Applied Geoscience and Technology Division (SOPAC)

Preliminary least cost analysis of storm surge hazard mitigation in the Tuamotu Islands, French Polynesia

August 2013

SOPAC TECHNICAL REPORT (PR170)

Anna Rios Wilks

Natural Resource Economics Section, Technical Support Services

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Original text: English

Secretariat of the Pacific Community Cataloguing-in-publication data

Rios Wilks, Anna

Preliminary least cost analysis of storm surge hazard mitigation in the Tuamotu Islands, French Polynesia / by Anna Rios Wilks

1. Storm surges — French Polynesia.
2. Hazard mitigation — French Polynesia.
3. Natural disasters — French Polynesia.

I. Rios Wilks, Anna

II. Title III. Secretariat of the Pacific Community

551.463 AACR2

ISBN: 978-982-000644-7

ACKNOWLEDGMENTS

For their valued expertise and support while in French Polynesia:

- Emilie Nowak of the Service de l'Urbanisme for support in logistics and data collection in French Polynesia and her dedication to the project throughout.
- Bruno Peaucellier of the Service des Relations Internationales and Charles Garnier of the Bureau des Affaires Européennes for their general support.
- Henry Cinquin of the Direction des Affaires Froncières for data on the value of land in Rangiroa.
- Colonel Maxence Jouannet of the Direction de la Défense et de la Protection Civile (DDPC) for their information on cyclone disasters in French Polynesia.
- Stephan Challier, Charly Bodet, Patricia Anneville of the Institut Statistique de la Polynésie Français (ISPF) for census data.
- Raymond Siao of the Direction de l'Equipement for information on the infrastructure used on the Tuamotu Islands.
- Jean Suenko, James Nordhoff, Rudolphe Reia and Dougall Deane from the Fonds de Développement des Archipels, for their technical inputs on the use and construction of MTR houses.
- Jerome Lecerf of the Institut de l'Agriculture for information on the primary sector of Rangiroa.
- Jean-Michel Corteel for information on the value and characteristics of real-estate in Rangiroa.
- Eric Sacher, Head of the Administrative Subdivision of the Tuamotu-Gambier, French High Commission, for details on the cyclone shelter projects in the Tuamotu Islands.
- Alain Timiona, Secretary General of Avatoru motu in Rangiroa for the insight into the implementation on cyclone risk reduction in Rangiroa.
- Boris Peytermann, from the Port Autonome for information on the Tahiti seawall.

SOPAC, SPC colleagues who provided valuable assistance:

- Paula Holland, Manager, Natural Resource Economics, for technical input and review.
- Frederique Lehoux, Project Manager, for her organisational support, correspondence with counterparts in French Polynesia and insurance of the success of the project.
- Anja Grujovic, for her collection and synthesis of extensive background information on French Polynesia.
- Herve Damlamian, Coastal Numerical Modeller, for technical advice on likely inundation during storm surges.
- Jens Kruger and Aseri Baleilevuka for specialised maps on Rangiroa.
- John Tagiilima, Engineer SOPAC, for his valuable advice on structure durability.
- Anna Fink for review of the report.

ACRONYMS

ASCE	American Society of Civil Engineers
COD	Coefficient of Durability
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
DAF	Direction des Affaires Froncières
DDPC	Direction de la Défense et de la Protection Civile
EDF	European Development Fund
EU	European Union
FDA	Fonds de Développement des Archipels
FPF	French Pacific Franc
GDP	Gross Domestic Product
IEOM	L'Institut d'Emission d'Outre-Mer
LCA	Least cost analysis
MTR	Pre-fabricated building (kit house)
NIWA	National Institute of Water and Atmospheric Research
NRC	Net Replacement Cost
OCTs	Overseas countries and territories
PDN	The Pacific Disaster Net
PICs	Pacific Island countries
SOPAC	Geoscience and Technology Division of the SPC
SPC	Secretariat of the Pacific Community
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
XPF	French Pacific Francs

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EXECUTIVE SUMMARY

In order to assist Pacific overseas countries and territories (OCTs) develop resilience to natural hazards, the European Union (EU) has commissioned the SOPAC Division of the SPC to work alongside OCTs to increase the protection and management of the coastal environment. The project, which falls under the European Development Fund (EDF) 9 C Envelope, will focus on the analysis, development and efficient implementation of the disaster risk solutions in Wallis and Futuna, New Caledonia, the Pitcairn Islands and French Polynesia.

This document forms part of the work undertaken for French Polynesia. Specifically this document provides a preliminary least cost analysis of different adaptation options for the Government of French Polynesia to combat coastal flooding in Rangiroa, in the Tuamotu Archipelago.

The Government of French Polynesia is interested in reducing the risk posed by storm surges with a significant wave height of 12 metres.

This preliminary least cost analysis (LCA) forms the first volume of the preliminary cost benefit analysis of 13 different adaptation options that the Government of French Polynesia could pursue to reduce the negative impacts of such a storm surge event. These options can be grouped into 4 categories; the construction of a seawall, the implementation of a setback zone, the elevation of buildings to 1 m and the replacement of buildings with MTR (kit houses) elevated to 1.5 m. These options are by no means the only options available to the government. They are analysed in 13 illustrative scenarios in order to provide an indication of the costs of each option.

Types of costs and benefit considered in this analysis

This analysis quantifies only the material costs of each option and the reduction in damage to buildings in its benefits. Table 1 outlines all the values that could be considered in a LCA. Those in grey are not included in this analysis.

Table 1: Summary of costs for each adaptation option.

	Setback zone	Seawall	Elevation	Kit houses (MTR)
Material	Relocation costs (purchase of new land and construction of houses)	Construction costs	Construction costs	Construction costs (purchase of MTR houses)
Social	Cultural attachment to location in setback zone. Increased crowding of other areas.	Reduction in natural beauty		
Environmental		Marine biodiversity		
Service provision	Implementation of power lines and plumbing to the new houses			Implementation of power lines and plumbing to the new houses
Business		Disruption of coast effects tourism and fishing		

Summary of analysis results

For each adaptation scenario considered the economic costs of its implementation are calculated every year over a 50 year time span. The relative costs of adaptation options change over time.

