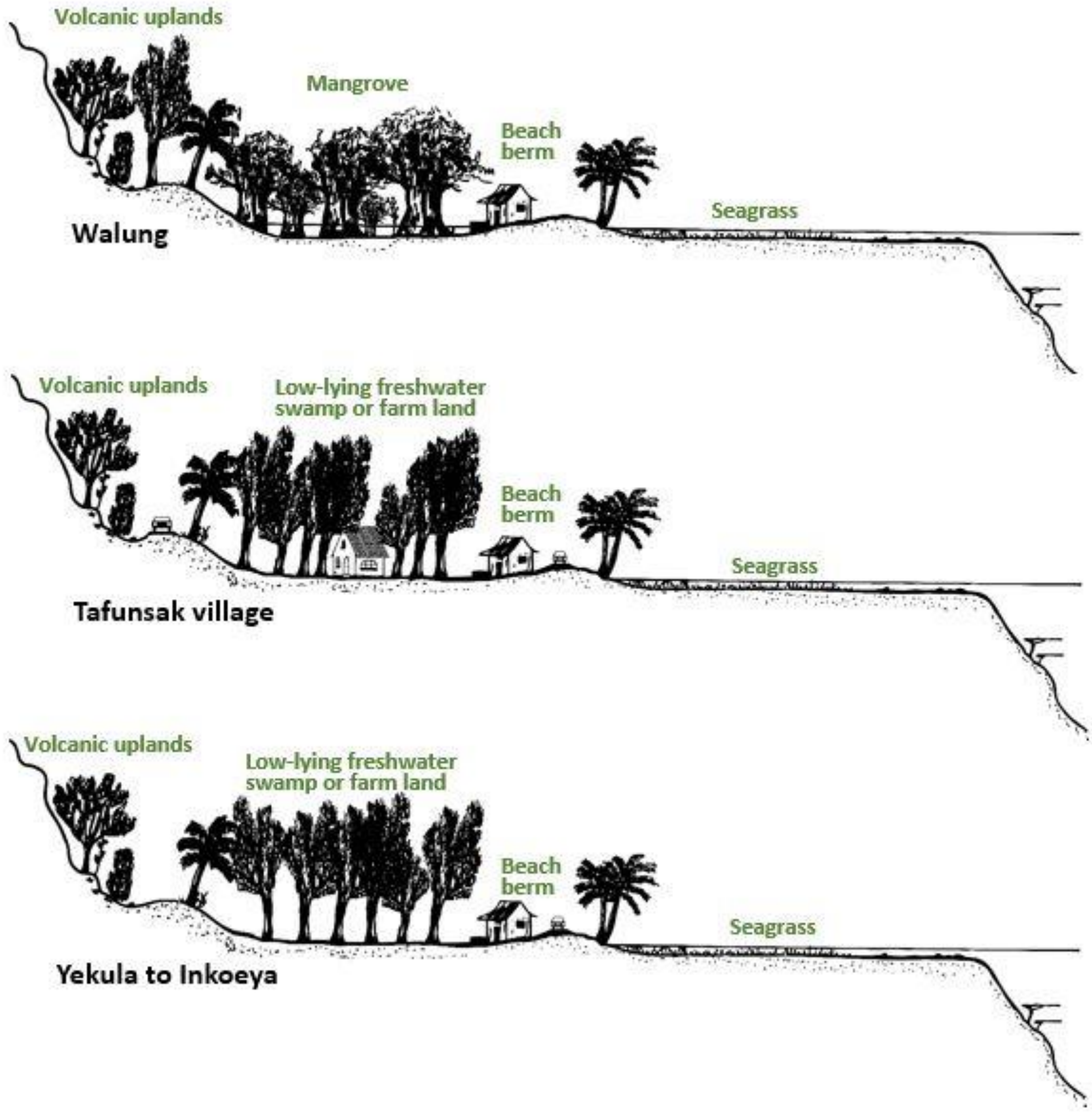

Figure B-2: Typical cross-sections for the coastline at Walung (top), Tafunsak village (middle) and between Yekula and Inkoeya (bottom).

The beach sediments along the Tafunsak and Walung coasts are dominated by reef-flat derived foraminiferal tests and other reef and reef flat derived biogenic fragments (corals, algae, gastropods and bivalves). Beach sediment generated upon the reef flat continues to be an important source of sediment to these beach systems.

Along the north coast the beach berm has developed from the supply of dominantly reef-flat derived sediments, a trade-wind wave induced net longshore transport of beach sediment to the west, and the shape of the outer fringing reef, which influences the way waves propagate to the shoreline over the reef (Figure B-3 to Figure B-5).The elevation of the beach berm is also strongly related to wave exposure and tends to be higher along the Tafunsak coastline and relatively lower at Walung and the northern part of Lelu Lagoon.

Figure B-3: Key sediment sources, longshore transport processes, and sediment losses along the Tafunsak shoreline.

Key coastal process features along the Tafunsak coastline include:

- Primary sediment sources are from the sediments generated over the wide reef flat areas along this north-facing coast and transported by waves onshore. Sediment is also generated and trapped within the extensive seagrass beds occurring along the inner to mid-part of the reef flat. This raises the level over the reef flat and helps stabilise the shoreline from wave-induced change.
- Another important source of sediment to this coastline is from longshore transport from the Finaunpes region as the large salient that built up at Finaunpes due to protection provided by past banks of coral rubble on the outer reef flat has retreated landward (see coastal change figures later in this Appendix). This has resulted in a general build-up of land from Inkoyea to Sialat over at least the last fifty years.
- At Finfukal the shape of the outer reef and shallow channel influence the way waves approach this part of the shoreline causing beach sediment to be moved away from the beach at Finfukal (drift divide). This has resulted in ongoing retreat of this short section of coast requiring a rock armour revetment to protect the road.
- At Wiya and Finfokoa the position of the coastline has moved little when comparing the position of the coast between 1944 and the present (see section below). Occasional cut down of the beach does occur during large wave events, particularly at Finfokoa with the issue along both these areas being the proximity of the coastal road right on top of the beach crest, rather than any retreat of the shoreline.
- The dredge pits at Tafunsak have been, and may well continue to be a sink of both beach and reef flat sediments.
- The net westerly longshore transport of beach sediment means that downdrift erosion problems (such as occurred at Sandy Beach and to a lesser extent at the western end of the Tafunsak seawall) are likely where poorly considered seawalls or reclamation is conducted.

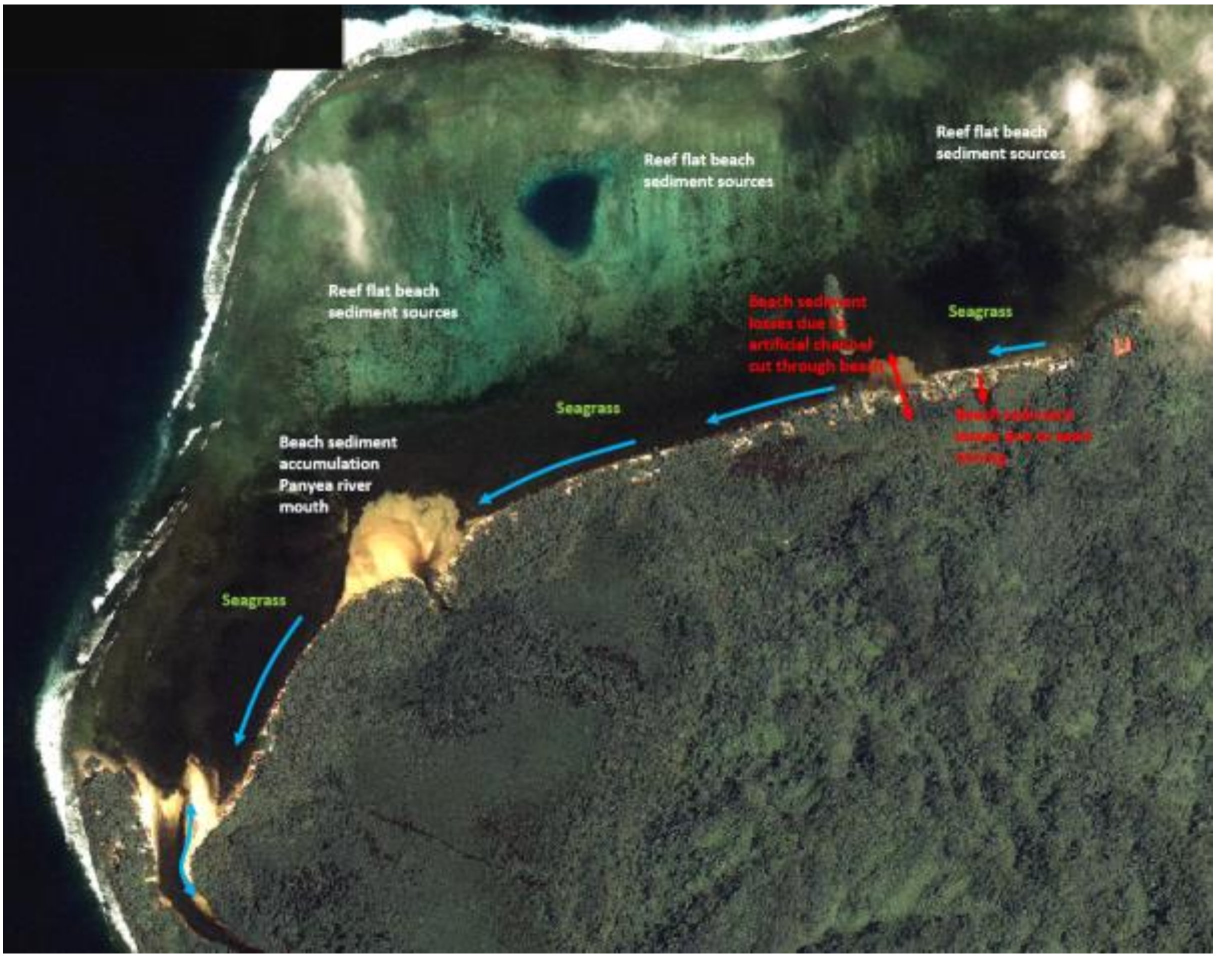

Figure B-4: Key sediment sources, longshore transport processes, and sediment losses along the Walung shoreline.

Key coastal process features along the Walung coastline include:

- Again the reef flat will have been the primary sediment sources for sediments forming the beach berm between Insiaf and Koasr, and for the beach at Mwot which is separated by a rock headland. However, due to the relatively much more sheltered wave environment, present day sediment movements from the reef flat to the shoreline are likely to be relatively modest.
- Between Insiaf and Leap, this lack of sediment entering the beach system is one of the causes for the erosion occurring along this section. However, this has been significantly exacerbated by two activities: 1) the cutting of the drainage channel at Leap in the 1970s, and 2) the removal of sediment from the beach for building construction.
- Between Leap and the entrance to the channel between Koasr and Saoksa the position of the shoreline between 1944 and the present day has been relatively stable (see Section below), with some slight changes at the mouth of Infal Panyea and on the eastern flank of the Utwe-Walung channel entrance both associated with the general westerly longshore transport of beach sediment.

- The net westerly longshore transport of beach sediment means that downdrift erosion problems are likely where poorly considered seawalls or reclamation is conducted. This occurred at Leap after the opening of the channel and construction of the seawall in the 1970s (Xue, 1996) and would have occurred with the construction of the new seawall associated with the road extension at Insiaf. However the western end of the seawall was terminated at a large *Ituc* tree (Calophyllum inophyllum) the roots of which have extended over the beach over many years acting as a groyne which has held the position of the shoreline to the east but resulted in downdrift erosion to the west of the tree.

Figure B-5: Key sediment sources, longshore transport processes, and sediment losses along the Putukte to Finpukal shoreline.

Key coastal process features along the Putukte to Finpukal coastline include:

- Historically, the majority of sediment that has formed the beach berm between Putukte and the Mutunnenea channel will be have been transported southwards along the Pukusruk shoreline into the northern part of Lelu lagoon. However, present day transport of beach sediment from the Pukusruk shoreline is now extremely low.
- The effect of mangroves in trapping sediment and building up the beach can be seen along the central section of the shoreline.
- Changes in position of the shoreline between 1944 and the present day has shown relatively little movement (see Section below). At Putukte the cut back of the beach, resulting in the concrete mattress protection in from to the Treelodge hotel is typically where there is a net south-westerly net movement of sediment towards Finpukal but with little new sediment being transported around the corner from the Pukusruk shoreline.

Storm berm

Much of the east and south coastline on Kosrae has been built by storm and typhoon events over many years. The east coast is characterised by relatively narrow fringing reef, a narrow storm berm upon which the coastal road and most development has occurred, with areas of low lying infill swamp, farmland or lagoon mangrove, behind the berm to the volcanic part of the island (Figure B-6 and Figure B-7).