Those options that use structures which need replacing relatively more frequently will accumulate relatively higher costs over time. The options which are implemented more gradually tend to be relatively cheaper to implement due to the discounting of future costs. Finally, options which only focus on the area within the setback zone will of course be cheaper to implement than those options which are implemented across the whole town area.

The total costs of each scenario over the 50 years of this analysis are displayed in Table 2. The analysis is first conducted without time discounting and later using discounting at 10 per cent for comparison. The scenarios are ranked with number "1" being the least cost option. The next column asks which parties might be expected to pay for the adaptation options assuming current social norms. Then other considerations are noted.

The least cost option

The least cost option when no time discounting is used is found to be the gradual elevation of buildings in the setback zone. Using a social discounting rate of 10 per cent, the least cost option is found to be the gradual replacement of buildings in the setback zone with MTR (kit houses).

Important considerations

This LCA is only the first section of an economic analysis of adaptation options for Rangiroa. It is critical that it be used in tandem with an analysis of the expected benefits of each adaptation option before decisions can be made as to which option could best serve the needs of Rangiroa. Such a cost benefit analysis (CBA) will form the second part of the economic assessment, due later in 2013.

Table 2: Summary of LCA results.

Adaptation scenario		Cumulative cost at year 50 (millions XPF)	Affordability rank	Cumulative cost at year 50 (millions XPF) with 10% discounting	Affordability rank	Who pays?	Other considerations
Seawall		10084	*9*	6787	11	Government	Environmental and tourism effects.
Immediate MTR implementation	Whole area	53915	*13*	21040	13	Immediate implementation may be expected to be funded by government. Gradual implementation might be funded by private individuals aided by government subsidies or loans.	Immediate implementation leaves the current buildings of Rangiroa unused.
	Setback zone only	1544	*4*	603	6		
Gradual MTR implementation	Whole area	32349	*12*	4528	9		Gradual implementation is likely to have more support from inhabitants, as they only change their home once the current one is no longer of use.
	Setback zone only	926	*3*	130	1		
Immediate elevation to 1 m	Whole area	31680	*11*	14691	12		Immediate implementation (elevation of current buildings) is relatively costly due to its engineering challenges.
	Setback zone only	907	*2*	421	3		
Gradual elevation to 1 m	Whole area	21729	*10*	4740	10		Gradual implementation is much less costly than immediate implementation because of the extra cost of elevating a building during its construction is relatively low.
	Setback zone only	622	*1*	136	2		
Immediate implementation of setback zone	Relocated to concrete building	2505	*5*	2505	7		Immediate implementation leaves the current buildings in the setback zone unused. Also for any type of implementation method other challenges include obtaining land for the displaced and the cultural attachment inhabitants feel for the land and homes they must give up.
	Relocated to MTR	3467	*8*	2526	8		
Gradual implementation of setback zone	Relocated to concrete building	2505	*6*	546	4		
	Relocated to MTR	2849	*7*	549	5		

1 INTRODUCTION

The disaster risk reduction project

The EDF 9 C Envelope funded by the EU aims to reduce risk from natural disasters in the Pacific OCTs.

The French Polynesia component of the project has been undertaken by the SOPAC Geoscience and Technology Division of the SPC and focuses on the Tuamotu region. The main natural hazard risk affecting this region is cyclone storm surges and the purpose of this project is to study the storm surge hazard and analyse development plans to reduce these risks.

The French Polynesia project has two parts; a scientific investigation of the risks posed to the Tuamotus through the collection and analysis of bathymetric and topographic data collected from Rangiroa; and an economic analysis of the most efficient ways to reduce these risks.

This report constitutes volume 1 of the economic analysis, providing a preliminary assessment of the costs of adaptation options available to the Government of French Polynesia in order to reduce the risk of damage and loss from cyclone storm surges. This analysis does not provide an exhaustive valuation for each option, but should nevertheless provide solid and well founded estimates and policy implications given the availability of data.

Purpose of work

In response to the threat of cyclones and the storm surges they produce, French Polynesia, including Rangiroa and its neighbouring atolls, introduced a risk prevention policy including regulations for development activities to offer residents a higher level of protection.

The risk prevention policy has so far focused on the application of setback zones in Rangiroa, a restricted zone within which residents are not authorised to rebuild or maintain any existing properties or undertake any new construction work. The present proposed setback zone covers the land which is within 30 metres of the first vegetation line on the coast side, and 10 meters of the coastline on the lagoon side of the small islets called *motus* (Figure 1). Authorities have the ability to request residents to observe the regulations of the setback zone although compliance has been a problem to date (Alain Timiona, Secretary General of Avatoru, Rangiroa, personal communication, 2012). Government stakeholders generally consider that a greater understanding of the value that zoning may have for the local communities in the protection of their assets may result in improved compliance with the regulations (Emilie Nowak, Engineer in Natural Hazards, Urban Planning Department of French Polynesia, personal communication, 2012). Nevertheless, the acute lack of available land on the atoll and the strong sentimental attachment inhabitants have for their land may present problems.

While seeking to strengthen compliance with proposed zoning systems on Rangiroa, the government has retained interest in exploring alternative measures to adapt to storm surges. At present there is a lack of infrastructure able to withstand the intensification of cyclones on the Tuamotus. Three options might go some way in improving the resistance of Rangiroa's infrastructure to cyclones swells: residents could use more easily replaceable kit homes instead of the present permanent concrete housing which is relatively costly to repair following a strong or cyclonic swell, elevation of buildings (elevated on columns of 1.5 m) is another possible option, and as a basis for comparison a seawall could be constructed along certain areas of the atoll's coastline. It is important to note that a seawall is not part of the Government of French Polynesia's development plans for Rangiroa, however for adaptation the government requires guidance on the relative merit of such different approaches as a means to increase community resilience and reduce the impact of future coastal floods and storm surge impacts.

Purpose of study

To inform future considerations, this document outlines the potential cost implications of the four adaptation options for Rangiroa: a setback zone, the use of kit houses, the elevation of buildings and, as a means of comparison, the establishment of a seawall. This analysis focuses on options for adaptation to a storm surge with a significant wave height of 12 m.

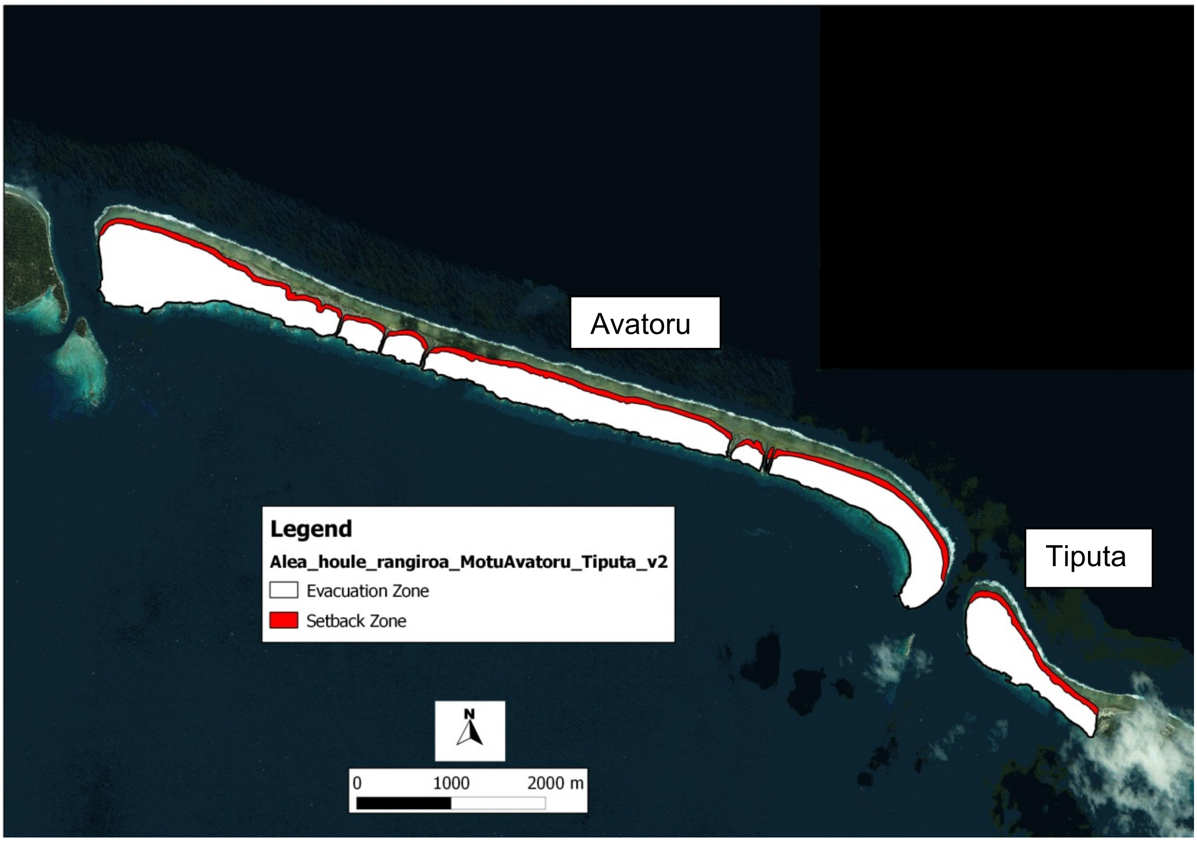

Figure 1: Map of the area under study. Source: SOPAC, SPC (2013).

Structure of report

Section 2 provides relevant background information on French Polynesia, its economy and climate relevant to coastal inundation threats. It then details the risks faced by Rangiroa during cyclones and the current and future possible options for risk reduction. Section 3 outlines the methodology of the analysis and the assumptions. Section 4 outlines data and calculations made. Section 5 analyses the results of the analysis and demonstrates how the cumulative costs of each option can be expected to change over the 50 year time period analysed. Section 6 notes the future analysis recommended.

2 BACKGROUND

French Polynesia

French Polynesia is a mid-Pacific country within the French Republic, located between the 7° and 28° latitude south and the 134° and 155° longitude west. The majority of its islands are very isolated, with vast swathes of ocean between them. Its 118 islands have a total landmass of around 3500 km^2 but when combined with the expanse of French Polynesia's ocean, the area covers 2.5 million km^2 (Figure 2).