The storm berm probably began to form some 2500 to 3000 years before present when the post-glacial rate of sea level rise slowed and relative sea level reached its present level (there is little evidence of sea-level high stand and subsequent fall in sea level at this time on Kosrae). Along the eastern facing Lelu and Malem exposed coastline, this storm berm will have formed due to many storm/typhoon events depositing coral rubble and sediment on the reef flat. Over time wave action moves this coral rubble and sediment landwards which “feeds” and builds up the storm berm (Figure B-8). The height of the storm berm is also closely related to the incident wave conditions experienced along the shoreline.

On the leeward south coast from Kuplu all the way to Saoksa in Walung the storm berm will have formed from much more infrequent but severe typhoon events which results in larger blocks of coral being deposited (as can be seen along the coastline at Kuplu). At Kuplu, there are a number of historic storm berms evident (which have formed the lake at Infulu Kuplu) but between Uwte Ma and Saoksa the storm berm is narrow and formed close to the edge of the reef (reflecting the generally mild wave climate outwith the very occasional storm or typhoon event).

To understand why coastal changes are occurring, particularly along the eastern facing Lelu and Malem shorelines, it is necessary to look back to the end of the 19th century (Ramsay, 2012). Kosrae is rarely affected by cyclone events, with the main tracks located to the north and west of the island (see Appendix C). The last major cyclone was in 1905 but it was a cyclone in 1891 that resulted in a bank of coral rubble being deposited on to the reef flat along much of the eastern coastline. In places it was so high that the breaking waves could not be seen (Buck, 2005).

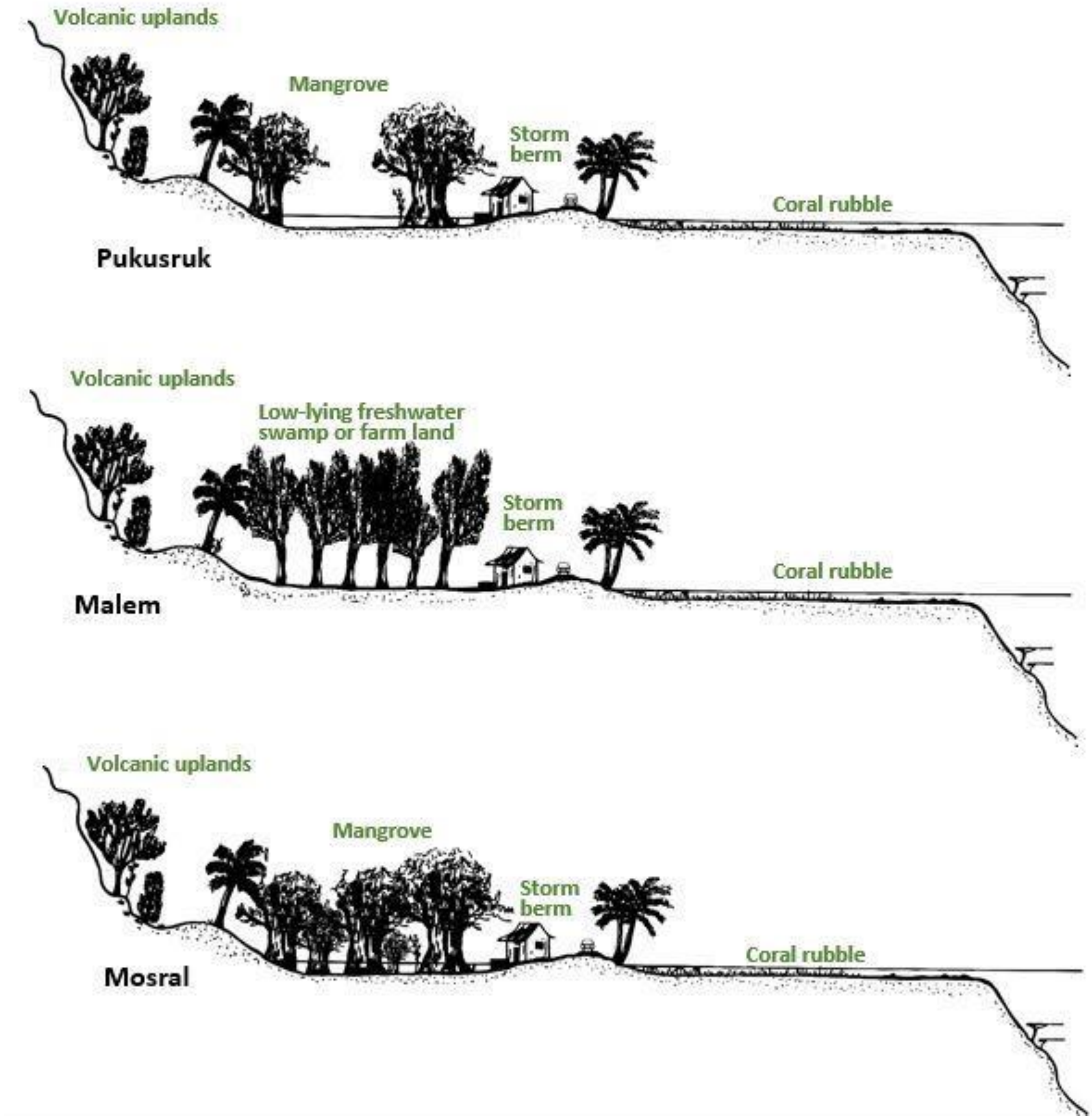

Figure B-6: Typical cross-sections for the coastline at Pukusruk (top), Malem (middle) and Mosral (bottom).

This bank of coral rubble acted as a breakwater blocking a substantial amount of the incident wave energy that would have normally reached the shoreline. This sheltered environment in the lee of the rubble rampart enabled the shoreline to gradually build out and fringing reef mangrove strands to develop at the mouths of streams over much of the early to mid-part of the last century. Over the subsequent decades these rubble banks gradually broke down but continued to provide a substantial level of protection to the eastern shoreline (Figure B-9).

However, it was in the decades after World War II when considerable development commenced, including the circumferential road, and the widening of a causeway. These projects utilised large amounts of coral rubble sourced from these banks. The removal of such a large amount of rubble from the banks both accelerated the breakdown and shoreward migration of the remaining coral rubble but also substantially reduced the protection provided to the shoreline. The increase in wave energy reaching the shoreline has subsequently resulted in a loss of the fringing mangroves along the Malem coastline and long-term and on-going readjustment of the shoreline along much of the eastern coastline with much higher rates of erosion than has been occurring on any of the other shorelines around Kosrae.

Figure B-7: Location of the storm berm along the Malem coast.

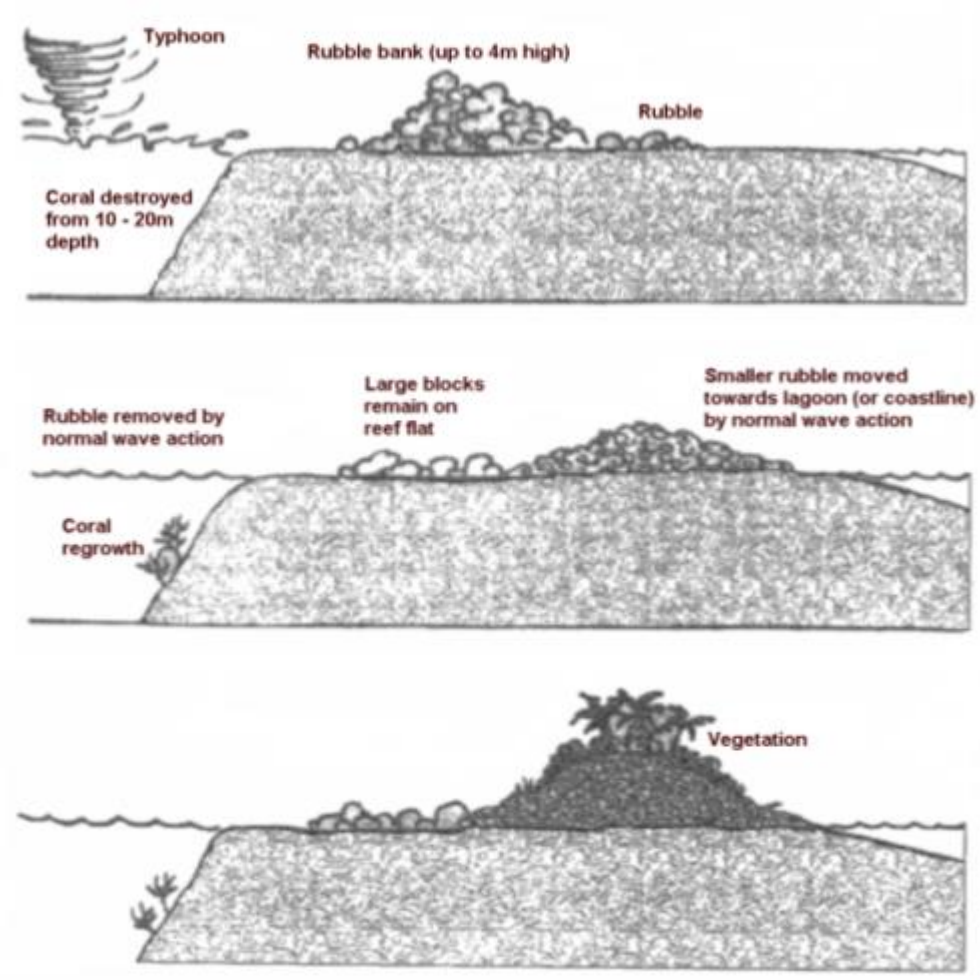

Figure B-8: Basic process forming the storm berm along the eastern facing Lelu and Malem shorelines and southern coastline of Utwe.

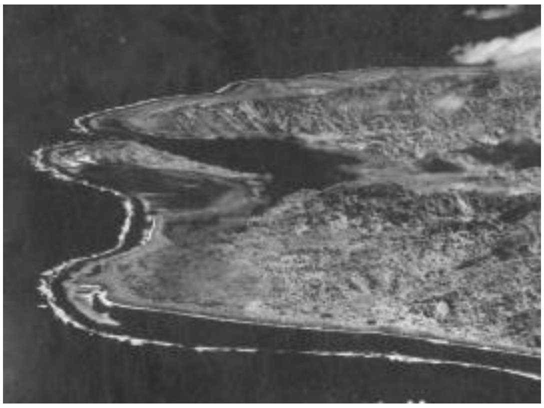

Figure B-9: Aerial photograph of the north-east Kosrae coast in 1944 (left) and the remnants of the rubble ridge in 2013 at Putukte (right). The rubble ridge extending from Finaunpes all the way down the Pukusruk shoreline to Putukte can be clearly seen in 194. The size of the ridge between Finaunpes and Finfokoa resulted in a build out of the shoreline in a bulge in the lee of the ridge. With the breakdown/removal of the rubble ridge, the sediment in this bulge in the shoreline has been redistributed along the adjacent coastline (see shoreline position comparisons in the section below).

The tradewinds and resulting waves also result in coral rubble and beach sediments being moved in a net southwards direction along much of the east coast. Along the Pukusruk coast (Figure B-10):

- Sediment tends to move away from the Finfokoa area moved alongshore both to the north and to the south. However, the rate of longshore transport, particularly to the south will be presently relatively small.
- Along the Pukusruk coast there are a couple of small, very shallow channels through the outer reef (Figure B-10). These may be locations in the past where part of the Mutunnenea channel drained through and are locations where some beach / reef flat sediment will be lost offshore.
- Changes in position of the shoreline between 1944 and the present day has shown relatively little movement (see Section below) for much of the Pukusruk shoreline south of Finfokoa. The most notable retreat is occurring at the locations of the two shallow channels which may allow greater wave energy to reach the shoreline'

Figure B-10: Key sediment sources, longshore transport processes, and sediment losses along the Pukusruk shoreline.