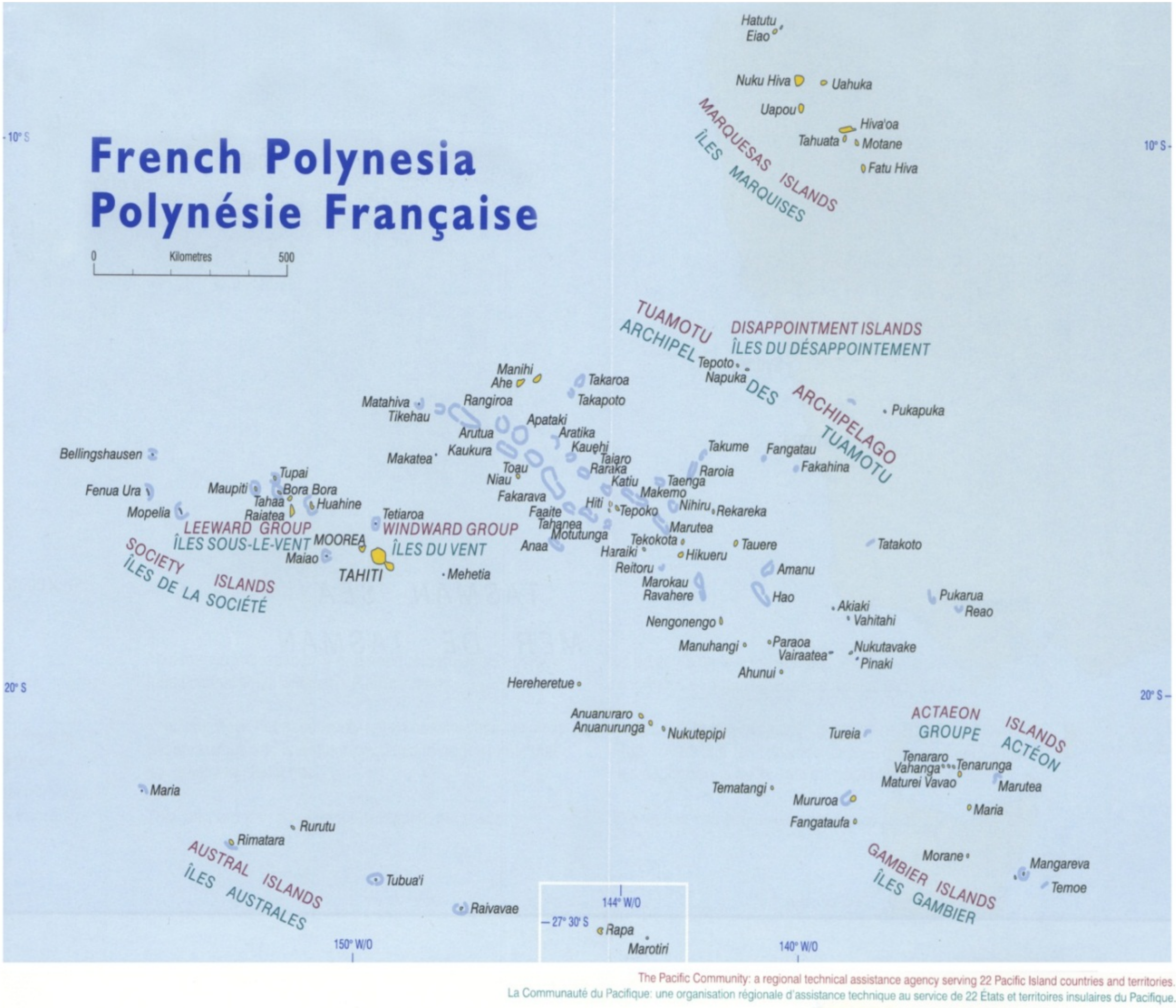

Figure 2: French Polynesia. Source: SOPAC, SPC (2013).

French Polynesia has a population of 260,000 people (ISPF, 2007) and has been growing at a rapid pace, tripling between 1962 and 2007 (ISPF, 2009). The average population density (74 inhabitants/km^2) is fairly low compared to many Pacific Island countries (UNESCO, 2011) but varies across islands.

The islands of French Polynesia form 5 archipelagos: the Society Islands, the Tuamotu Islands, the Gambiers Islands, the Marquesas Islands and the Austral Islands (Figure 2). The capital city of Papeete is located on the island of Tahiti, part of the Society Islands archipelago.

Brief economic background

French Polynesia, like many Pacific Island countries, relied on the primary sector and subsistence farming until the second half of the twentieth century. Two of its most important exports were phosphate and vanilla, and Tahitian vanilla is still a popular product.

Tourism makes up about a quarter of income produced in French Polynesia's tertiary sector. Tourism sites are principally located in coastal areas, about 80 per cent occurring close to lagoons (Avangliano et al, 2009). Since 2003, the tourism sector has undergone significant decline partly due to a reduction in airlines servicing the country, the weakening of the US dollar (making it relatively more expensive for US tourists) and also a relatively narrow selection of tourist products offered by French Polynesia (Avangliano et al, 2009). Nevertheless, damage to coastal areas due to cyclones will further impact the tourism sector.

Aside from the tertiary sector, pearl manufacture and fisheries are also a major source of income for the country. Unfortunately, recently the French Polynesian Pearl industry has seen a slowdown. The industry has gone from producing 75 per cent of the country's export revenue and employing over 5000 people in 2008 (IEOM, 2008), to a declining industry, hit hard by decreasing world prices and sales. Even before 2008, pearl sales had declined by 50 per cent between 2002 and 2007, and exported pearls by 32 per cent (ISPF, 2009). This has had a significant impact on the economy of the Tuamotu Islands, where many of the pearl farms were located. Nevertheless, the fishing sector has seen increasing returns over the recent years, the value of fisheries exports has risen and deep sea fish exports totalled 626 million CPF in 2010 (IEOM, 2011).

The agricultural sector is relatively small, most finding it more profitable to work in other sectors. Much of the primary produce consumed in French Polynesia is imported.

Between 2004 and 2007 (the last published census) the unemployment rate remained steady at 11.7 per cent. After the 2008 global economic downturn the L'Institut d'Emission d'Outre-Mer (IEOM, 2011) expects that the unemployment rate has now risen to over 20 per cent.

Within the Tuamotu Islands, resources are varied. Farming is limited due to poor soil quality on the coral atolls, although some crops can be grown in taro pits (Lonely Planet, 2009). Fish however, are quite plentiful in the lagoons and pearl farming produces some further income for the Tuamotu Islands. Copra production is also of importance to the economy, with Rangiroa producing the largest quantities. The Tuamotu Islands also rely heavily on tourism and are world renowned for their beautiful lagoons (Lonely Planet, 2009). Partly in light of this, the Tuamotu group now form a strategic area in French Polynesia for tourism as well as pearl farming, two of the country's key economic drivers.

There is a limited housing market in Rangiroa, with most land being passed down through generations.

Climate

The climate in the Tuamotu region is tropical, hot and humid. The El Nino phenomenon is present in the French Polynesia, which increases considerably the number of cyclones likely to hit this area (Avangliano et al., 2009).

Cyclone and storm surges are of course, not always of the same magnitude. Usually, smaller events happen more frequently, perhaps only one in every five years, whereas the larger events would happen less frequently, perhaps only every fifty or one hundred years.