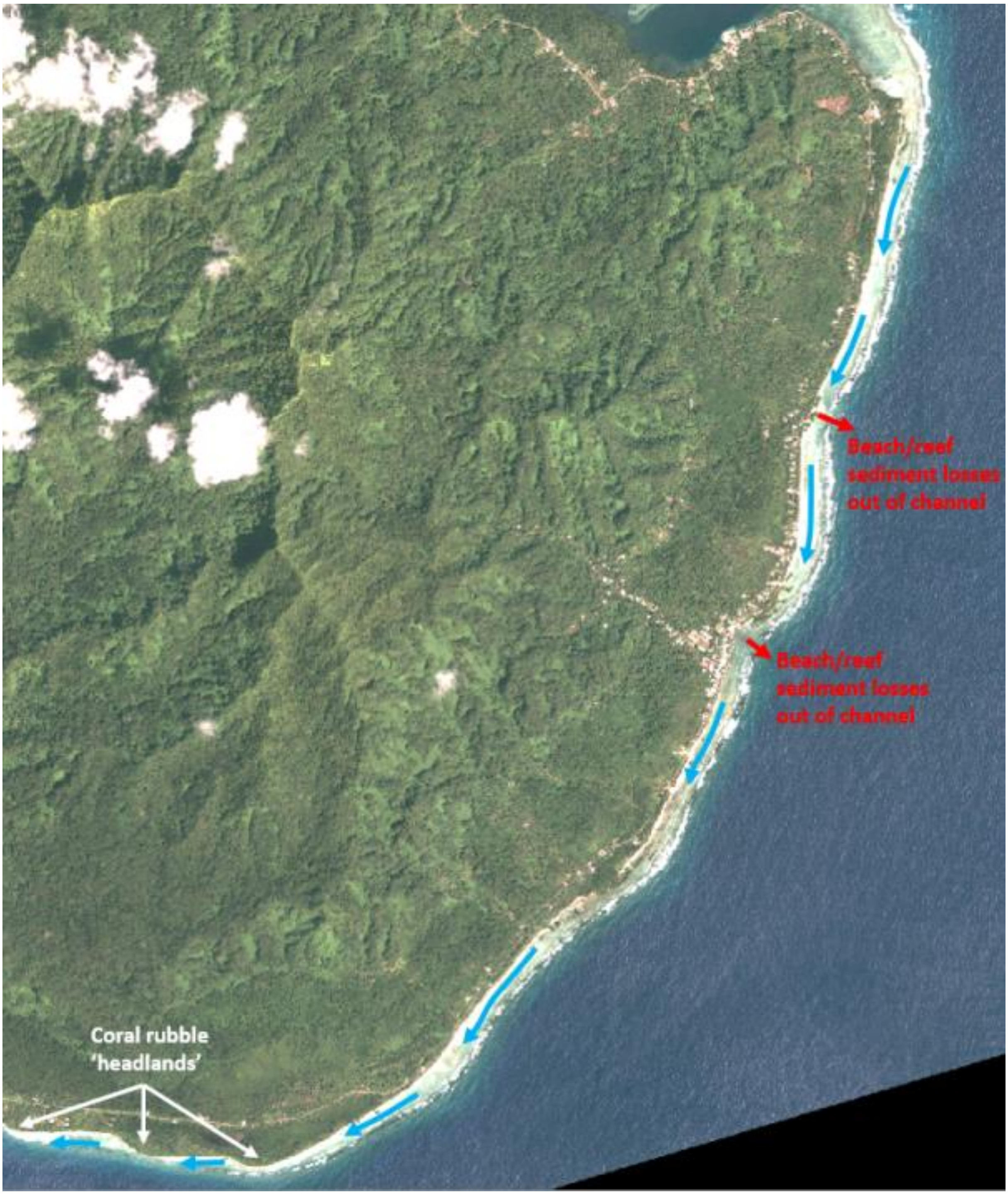

Figure B-11: Key sediment sources, longshore transport processes, and sediment losses along the Malem shoreline.

Along the Malem coastline (Figure B-11):

- The net southerly longshore transport can be observed by the build-up of beach sediment to the north of the old Japanese blockhouse and subsequent downdrift erosion to the south at the house of Chris Collin's in Pilyuul and similarly at the position of the tideflex at the Mosral River mouth.

- The increased wave energy reaching the shoreline and resulting southward longshore transport also result the mouths of some of the smaller rivers being blocked
- The reef flat channels at Malem, and Pilyuul are locations where beach / reef flat sediment will be lost offshore. The locations of these channels are also where erosion problems tended to most significant, notably at Malem. However, increasingly continued retreat of the shoreline at Pilyuul will
- The Kuplu area has been an area of sediment deposition with some significant changes apparent between 1944 and the present day (see section below) including the closing of the eastern outlet of Infulu Kuplu.

Along the south coast, from Kuplu to Utwe, sediment tends to be moved westwards. However, deposits of large coral boulders on the reef flat tends to create a series of headlands and bays with the shoreline rotated to face the incident wave direction and longshore transport rate is likely to be low.

Mangrove coastlines

Mangroves only provide coastal protection along relatively sheltered coastlines, i.e. those that experience low wave energy. Mangrove areas on Kosrae provide direct coastal protection for about 22% of the coastline and are also an important component of the overall natural coastal defenses where they are located in back lagoon settings (but do not provide direct coastal protection to ocean waves).There are three basic mangrove settings (Figure B-12) on Kosrae (Fujimoto et al, 1995):

- Reef flat mangroves: The mangroves along the coastline between Tafunsak and Mwot is the only significant strand that provides protection on a reef flat location, albeit one that is relatively sheltered from typical tradewind wave conditions.
- Harbour mangroves: Located around the fringes of Okat, Lelu and Utwe where some ocean wave energy can be experienced but predominantly local wind-waves generated within the harbours.
- Lagoon mangroves located behind storm or beach berms, for example Mutunnenea, between Utwe and Mosral and between Utwe Ma to Walung which are largely sheltered from any wave action.

The effectiveness of mangroves in providing shoreline protection is highly context specific, depending on the geomorphology of the area and the frequency and magnitude of storm events that have the potential to cause shoreline change, the width, age, density and structure of the mangrove strand.

The narrow strands of mangroves that previously occurred on the outer coastlines, such as along the Malem coastline, provided little effective coastal protection from wave and storm conditions. Mangroves only developed along coastlines such as Malem, due to the protection from waves provided by the coral rubble banks that were previously located on the outer part of the reef flat. The loss of mangroves from these more exposed coastlines is related to the loss of the rubble banks and has not been a dominant cause of the erosion along these sections of coastline.

Figure B-12: **Key mangrove settings on Kosrae.** Top left: reef flat mangroves between Okat and Yela; Bottom left: Fringing harbour magroves in Lelu Harbour at Tofol; Right: Back lagoon mangroves between Nefalil and Utwe Ma.

Modified or man-made coastlines

A substantial amount of Kosrae's development and infrastructure is located on land that has been modified by reclamation or engineered structures:

- Reclaimed areas upon which development is located, for example the main part of Lelu village on Lelu Island, the area upon which Utwe village is located and the airport and port infrastructure at Okat.
- Seawall or revetment structures built to protect land or development, such as at Tafunsak and Malem.

All these modified areas tend to be fronted by form of engineering structures resulting in natural coastal change limited, except where such structures have been poorly built or maintained. If a severe typhoon or storm were to occur many of these defences would not provide adequate protection and significant wave overtopping damage would be expected. The most significant changes are where poorly designed structures have exacerbated erosion on adjacent sections of coastline, for example at Sandy Beach Hotel in the 1980s and 1990s.

Assessment of coastal change between 1944 and 2011

Introduction

An assessment of the change in shoreline position between aerial photographs collected in 1944 and a Quickbird high resolution satellite image collected in 2012. After an initial assessment of the resolution of the scanned 1944 aerial images it was decided that these would need to be scanned at a higher resolution. Copies of the original prints are held at the US Forestry Service Institute of Tropical Forestry in Hilo, Hawaii with rescanning of the prints at 1200 dpi kindly conducted by Mr Thomas Cole.

Comparison of the 1944 aerial images and 2012 satellite image was done in collaboration with Dr Arthur Webb of the Oceans and Islands Programme of the Secretariat of the Pacific Community Applied Geoscience and Technology Division (SPC-SOPAC).

A total of 21 of the 1944 scanned aerial images were georeferenced and rectified against the 2012 satellite image using Erdas Imagine 2013 software. For each scanned print over one hundred matching locations between the 1944 image and the 2012 satellite image were identified to rectify the 1944 image to the satellite image. If the rectification was not to a satisfactory accuracy the process was repeated.

Once all images had been rectified the shoreline vegetation line was digitised for both the 1944 and 2012 images and the shorelines compared. The quality of the 1944 imagery was not sufficient to ass quantitatively shoreline change but general patterns of change can be observed.

The figures below show the general shoreline changes between 1944 and 2012 around coastline of Kosrae:

- The image on the left shows the rectified 1944 aerial image with the digitised 2012 shoreline (red line). Where:
  - The red line is seaward of the shoreline shown in the 1944 aerial image, the coastline has built out (accreted) between 1944 and 2012.
  - The red line is landward of the shoreline shown in the 1944 aerial image, the coastline has eroded between 1944 and 2012.
- The right hand image shows the 2012 satellite image with the 1944 digitised shoreline (orange line). Where:
  - The orange line is seaward of the shoreline shown in the 2012 satellite image, the coastline has eroded between 1944 and 2012.
  - The orange line is landward of the shoreline shown in the 2012 satellite image, the coastline has built out (accreted) between 1944 and 2012.

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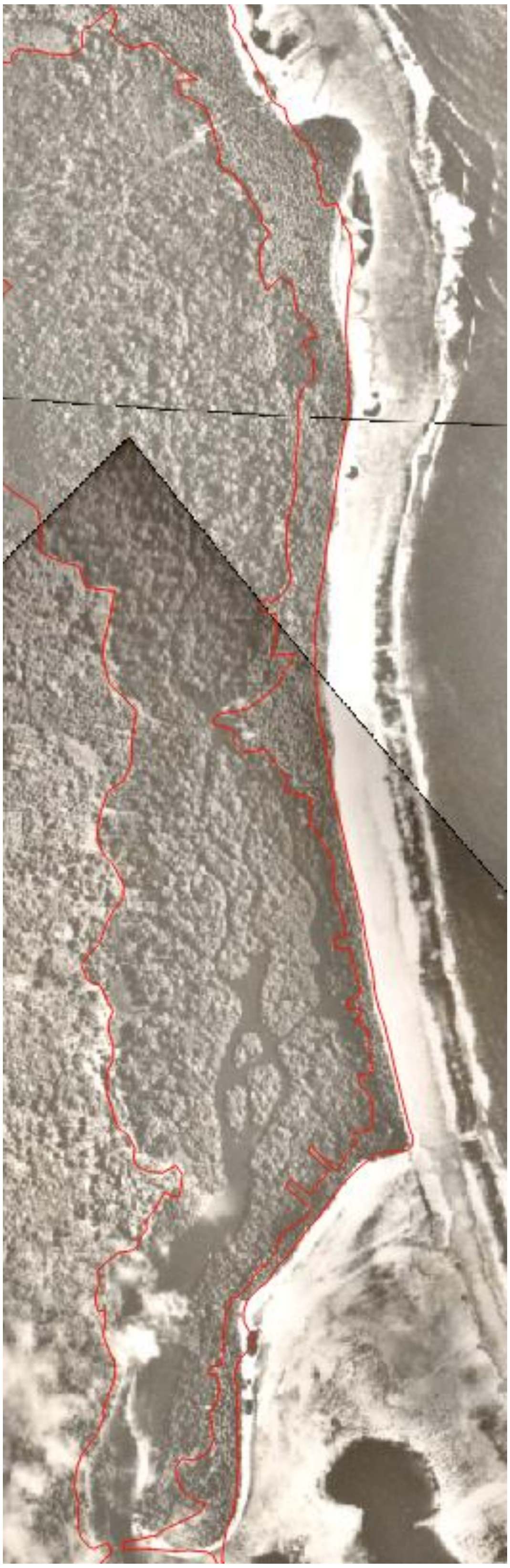
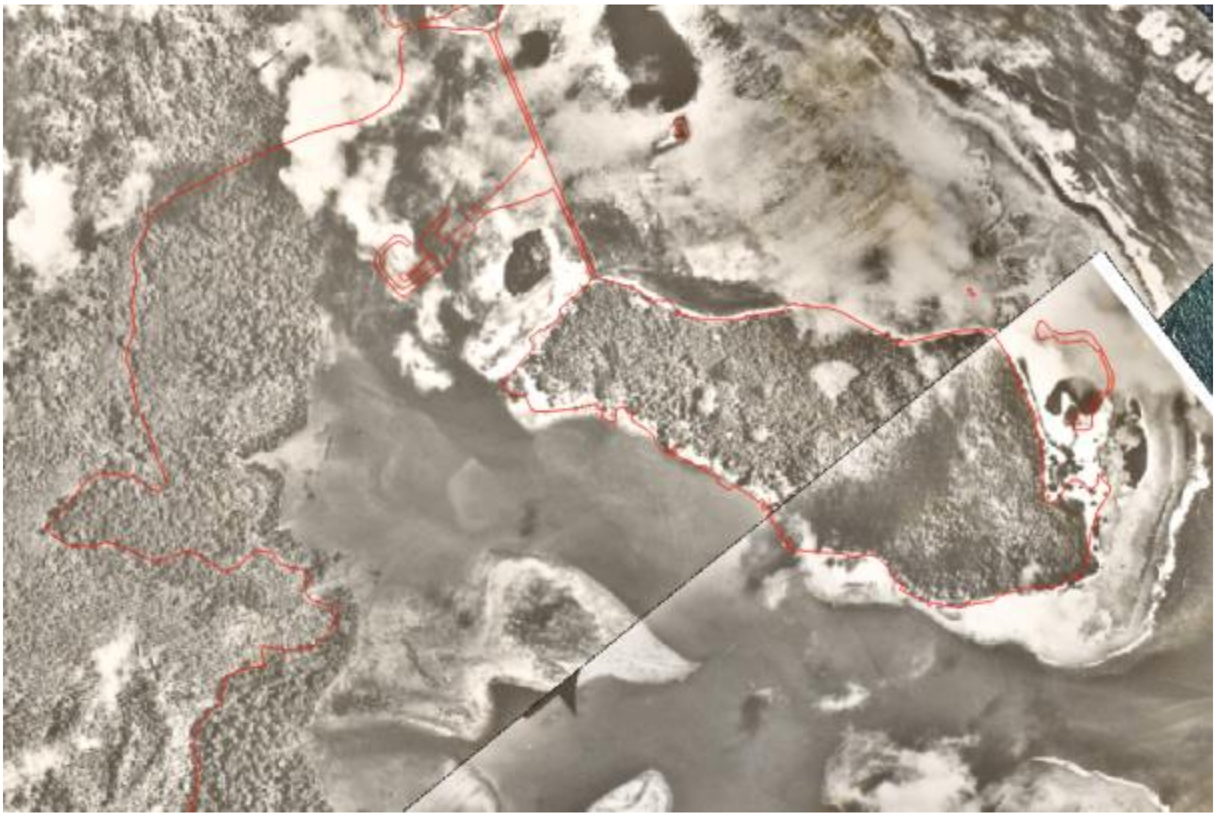
Lelu: Finfokoa to Finpukal

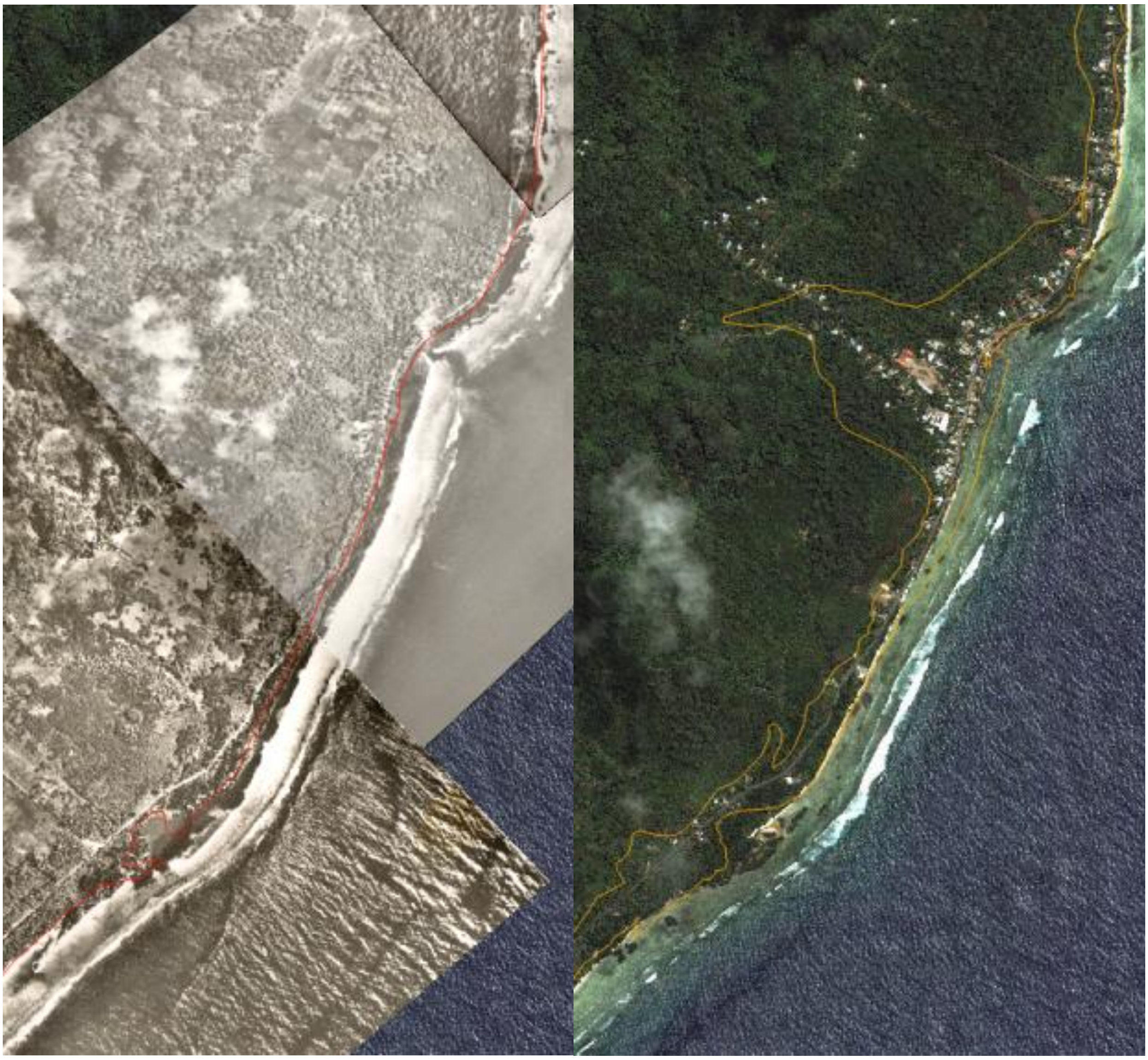


Lelu: Lelu Island and Tofol



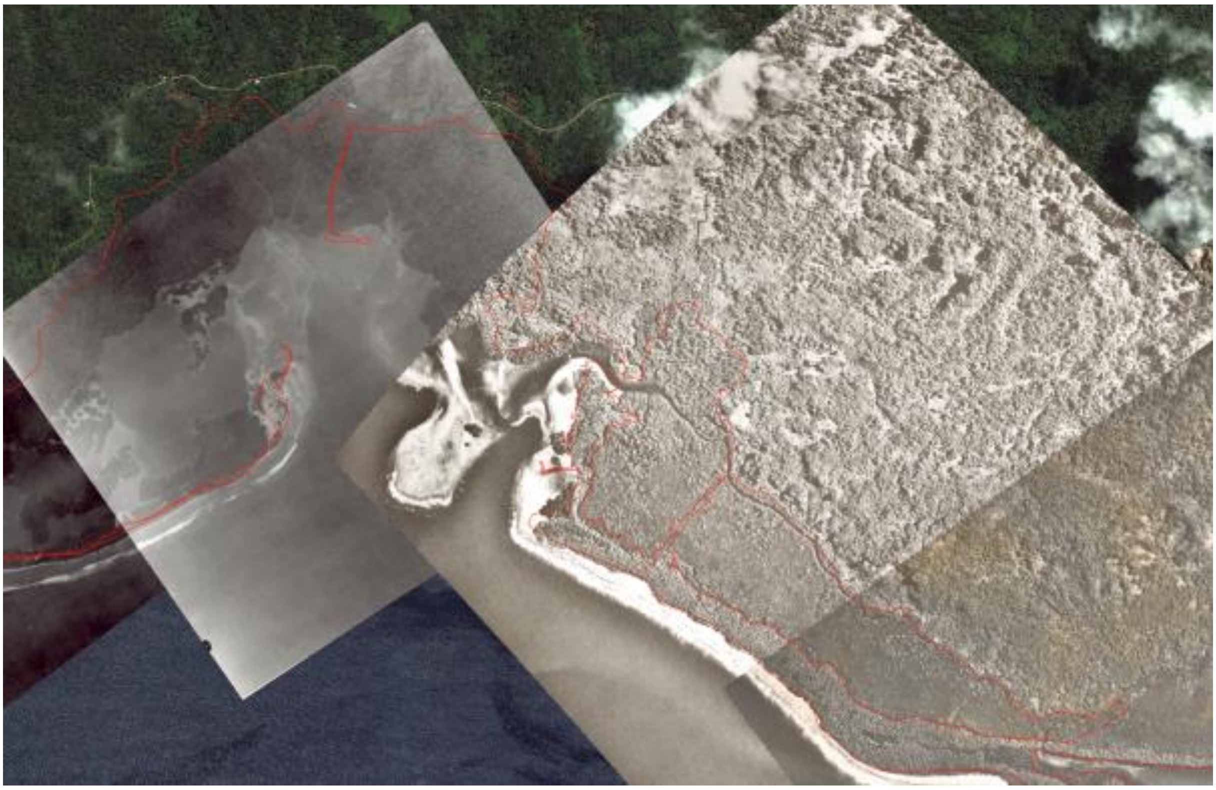
Lelu: Tafuyat to Pilyuul

Malem: Yewak to Yeseng

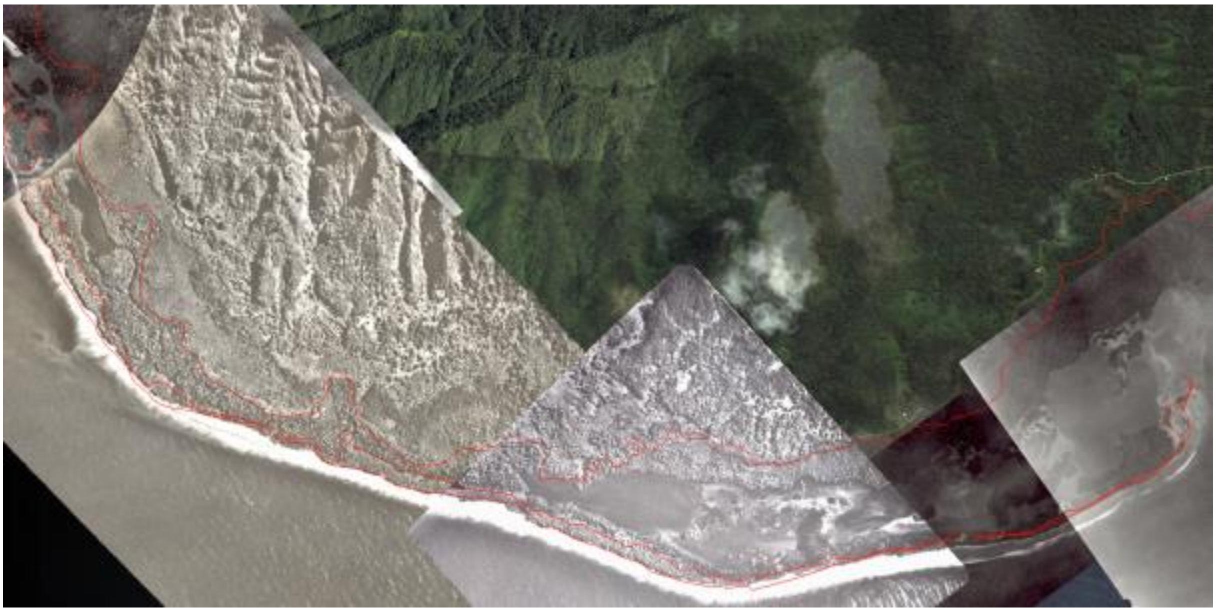


Malem: Mosral to Kuplu

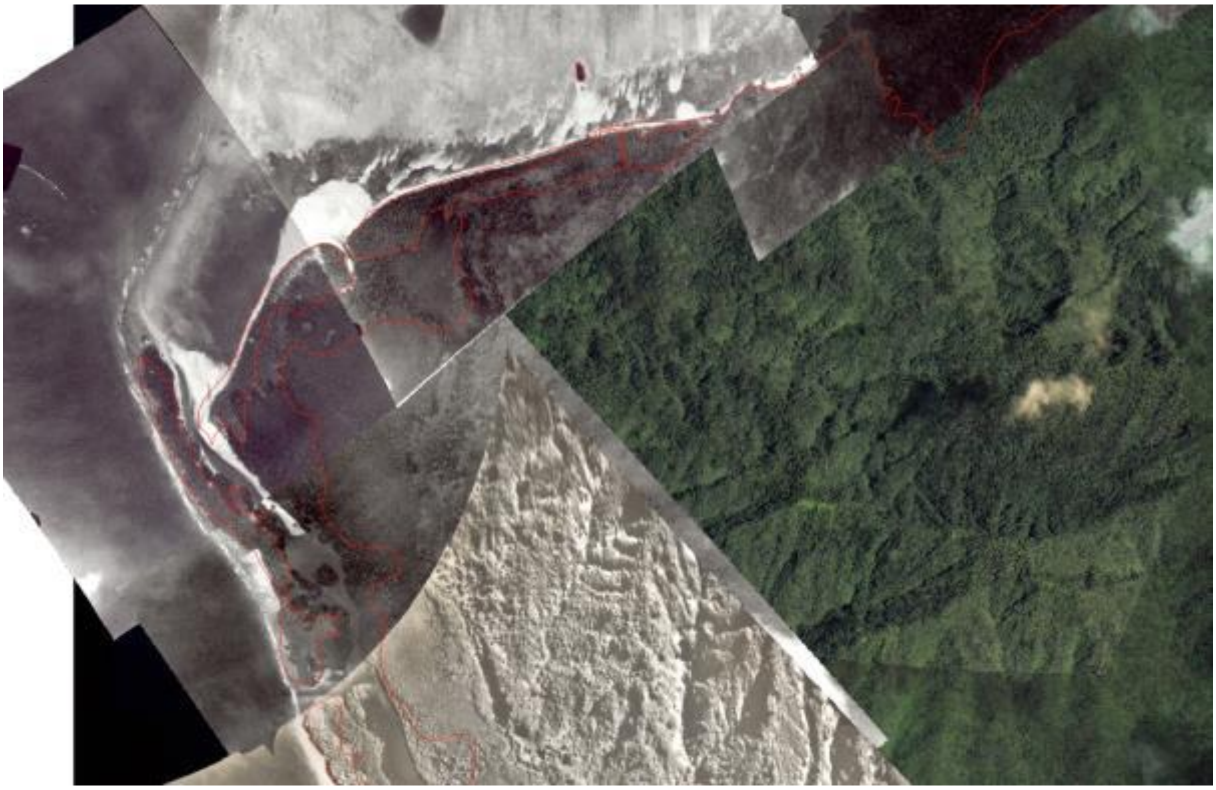
Utwe: Kuplu to Utwe Ma

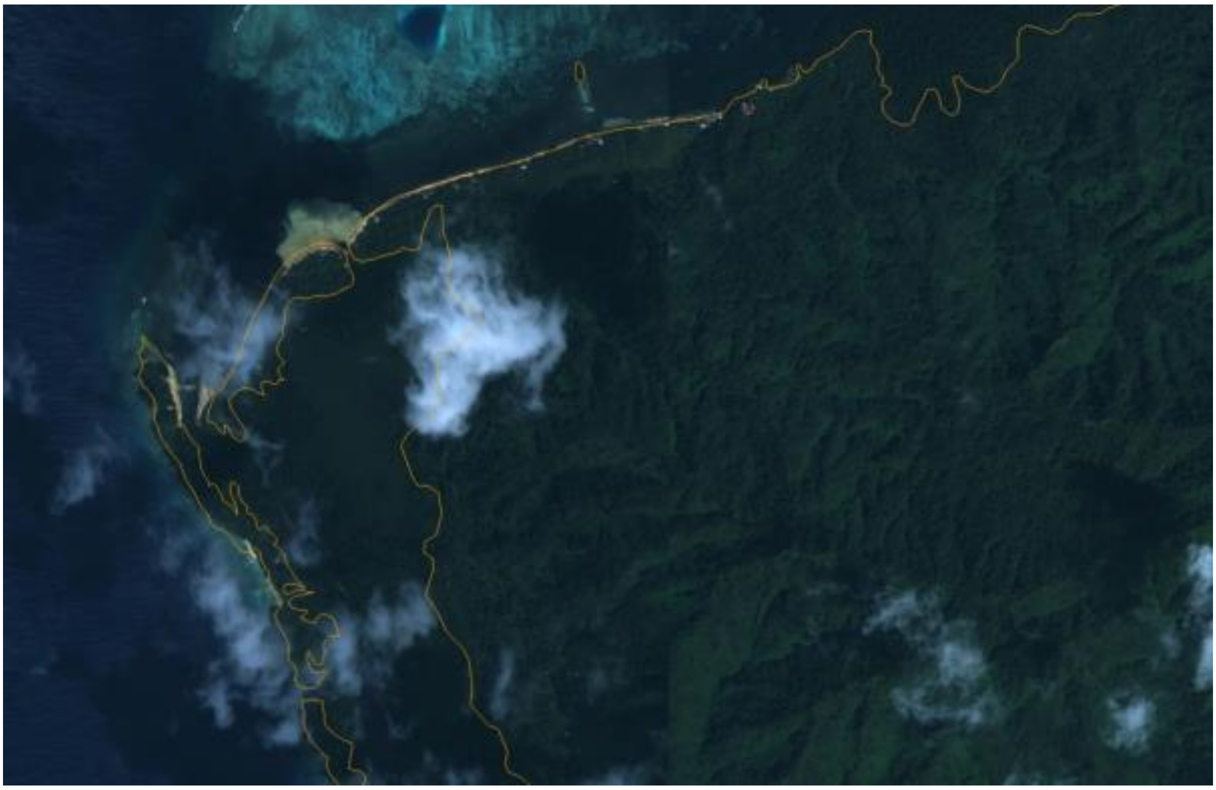


Utwe: Utwe Ma to Tukunsru

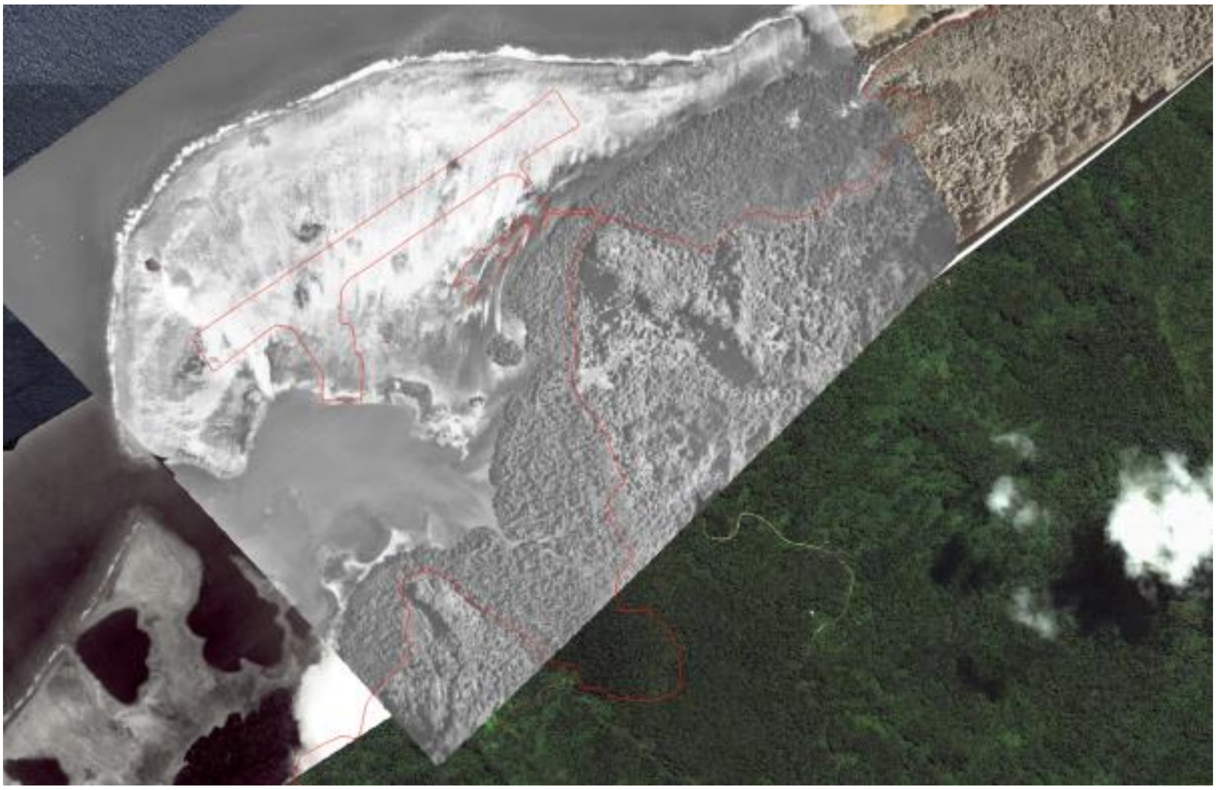


Walung: Tukunsru to Mwot





Tafunsak: Okat



Tafunsak: Tafunsak to Finaunpes

Appendix C An overview of coastal inundation of Kosrae

Flooding of land from the sea on Kosrae tends to occur episodically due to three types of event, Table C-1. Further information on sea-level components, variability and change on Kosrae are provided in Appendix D.

Table C-1: Types of coastal-related inundation events on Kosrae and an indication of their relative frequency of occurrence.

Inundation event	Indicative frequency of occurrence
Higher than normal high tide levels.	▪ Every year: – Particularly between December and February – Much higher than normal every 2 to 4 years during period of La Niña
Large swell waves caused by distant storms in the north Pacific.	▪ Once in a generation
Typhoon events that track close to Kosrae.	▪ Once in a lifetime: – the last cyclone to directly impact Kosrae was in 1905 outwith the living memory of all current residents

High (King) tides

Flooding of land on Kosrae most commonly occurs due to higher than normal high tide levels, or high tides occurring at the same time as moderate to large wave conditions. With the exception of storm or typhoon-related flooding events (see next sections) which are rare on Kosrae, coastal flooding tends to most commonly occur:

- Between November and February and June to August.
- During strong phases of La Nina.

This is because high water levels, and hence inundation experienced around Kosrae, tend to occur when a number of components combine:

- The most significant is the astronomical tide - the regular rise and fall of water level due to the influence of the moon and the sun. Tide levels on Kosrae tend to be higher between November and February and between June and August.
- The influence of El Nino and La Nina oscillations. During strong El Nino events, sea levels around Kosrae tend to be depressed. During strong La Ninas, the opposite occurs and sea levels tend to be higher. This can cause variations in sea-level of up to 0.25 m (10 inches) or more.
- The effect of continuous north-east trade winds which tend to increase tide levels between November and April.

Hence when larger tides, combine with La Nina conditions and north easterly trade winds, as occurred around December/January 1999/2000 (Figure C-1) and November 2007 to February 2008, higher sea-levels occur and inundation and coastal damage is more likely.

Figure C-1: High tide levels at Lelu during December 1999 (left) and Utwe during December 2010 (right).

The main locations where high tides alone cause inundation problems to property or infrastructure tends to be where land has been reclaimed in the harbour areas or within the mangroves sheltered from waves:

- Lelu Island – Much of the reclaimed areas on Lelu Island have land levels that are barely above present day high tide levels. Flooding of land during December and January commonly occurs adjacent to the canal sections in Lelu.