Future climate change predictions

Although predictions have been made as to the future frequency and magnitude of tropical cyclones in the pacific region, there is large variation in the predictions produced by different scientific models. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has used various models in order to determine projections of the frequency and magnitudes of tropical cyclones for the Pacific region under the A2 (high emissions) scenario (Australian Bureau of Meteorology and CSIRO (2011). For the Southeast Basin, where French Polynesia is located, changes in frequency of tropical cyclones in the future years (2080-2099) compared to the present years (1980-1999) range between a 10 per cent increase to a 70 per cent decrease. The predicted changes in the Maximum Potential Intensity of cyclones from the various models employed vary between increases of 13 per cent and decreases of 59 per cent for the Pacific region studied. Due to the extreme variation in the predictions, any adaptation which reduces damage and loss can be deemed as beneficial, as it will allow for better preparedness for the worst climate change outcomes.

Disaster risk issues

To date, the Pacific Disaster Net (PDN) reports a total of 11 nationally declared natural disasters recorded for French Polynesia since 1980. The majority of these were tropical cyclones (8 events), followed by landslides (3 events), (Table 3). In total, these 11 events resulted in 56 fatalities and created major housing, infrastructure and crop damage.

Table 3: Number of natural disaster events and total lives lost, 1980-2012.

	Number of events	Total lives lost
Tropical cyclones	8	33
Landslides	3	23

Source: PDN database (2012).

The eight cyclones registered in the PDN database are listed in the table below, together with recorded details of estimated damage and lives lost. For the two cyclones for which the estimated cost was provided (Tropical Cyclone Veena and Tropical Cyclone Orama), the average cost of a cyclone amounted to around US$18.5 million (in 1983 prices). Five out of the eight registered cyclones resulted in fatalities, with an average 6.6 deaths per event.

Table 4: List and details of recorded tropical cyclones in French Polynesia, 1980-2012.

Tropical cyclone name	Year	Estimated nominal cost in thousands of USD	Lives lost	Population affected	Comments
TC - Veena	1983	21,000	1	5050	
TC - Orama	1983	16,000	6		
TC - Arthur	1991				
TC - Osea	1997			5600	Major housing; infrastructure and crop damage
TC - Martin	1997		8		Major building and crop damage - wind & major storm surge
TC - Alan	1998		8		Building; crop and infrastructure damage. Fatalities caused by mudslides.
TC - Veli	1998				Housing and coastal damage
TC - Bart	1998		10		Minor damage. Deaths due to heavy seas that capsized a boat.

Source: PDN database (2012)

Damage accounts from Cyclone Oli (2010)

Cyclone Oli (2010) appears to be one of the most devastating cyclones that hit French Polynesia in recent years. French Polynesia reported that the total damages from Cyclone Oli amounted to US$70 million in-housing and infrastructure. (Radio New Zealand International, 2010a) Some 1000 houses were damaged by the strong winds, 600 of which were in Tubai and the Austral Islands. A total of 284 houses were completely destroyed (Radio New Zealand International, 2010b). The cyclone also cut power to the fifth of the main islands of Tahiti and Moorea (Australian Broadcasting Corporation, 2010). Some 3400 people living on the coast of Tahiti and Moorea were evacuated to higher ground, but in other parts efforts for evacuation were made difficult by the large distance between the islands. Inhabitants of Tubai claimed Cyclone Oli to be the area's worst storm in living memory (Australian Broadcasting Corporation, 2010).

Coastal flooding is common in the majority of French Polynesian islands with disaster reduction efforts concentrated on inhabited islands, especially those which are low lying or with little or no high ground to which inhabitants could flee during cyclones and storm surge events. The Tuamotu Islands only stand a maximum of 2 to 3 metres above sea level and are home to a relatively high number of inhabitants. Rangiroa, the most populated atoll of the Tuamotu Islands, will be the focus of this economic analysis, which aims to provide an economic assessment of the efficiency of cyclone inundation solutions on the atoll.

Tuamotu Islands

The Tuamotu Islands archipelago comprises 77 atoll islands, lying to the northeast of Tahiti, the closest 300 km away (Figure 3). The total land area for all the islands combined is 700 km^2, with thousands of square kilometres of ocean in between. Some of the atolls are completely surrounded by outer reefs. Only about 30 atolls have a channel, through which it is easy to manoeuvre a boat into the lagoon.