- Pukusruk – Landward of the road, many properties are built on reclaimed land in to the mangrove with levels barely above high tides.
- Utwe village – Much of Utwe village lies on reclaimed land on top of a sand spit. Again the level of the land is barely above present day high tide levels.
- Walung – The section of coast between Insiaf and Pilyuul (old elementary school) is largely sheltered from waves with the level of the coastal berm barely above high tide levels.
- Tafunsak – The communities at Malsu, Yekula, Finfukul and Sialat that are located on land that is lower than the crest of the beach berm / coastal road, and overwashing of the seawall at Finfukul on to the road.

On the open, generally eastern-facing, coastlines of Lelu and Malem Municipalities, high tides and tradewind generated waves combine to cause overwashing of the coastal berm. This is where larger waves reach the shoreline due to deeper water depths over the reef flat, run-up the beach or seawall and overwash the coastal berm behind the beach.

The height of the coastal berm along this eastern coast is generally related to the height of waves experienced along it:

- Along the Pukusruk coast (Finaunpes to Sroanef) and from Tenwak to Malem, the coastal berm tends to be higher and wave overtopping less of an issue unless waves are higher than normal.
- From Shroanef to Finpukal and Malem south to Mosral, the coastal berm tends to be lower and wave overwashing tends to occur when normal tradewind

waves coincide with most spring high tides, for example at Fukrin and Pal in Malem (Figure C-2).

It is on the frequency and magnitude of high-tide related flooding that sea-level rise will have the most significant impact.

Figure C-2: Wave overwashing at Fukrin in Malem during February 2000 (left) and high tide wave overtopping of the seawall at Malem village during December 2010).

Inundation from swell wave events

The coastal flooding that affected the northern coastline (Tafunsak, Walung and parts of the Lelu coastline) of Kosrae during the 8 and 9 of December 2008 (Figure C-3) was due to large swell waves generated by a severe storm far to the north of Kosrae[5]. The inundation extent along the Tafunsak coastline is shown in Figure C-4 which shows some particular characteristics:

- The seawall at Tafunsak did not provide any greater protection to the land behind from overwashing waves than the beach sections of coast.
- The extent of inundation was worst over the low-lying land adjacent to the stream outlets at Yekula, Malsu (Senny's Store) and at the old outlet of Infal Mutunte in Tafunsak village)
- Inundation extent was least where there was a largely natural vegetated buffer behind the beach (e.g. between Finaunpes/Inkoeya and Sialat) or seawall (such as west of the church in Tafunsak).

[5] Further information on this event is available at: http://kosraecoast.com/?page_id=158

Figure C-3: Debris from overwashing of the seawall at Tafunsak (left) and at Malsu (right) during the swell event of 8-9 December 2008.

Figure C-4: Extent of inundation along the Tafunsak coastline during the swell event of 8-9 December 2008. Inundation extent information courtesy of KIRMA.

These large swell events, due to particular storm conditions well north of Kosrae, appear to happen infrequently and generally impact on the northern coastline (Walung, Tafunsak and to a lesser extent the Pukusruk coast of Lelu). Known events include:

- 1979: A swell wave event damaged the old school buildings in Walung. This is likely to have been the same event in late November 1979 that caused much damage in the Marshall Islands[6].
- 1969: In December 1969 two storms in the North Pacific between 40ºN and 50ºN resulted in swell waves of between 4 m and 6 m (12 to 18 ft) travelling over 7000 km to the south. This is likely to have affected the north coast of Kosrae as well as the northern coasts of islands in Kiribati, Tuvalu, Samoa, Cook Islands and Tahiti.
- 1961: On October 13 and 14 large waves inundated parts of Walung causing much damage to property at Insiaf and Leap. The waves caused a coconut tree to fall resulting in the deaths of two small children.

[6] http://marshall.csu.edu.au/Marshalls/html/typhoon/typhoon.html

Typhoons

Despite no typhoon directly affecting Kosrae since 1905, there is a very real risk that should a typhoon or severe tropical storm track close to Kosrae, catastrophic damage would occur.

Table C-2: Summary of past cyclones experienced on Kosrae.

Year	Details
1780?	
1835/37?	Severe typhoon
1874	15 March: Severe storm or typhoon from the south sinks Bully Hayes ship.
1900?	Typhoon
1891	3-4 March: Typhoon from the south through Kiribati, Kosrae, Pingelap, Mokil, Pohnpei, Chuuk and the Mortlocks. All but six houses left standing and virtually all breadfruit and coconut trees destroyed.
1900	
1905	19-23 April: Typhoon lasting seven hours with much destruction of property and trees.
1986	19 May: Typhoon Lola passed to the north west of Kosrae.
1992	5 January: Typhoon Axel passed 75 km north of Kosrae. Maximum sustained winds of up to 80 knots were recorded resulting in severe crop losses, trees and vegetation damaged, and some wooden and tin-roofed structures destroyed.
2001	17 December: Tropical Storm 31W (Faxia) tracked west of Kosrae causing overwashing on the east coast.

Many of the typhoons that affect Guam and the western FSM islands originate in the region around Kosrae as tropical depressions and tropical storms, developing into full typhoons further to the west and north. Typhoons tend to occur between June and November and are more likely to track closer to Kosrae during El Niño phases.

Whilst strong winds are likely to cause most of the damage, higher sea levels due to storm surge (only if the cyclone tracks close or directly over Kosrae), and large waves (which also increases the water level at the shoreline due to wave set-up on the fringing reef) would cause significant wave overwashing and inundation of the immediate coastal margins. Inundation would also be exacerbated by heavy rainfall which would cause flooding of low-lying swamp and

The location and severity of wave overwashing, inundation and resulting damage depends on the track of the typhoon relative to Kosrae. Typically typhoons track in a westerly direction and are more likely to occur to the north of Kosrae

Table C-3: General cyclone tracks and resulting areas on Kosrae most likely to be affected by inundation.

Typhoon track (westerly movement)	Areas most likely to be inundated
North of Kosrae	▪ North-east Lelu, Tafunsak and possibly Walung coastlines.
South of Kosrae	▪ All of the Utwe and Malem coastline and possibly parts of the Lelu coastline. ▪ A cyclone tracking just south of Kosrae is likely to cause the most significant inundation-related damage
Directly over Kosrae	▪ Inundation-related damage would be most significant on the right-hand side of

Typhoon track (westerly movement)	Areas most likely to be inundated
	the typhoon track. ▪ The most significant inundation is likely to occur along the Malem and/or Lelu coastlines. ▪ Tafunsak, Walung and Utwe coastlines may also experience inundation as the typhoon passes over Kosrae.

Virtually everyone on Kosrae lives on land that is less than 4m (12 feet) above mean sea level. All of this land is at very high risk from the impacts of a typhoon with there being potential for significant loss of life and destruction of a high percentage of residential property from the effects of wind and storm surge and waves.

The areas potentially at greatest risk are those parts of the coastline fronted by a narrow reef with low-lying swamp land behind a narrow strip of coastline, such as:

- Finfokoa to Pukushruk in Lelu.
- Virtually all of the Malem coastline.
- The southern part of Utwe village.

Furthermore, all of Kosrae's infrastructure (roads, utilities) are located on low land close to the coastline. If a typhoon were to directly affect Kosrae there would be significant damage to the road and loss of much power and telecommunication infrastructure. Existing coastal defenses will not protect the coastline, or the land, property and infrastructure behind, from the effects of high water levels and waves caused by a typhoon.

A typhoon or severe storm could also destroy much of the mature mangrove areas such as those at Okat and Yela and have a short term impact on the coral reef. However, typhoon events are also a vital natural process in limiting long-term coastal erosion by re-supplying sand, cobbles and coral rubble to the reef flat and coastline from the coral reef.

Appendix D Climate change and sea-level rise

Background

The most recent assessment of past and potential future climate change was carried out by the Australian funded Pacific Climate Change Science Program. For the FSM[7] this concluded that for the course of the 21st century:

- Surface air temperature and sea-surface temperature are projected to continue to increase (*very high* confidence).
- The intensity and frequency of days of extreme heat are projected to increase (*very high* confidence).
- Ocean acidification is projected to continue (*very high* confidence).
- Mean sea-level rise is projected to continue (*very high* confidence).
- Annual and seasonal mean rainfall is projected to increase (*high* confidence).
- The intensity and frequency of days of extreme rainfall are projected to increase (*high* confidence).
- The incidence of drought is projected to decrease (*moderate* confidence).
- Tropical cyclone numbers are projected to decline in the tropical North Pacific Ocean basin (0–15ºN, 130ºE –180ºE) (*moderate* confidence).

The assessment also concluded that a warming trend was evident for Pohnpei and Yap in annual and seasonal mean air temperatures for the periods 1950–2009 and 1951–2009 respectively but that annual and seasonal rainfall trends were not statistically significant.

Sea levels have also risen within the FSM, with increasing global sea levels a well-established consequence of global climate change. The following sections provide background information on sea-levels and sea-level change on Kosrae

What influences sea levels around Kosrae?

The level of the sea around Kosrae is influenced by a number of components:

- The astronomical tide: The twice-daily rise and fall of water has the largest influence on the particular sea-level occurring at any time. High and low tide times and levels can be accurately predicted many years in advance Over a year, tide levels on Kosrae tend to be higher between November and February[8] (Figure D-1). Most coastal flooding occurs on Kosrae when larger than normal waves coincide with high tide conditions. However, tide levels can be elevated (or lowered) by a number of factors outlined below.

[7] http://www.cawcr.gov.au/projects/PCCSP/publications1.html
[8] http://www.kosraecoast.com/november%20to%20february%20coastal%20damage.pdf

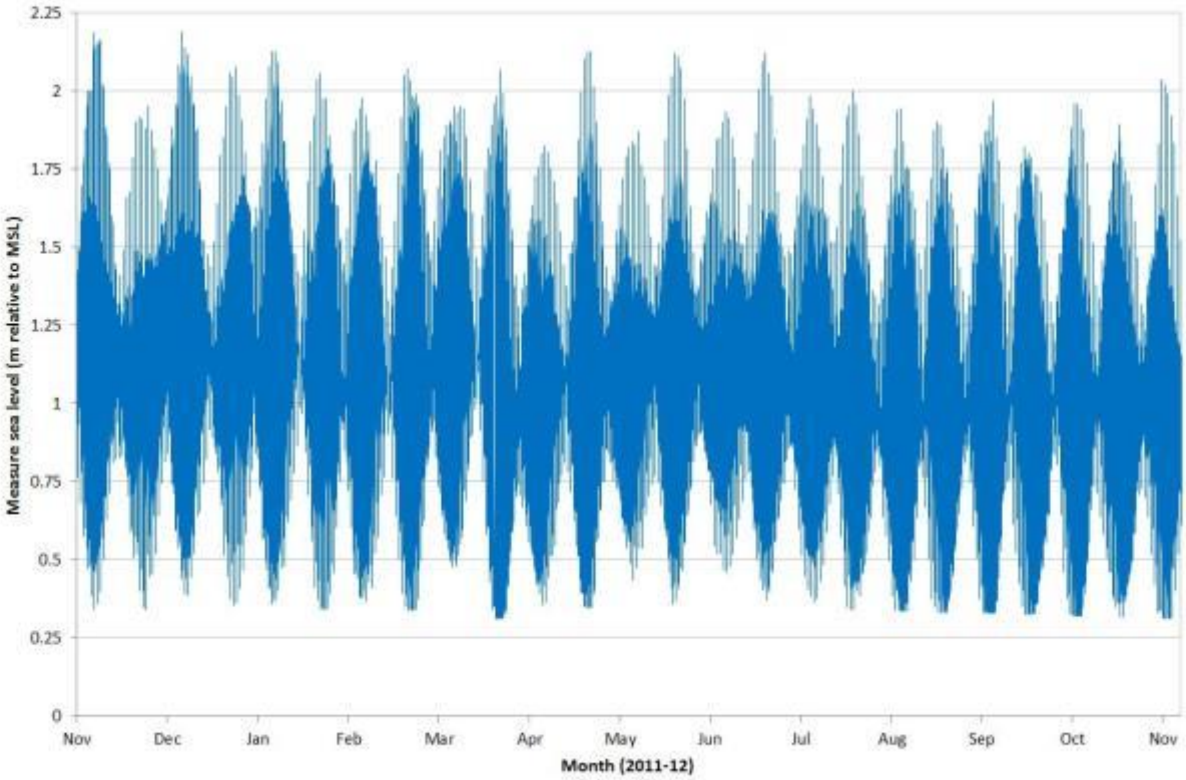


Figure D-1: Measured sea levels within Lelu Harbour between 20 November 2011 to 20 November 2012.

- The 2 to 5 year El Niño Southern Oscillation (ENSO) cycle: During El Niño phases sea levels around Kosrae are pushed down (resulting in lower high tide levels), and conversely during La Niña phases sea levels are pushed up, (resulting in higher high tide levels), Figure D-2. These effects can occur over a number of months to a year or more and can result in reductions in sea levels during strong El Niños of up to 20 to 25 cm (8 to 10 inches) and increased in sea levels during string La Niñas of up to 15 to 20 cm (6 to 8 inches), Figure D-3. However for about 80% of the time fluctuations in mean level of the sea are within ±0.1 m (±4 inches).

- Decadal / Inter-decal Pacific Oscillation: Over longer 20 to 30 year cycles a climate-ocean feature known as the Pacific Decadal Oscillation (DPO) or Interdecadal Pacific Oscillation (IPO)[9] influences the frequency and intensity of ENSO events. Between about 1978 to 2000, the IPO was in a phase where El Niño events were stronger and more frequent, hence sea levels over this period tended to be lower on average. Since around 2000 the IPO has been in a phase where La Niña events have been more common resulting in more frequent and higher sea levels relative to the twenty year period prior to 2000.

[9] The Pacific Decadal Oscillation and Interdecadal Pacific Oscillation are similar but not exactly the same phenomena and affect the northern and southern Pacific differently.

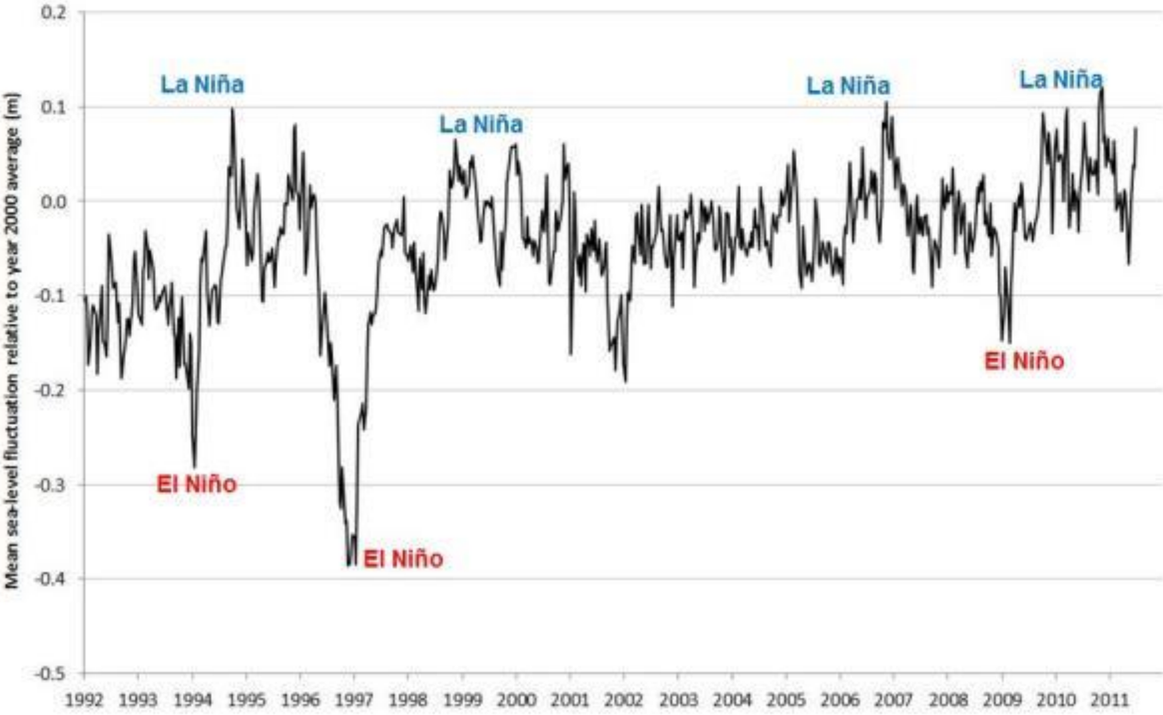


Figure D-2: Mean sea-level fluctuations between 1992 and 2012 for Kosrae showing effects of El Nino and La Nina periods on sea levels. Sea level anomalies measured by satellite and downloaded from http://sealevel.colorado.edu/content/interactive-sea-level-time-series-wizard