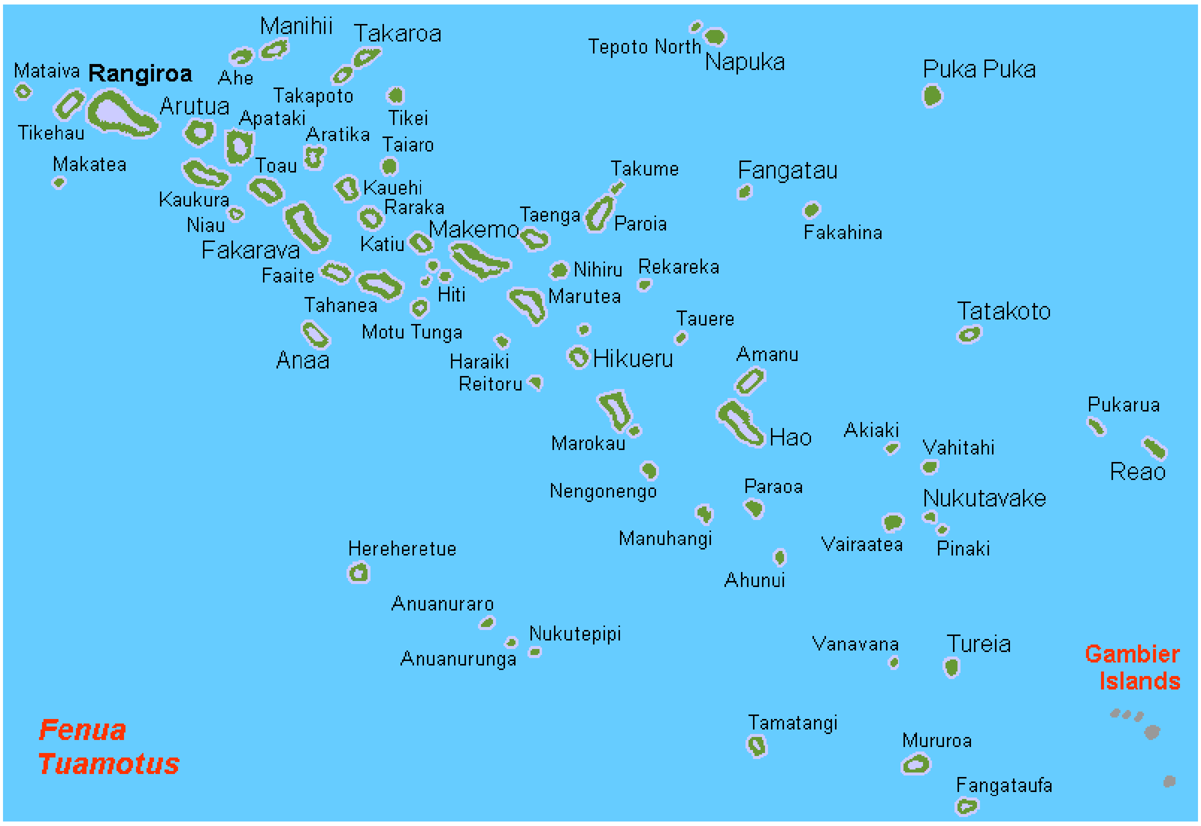

Figure 3: Tuamotu group. Source: Lonely Planet (2009).

The Tuamotu Islands are grouped into municipalities, with the municipality of Rangiroa holding the largest population, 3245 inhabitants. It is made up of three atolls: Rangiroa, Mataiva and Tikehau and the island of Makatea (ISPF, 2007a).

Rangiroa is the largest atoll in the Tuamotu Islands, both in size and population (Figure 4) and one of the largest atolls in the world. It stretches 75 km in length and 25 km in width, its many *motus* forming a permeable wall around its lagoon. The *motus* themselves are like small islands, their maximum width between the ocean and the lagoon being only a few hundred metres (Ocean and Islands Program maps, SOPAC, SPC).

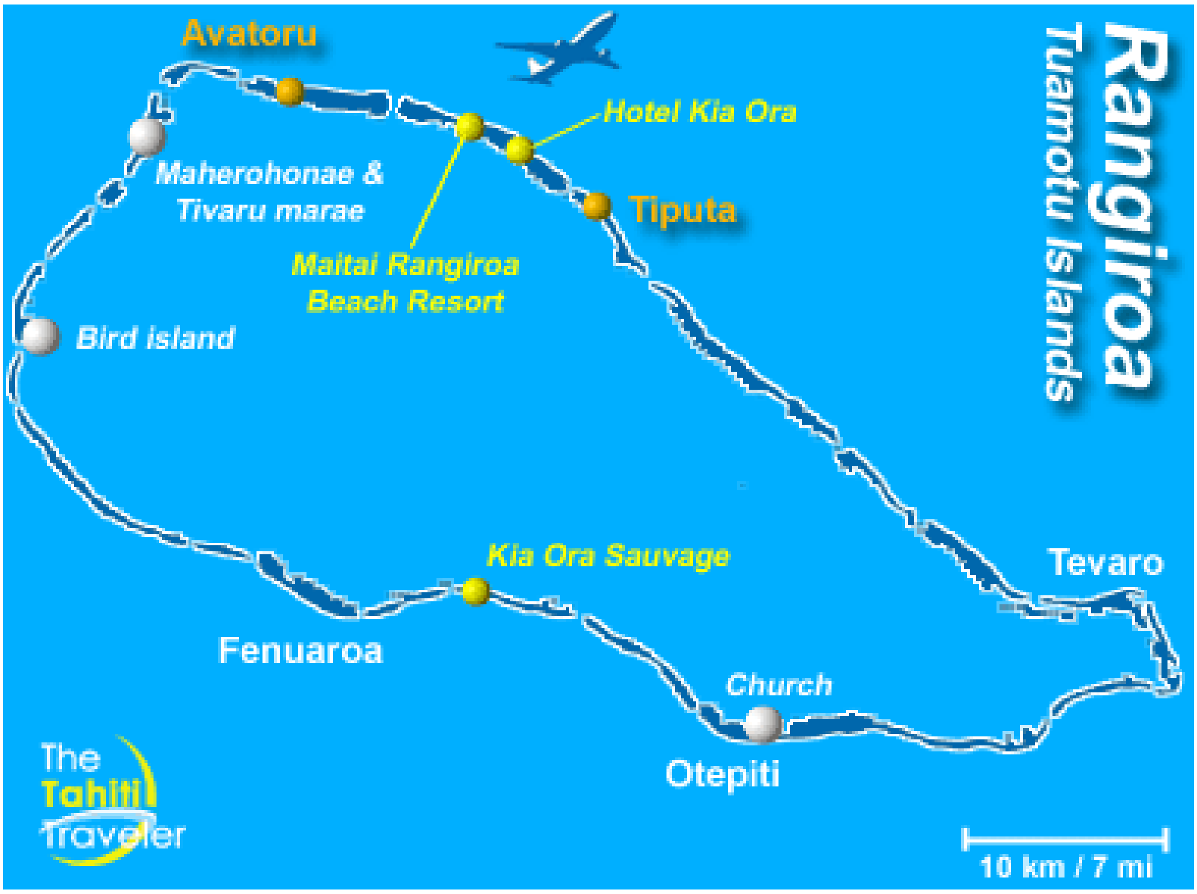

Figure 4: Rangiroa. Source: The Tahiti Traveller (accessed 2012).

On Rangiroa Atoll the two main villages, Tiputa and Avatoru, hold the majority of its 2473 inhabitants (ISPF, 2007a). These villages are located only a few kilometres from one another in the north of the atoll. It is possible to travel between them using the main road running from Avatoru to the Tiputa Pass, and taking a ferry or boat to Tiputa on the other side.

Rangiroa has two channels between the ocean and its lagoon. These are used frequently, even by small ships, and there is a ferry which transfers people across the Tiputa Pass, many commuting between Tiputa and Avatoru each day for work and school.

As these two villages are the most populated locations of Rangiroa, this analysis will principally focus on these two main sites.