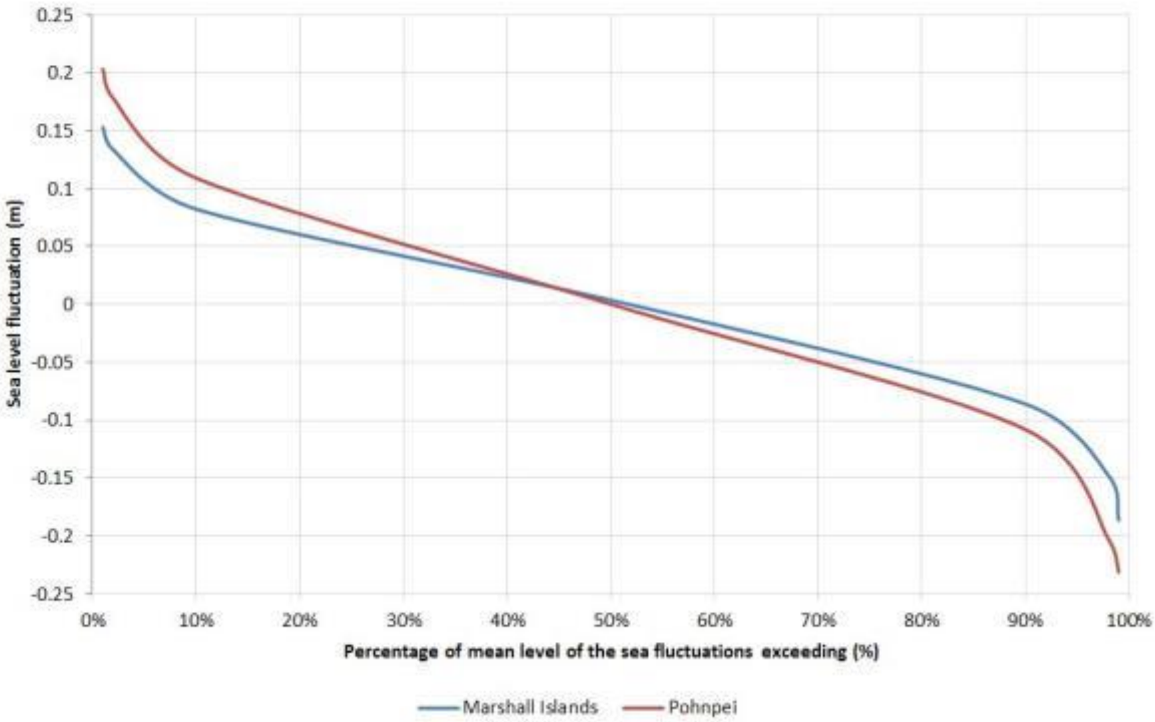


Figure D-3: Percentage exceedence in mean level of the sea fluctuation for Pohnpei and the Marshall Islands.

- Storm surge: Storm surge is the temporary increase in sea level over 1 to 3 days due to a reduction in atmospheric pressure and influence of wind on the sea surface. Due to the lack of severe storms and cyclones affecting Kosrae, storm surge only ever has a very minor influence (few cms) on sea levels. Only if a severe typhoon was to pass close to Kosrae would storm surge result in any significant increase short-term in sea levels.
- Wave setup: On ocean shorelines, the effect of large waves breaking on the seaward edge of the reef raises water levels over the reef flat. This has a much larger influence on sea levels along the ocean shorelines than storm surge. This can raise reef flat water levels by up to about 1 m (more during a large typhoon event), particularly during large swell conditions such as the event that affected the Tafunsak coastline on the 8-9th December 2008.
- Sea-level rise: The long-term increase in sea levels due to increasing global temperatures resulting primarily in a warming of the oceans causing them to expand, and melting or discharge of ice sheets and glaciers on land.

How much have sea levels risen around Kosrae?

Increasing global sea levels are a well-established consequence of global climate change. Measurements of mean sea-level changes over the last two centuries have primarily come from long-term data from tide gauges mounted on land, supplemented since around 1993 by measurements made by satellites. The longest records suggest that the rate of rise of global mean sea levels began to increase from around the early to mid-1800s compared with a relatively stable sea level in the preceding century. Over the 20th century global mean sea levels have increased by on average 0.17 m ±0.05 m (1.7 mm/yr ±0.5 mm/yr). More recently, Church & White (2011) show the global-average trend up to 2009 rose slightly from 1.7 mm ± 0.2 mm/year (starting from 1900) up to 1.9 mm ± 0.4 mm/year (starting from 1961).

The rate of rise of sea levels across the globe is far from uniform. In some places, notably the western Pacific, sea levels have been rising rapidly (> 10 mm a year in some places), in others it has fallen. Since 1993 these regional differences have been pleasured by satellite and are shown in Figure D-4. The spatial variability in the Pacific, resulting in higher than global average rates in the western Pacific is not necessarily an indication of an increasing rate of sea-level rise. Rather it is largely due to tradewind and oceanographic influences predominantly attributable to inter-decadal variability (Meyssignac et al. 2012), rather than a long-term higher rate of sea-level rise.

Sea-levels are also measured at particular locations by sea-level gauges. In Kosrae a sea level gauge was installed in Lelu Harbour in November 2011. However, there needs to be at least around 25 years of sea-level records before some judgement of long-term sea-level rise rates can be made. Longer-records, albeit still less than 25 years, are available from the SEAFRAME tide gauge network for surrounding islands to Kosrae (). Given the length or records, particularly at Pohnpei there will continue to be monthly and annual variations in the rate of sea-level rise over the foreseeable future.

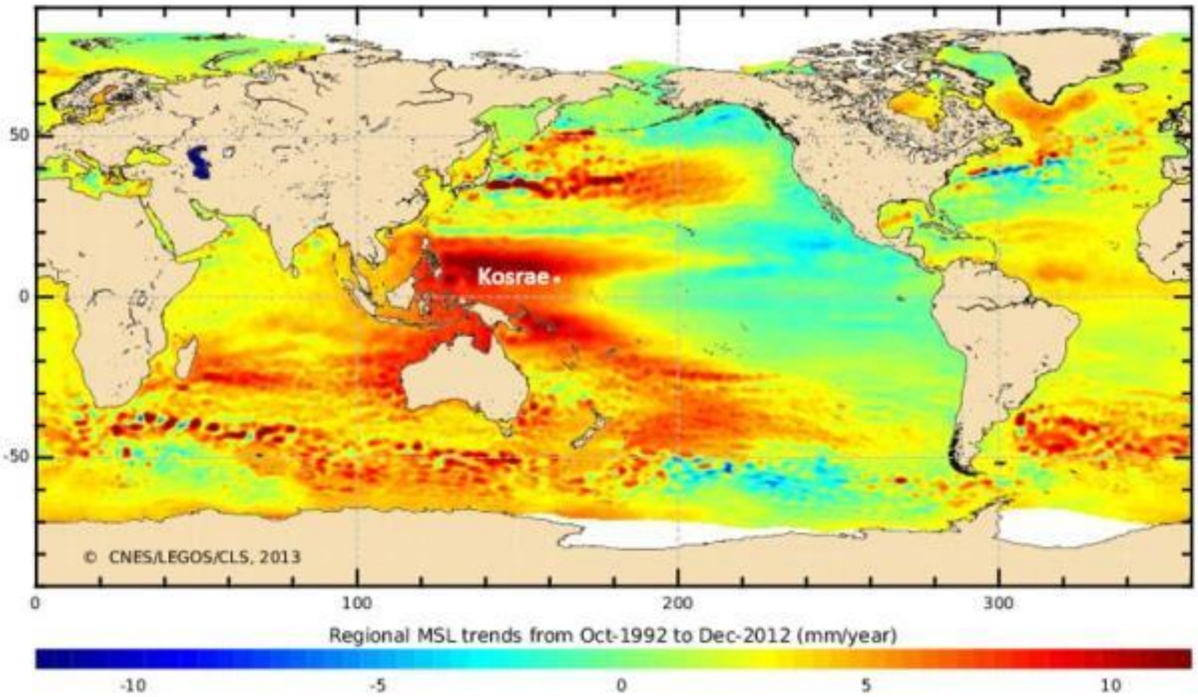


Figure D-4: Global distribution of the rate of absolute sea-level rise between October 1992 and December 2012 as measured by satellite altimeter data. Source: http://www.aviso.oceanobs.com/en/applications/ocean/mean-sea-level-greenhouse-effect/regional-trends.html.

Table D-1: Sea-level rise rates on surrounding islands to Kosrae from the SEAFRAME tide gauge network. Source: http://www.bom.gov.au/ntc/IDO60101/IDO60101.201206.pdf.

Island	Period of record	Rate of sea level rise (mm / year)
Pohnpei	Dec 2001 – Jun 2012	+17.8
Marshall Islands	May 1993 – Jun 2012	+5.7
Nauru	Jul 1993 – Jun 2012	+4.0

Is storm surge increasing?

Storm surge (the short term increase in sea level due to low atmospheric pressure and influence of wind) is a very minor component (except if a typhoon were to occur) of the sea levels experienced in Kosrae. There is nothing obvious to suggest that storm surge has increased in magnitude or frequency or will do so.

Are king tides becoming more frequent?

King tide is a popular name referring to any high tide or sea level that is well above an average height. Over much of the last ten years or so the perception is that king tides have become more frequent. This is indeed likely and is due to a combination of an increased frequency of La Niña events (compared to the period prior to 2000) which has pushed sea levels up and is further exacerbated by sea-level rise.

Long-term sea-level rise will continue to push sea levels higher resulting in high tide levels increasingly exceeding what may be presently considered a king-tide level.

How much sea level rise will occur in the future?

Sea levels will continue to rise over the 21st century and beyond. The basic range of projected global mean level rise estimated in the Intergovernmental Panel for Climate Change Fourth Assessment Report (AR4) is for a rise of 0.18 m to 0.59 m (relative to the 1980-1999 average) with potentially an additional 0.1 to 0.2 m in the upper estimates due to additional ice sheet discharge if contributions to sea-level rise were to grow linearly with global temperature change for each emission scenario (Figure D-5). It was also clearly stated that larger contributions from the Greenland and West Antarctic ice sheets over this century could not be ruled out. Subsequently, the increasing component of present-day sea-level rise due to ice-sheet losses has led to a number of more recent estimates of sea-level rise over the 21st century.