Risk reduction at present

Setback zone

Recently a "red zone" has been implemented in Rangiroa. This legislation prohibits any building or maintenance work to be carried out within the setback zone. The area of this zone can be seen in red on the map of the area of Rangiroa under study (Figure 1). The red zone boundaries can be observed for the most populated segment part of Avatoru (Figure 5).

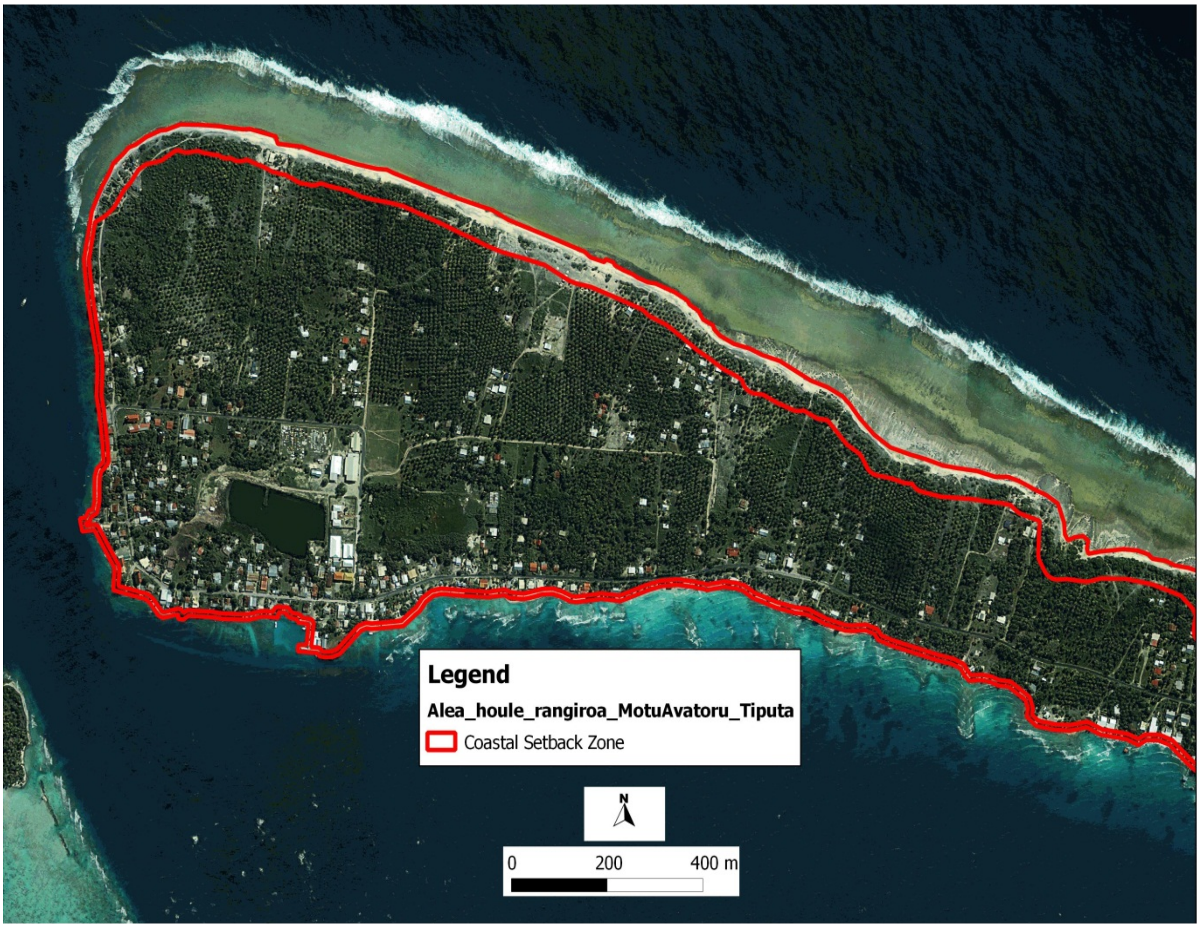

Figure 5: A detailed map of the setback zone boundaries, for a small section of Avatoru. Source: SOPAC map based on shape-file data from the Service de l'Urbanisme (2013).

Although theoretically a setback zone would reduce damage from large cyclone surges by causing inhabitants to relocate to areas further from the coast (outside the setback zone), it does restrict the area which inhabitants can use. The strip of land between the ocean and lagoon on Rangiroa is at most a few hundred metres wide so that the area lost to inhabitants by imposing the setback zone is significant. At present, anyone owning land within the setback zone (Figure 1) is not compensated for the loss of value of the land or the inability to build on it. Disincentives exist for local residents to support the controls, for example, residents may have saved money to buy a piece of land, purchasing the property before the setback zone had been introduced, and now find that it is within the red zone. They cannot build on their land, nor will they be likely to sell the land for the same price they paid now that the setback zone legislation is in place.

If the red zone is to be enforced, residences in the red zones will need to be relocated from the beach for any renovations or rebuilding to occur. This means that, aside from losing the use of property in this zone, inhabitants would ultimately need to incur the cost of leaving all of these plots of land and purchasing new ones. In addition, the mere thought of moving to a different plot of land is unacceptable for many people inhabiting the red zone. These plots of land have been passed down for generations and the people feel a strong connection to their land. (Alain Timiona, Secretary General of Avatoru, personal communication, Dec 2012).

Another challenge in enforcing the red zone is that many of the water osmosis plants, set up by the government under their drinking water program in which the municipality is required to provide freshwater to all its inhabitants, are located there (Alain Timiona, Secretary General of Rangiroa, personal communication, Dec 2012). This may cause a problem in the future, as technically no repairs and reconstruction can be undertaken in this zone.

The setback zone will be considered as one of the four options available to the government for the risk reduction of cyclone damage which are analysed in this report.

Bulkheads

Bulkheads are small walls that rise about 0.5 m above the surface of the sea, usually in order to reduce erosion of land next to the sea. These are unlikely to reduce damage from storm surges because even at a normal high tide, waves often splash over them, sometimes eroding sand from the beaches they were built to protect. At least one house in Rangiroa was abandoned because the sandy soil it was built on has been eroded causing subsidence, even though there is a bulkhead in place to stop this happening (Figure 6).