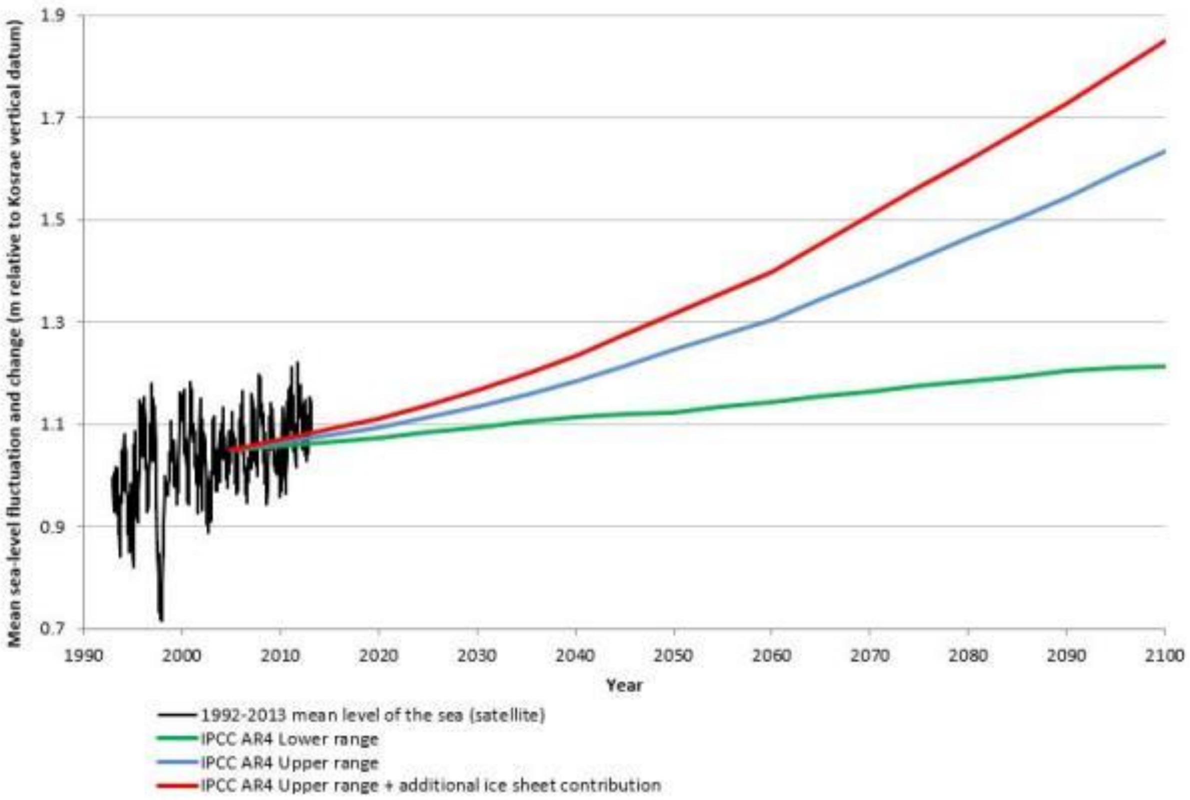


Figure D-5: Mean Level of the sea measured at Kosrae by satellite between 1992 and 2013 and the range in IPCC AR4 sea level projections out to 2100. All levels are relative to Kosrae vertical datum based on a comparison between mean level of the seas from satellite and the Kosrae tide gauge at Lelu between November 2011 to November 2012. The sea level projections have been adjusted to 2000-2009 average.

Sea levels will continue to rise primarily because of thermal expansion within the oceans and loss of ice sheets and glaciers on land. How much sea-level rise occurs depends on how humans continue to live and emit greenhouse gases. However, even if greenhouse gas emissions were stabilised today, sea levels would continue to rise. Indeed sea levels to about 2050 are relatively insensitive to changes in emissions over this timeframe because of the long time it takes the oceans to respond to changes in atmospheric temperatures, but future changes and trends in emissions become increasingly important in determining the magnitude of sea level rise beyond 2050.

How much sea level rise should we allow for when planning development and infrastructure?

As we don't know exactly how much greenhouse gases will be emitted in the future and what the response of the large ice sheets in Greenland and Antarctica will be to rising temperatures, it is difficult to provide a best or upper estimate of sea-level rise over this century.

Deciding on an appropriate sea-level rise amount to accommodate for a particular decision depends on a pragmatic decision based on a balance between the level of risk that is willing to be accommodated and the associated costs of addressing that level of risk. Essentially it comes down to a balanced consideration between:

- The possibility of a particular sea-level being reached within the planning timeframe or design life. For example over the next 100 years there is a possibility that mean sea levels could rise by 2 m but it is much less likely than sea levels rising by 1 m. However, we cannot say for certain for example whether a 0.7 m rise is more or less likely than a 1 m rise over this time period.
- The associated consequences and potential adaptation costs. For example the consequences of a 2 m rise in sea level are in most cases likely to be much greater than a 1 m rise in sea level, likewise the costs of accommodating a 2 m rise in mean sea level would be much greater than a 1 m rise.
- How any residual risks would be managed for any consequences if sea-level rise occurs at a quicker rate than that accommodated.

As a pragmatic start,Table D-2 provides suggested sea-level rise amounts to be accommodated for coastal-related development, infrastructure and hazard planning activities for the remainder of this century.

Table D-2: Suggested sea-level rise allowances relative to the present day for development planning and infrastructure design. The present day is assumed to be the 2000-2009 average.

Timeframe / Design life	Generational timeframe	Sea level rise (m)	Sea-level rise (feet)
2030s	1 generation	0.15	0.5
2050s	2 generations	0.30	1
2070s	3 generations	0.60	2
2090s	4 generations	0.90	3

How much more frequently will present-day high tide levels occur in the future?

Using the sea-level rise allowances over the four different future timeframes in Table D-2, Figure D-6 shows how frequently the high tide levels are exceeded in Kosrae. A high tide level of 2 m (relative to vertical land datum on Kosrae) is presently a very high tide. This level is currently exceeded by on average 2.8% of all high tide levels. By the:

- 2030s, this high tide level of 2 m will be exceeded by 12% of all high tides

- 2050s, this high tide level of 2 m will be exceeded by 27% of all high tides
- 2070s, this high tide level of 2 m will be exceeded by 69% of all high tides
- 2090s, this high tide level of 2 m will be exceeded by 95% of all high tides

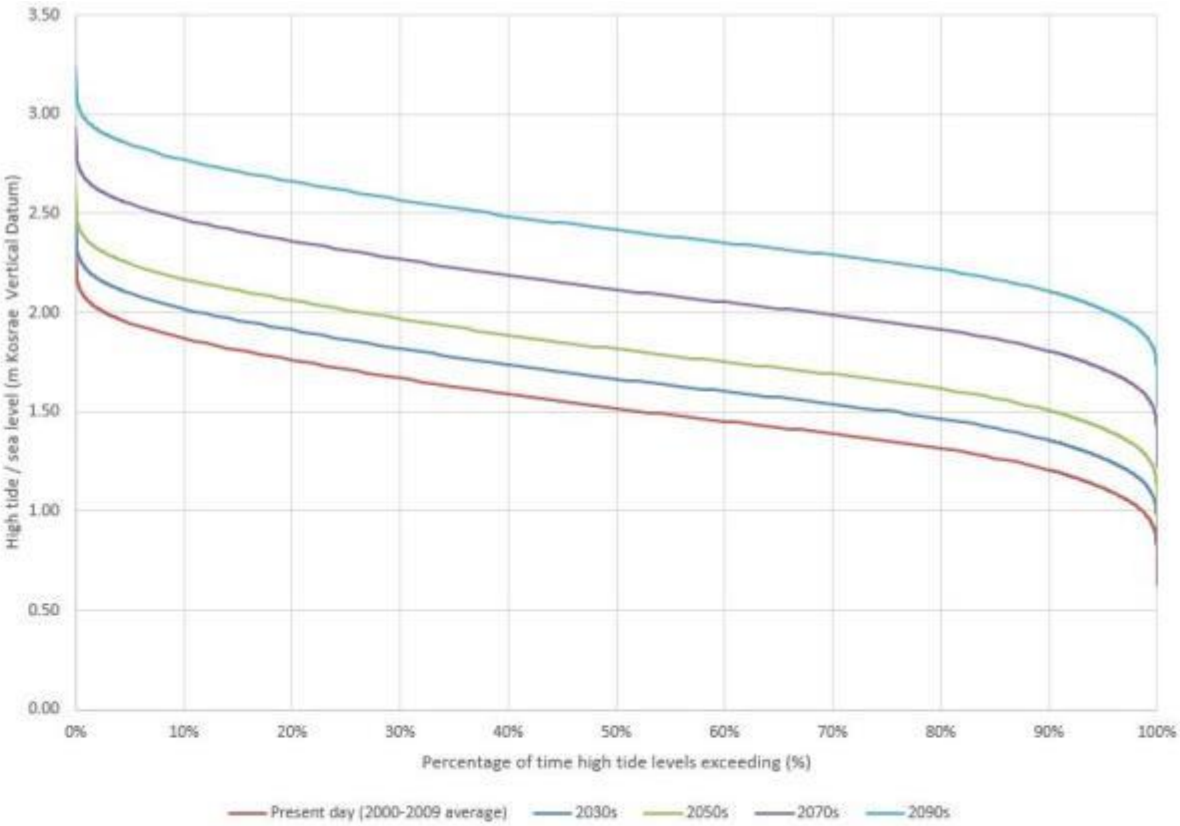


Figure D-6: High tide exceedence curves for the present day and for the 2030s, 2050s, 2070s and 2090s.

Essentially by the end of the century, assuming the sea-level rise rates indicated in Table D-2, virtually every high tide will be above what is presently considered a very high (king) tide level. Figure D-7 shows the same exceedence plot as Figure D-6 but with the levels in feet relative to Kosrae's vertical datum. Also shown is the level of the road at Tafuyat (solid black horizontal line) which, at a level of around 9 feet relative to the vertical land datum, is one of the lowest sections of the coastal road. The exceedence plot shows that for high tide and mean sea-level fluctuations along (i.e. not considering any wave overtopping), by the:

- 2070s, the road at Tafuyat will be inundated on the very highest of tides.
- 2090s, the road at Tafuyat will be inundated on average by 14% of high tides.

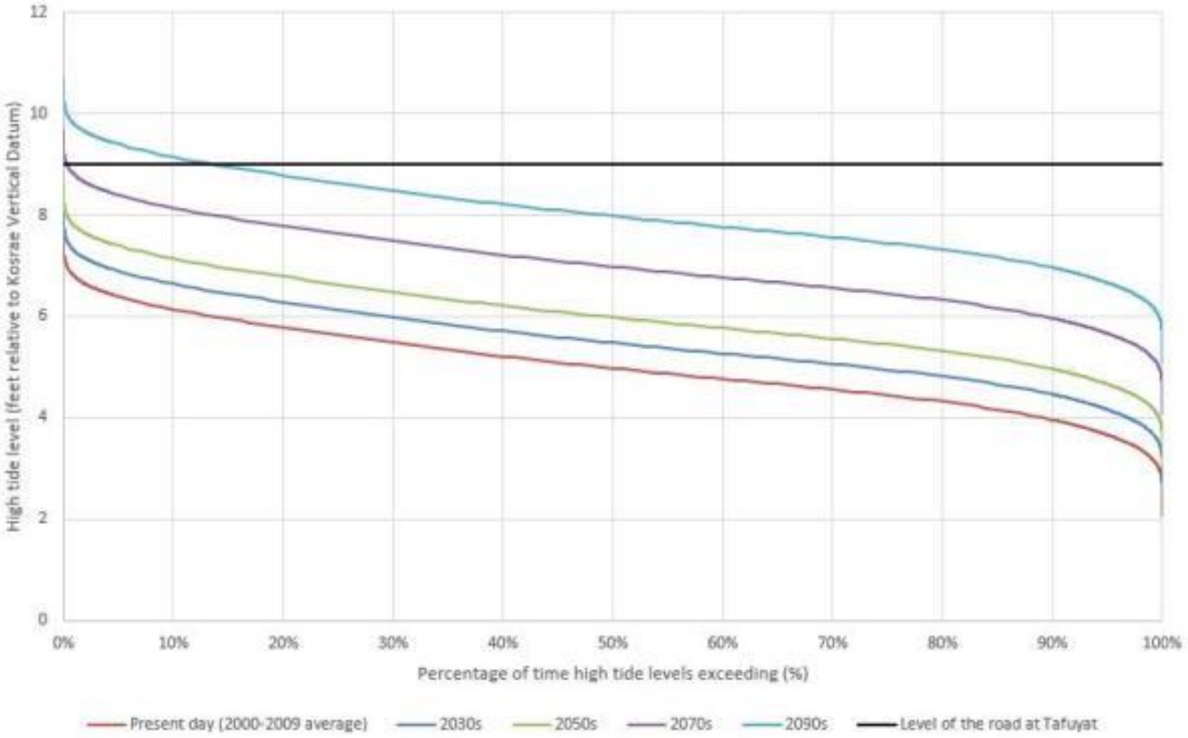


Figure D-7: High tide exceedence curves for the present day and for the 2030s, 2050s, 2070s and 2090s relative to the level of the road at Tafuyat.

What effects will climate change have on other factors influencing coastal hazards?

Much less is known about how climate change will affect other factors that influence coastal hazards (such as swell and wave conditions, storm frequency and intensity and influence of El Niño). However:

- Large swell events, such as occurred in December 2008, will occur occasionally in the future. Climate change is unlikely to have any noticeable change in the frequency of occurrence of such events (although sea-level rise may result in such events causing more significant or damaging inundation).
- A typhoon could potentially significantly impact Kosrae, most likely during an El Niño phase. At present there is little evidence to suggest that climate change will alter the potential for a typhoon to impact on Kosrae – indeed there is some indications that with climate change typhoons may track slightly further north. Whilst Kosrae has not directly experienced a typhoon for over a century there is still a small chance that a typhoon will impact Kosrae in the future.

How will sea-level rise affect overwashing of land and seawalls?

Increases in sea level, and hence increased water depths over the reef flats, will result in larger wave conditions reaching the shoreline on Kosrae. As both wave run-up and overwashing of the beach or coastal defences can be extremely sensitive to small changes in water levels and wave conditions reaching the shoreline, even very small changes in sea-level rise may have a significant impact on the frequency and volume of inundation of the immediate coastal margins of the ocean shorelines of Kosrae.