Figure 6: A bulkhead on the lagoon side of Avatoru, with beach erosion still unprevented. Image: Anna Rios Wilks (Dec, 2012).

Not only were waves observed to overtop these walls, but often the sea water can pass underneath them, removing their foundations and causing them to collapse (Raymond Siao of the Direction de l'Equipement, personal communication Dec 2012). This is especially likely when their construction is not properly overseen and the structure does not slope down into the sea to reduce wave impact.

In the past, many bulkheads have been used, especially in the Tuamotu Islands to protect the low-lying coastline. These are typically built using crushed coral (excavated onsite) mixed with cement to form a solid structure which offsets the wave impacts on the shoreline. They are usually about 1.5 m in height, although the sea level reaches around 0.5 m below the top of the wall.

These small walls, although perhaps reducing erosion for a small, limited number of years would help very little in slowing storm surges.

Shelters

During the 1983-84 period, when a series of cyclones hit Rangiroa, waves washed over its *motus*, not just from the ocean side, but also from the lagoon, devastating the homes that had been built along the beaches.

After these events, the government established a policy to construct cyclone shelters for the Tuamotu population. This program was not as successful as hoped, leaving the majority of the islands still with too little shelter, and shelters not able to withstand cyclones. Since then the French State and the Government of French Polynesia initiated a new policy program from 2007 to build sufficient shelters for all vulnerable populations at an expected cost of 11-12 billion XPF. Some shelters have been successfully built. Within the municipality of Rangiroa, the Tikehau Atoll received a shelter, as did the Makaiva Atoll which also uses the shelter as the high school as a boarding house. The municipality of Hau also has received a shelter. These shelters do not only provide a long-term solution to the protection of the population during cyclones and storm surges but they also double for use as community buildings throughout the year (Eric Sacher, Head of the Administrative Subdivision of the Tuamotu-Gambier, French High Commission, personal communication, Dec 2012). Also, during the construction phase, around 50 per cent of the labour used is contracted from the atoll site itself. This provides work for the local population, income multiplier effects for the atoll and can increase the quality of human capital.

There is already a 1600 million XPF shelter program underway in Rangiroa and the Tuamotu Islands. Previously, there has been a problem of insufficient space for all inhabitants in the buildings previously used as shelters. Often inhabitants from neighbouring areas would also come to find shelter in the main town of Avatoru, many children would stay for the week in the boarding school (one of the buildings currently used as a shelter). In addition, these buildings, often churches and similar structures, are not cyclone-proof.

In Rangiroa, three shelters have been planned; one in the village of Tiputa and two in the village of Avatoru. One of these new shelters has already been built in the Tiputa *motu*. This structure looks somewhat like a concrete house, elevated on large concrete arches and a central concrete section. The shelters are constructed in order to withstand winds of over 300km/hr (Eric Sacher, Head of the Administrative Subdivision of the Tuamotu-Gambier, French High Commission, personal communication, Dec 2012). The shelter can accommodate all the residents of Tiputa, each with about 1.5 m^2 of own space in the main living area. The kitchen, toilets and other rooms give additional services and space. The rooms are elevated between 3 m and 3.5 m above ground level. In non-emergency situations this shelter doubles as a primary school, providing a use for the building and ensuring its maintenance throughout the year. Funding is now almost fully secured for the two remaining shelters planned for Rangiroa. They will be located on the Avatoru side of the Tiputa Pass. When these shelters are built, they will be sufficiently large enough to hold all the inhabitants of Avatoru, over 1200 people, in an emergency. The dimensions of these shelters will be similar to that of Tiputa. One of the Avatoru shelters will have a usable surface area of 1100m^2 and will double as a new medical centre, while the other will be used as a municipality building (Alain Timiona, Secretary General of Avatoru, personal communication, Dec 2012). These two shelters are hoped to have their building commenced in 2013. This would mean that by 2016, all three shelters for Rangiroa would be finished. Once the project has been successfully completed in Rangiroa a new emergency plan would advise all inhabitants to move into these shelters during cyclone events.

The shelter project should in theory enable all lives to be protected in the event of a cyclone storm surge. Nevertheless, this project and the analysis of other risk reduction options is still important for the reduction of damage to property and infrastructure in Rangiroa.

Additional options for risk reduction

While existing strategies are in place for coastal community protection, the Government of French Polynesia wishes to consider options to minimise damage from inundation. Several additional options will be considered; elevation of houses, use of kit (MTR) houses and a seawall.

Seawalls

Very few seawalls have been used in French Polynesia, the main one being located in Tahiti, standing 5 m in height and costing about 170,000 XPF per metre in length of wall in 1978 (Boris Peytermann of the Port Autonome, personal communication, Jan 2013) this is about 560,692 XPF per metre if this 1978 cost was inflated to 2012 prices.

This seawall was built to protect the main port and principle strategic infrastructure of the capital, Papeete, making it economically feasible to invest in such a significant structure.

Seawalls are not infallible, as demonstrated in Japan, during the 2011 tsunami (Onishi, 2011). Nevertheless, seawalls of the kind used in Tahiti could be expected to reduce the force of inundation for most storm surge events.

Kit houses (MTR)

A kit house, or an MTR building, is a building which is brought to its final location site pre-manufactured. The kit houses considered in this analysis are quick and relatively cheap to construct in comparison with concrete houses. They are also anti-cyclonic, certified by the SOCOTEC independent risk analysis group to resist winds of up to 204 km/hr (Engineers, Fond de Developpment des Archipels, personal communication December 2012).

Kit houses are of interest to the government as an adaptation option for coastal inundation because they can offer relatively good protection from cyclone winds. Additionally, the kit houses considered in this analysis are elevated to 1.5 m above ground level, also providing some flood protection.

The Secretary General of the Avatoru *motu* in Rangiroa supported the engineers of the Fond de Developpment des Archipels in his view of the suitability of kit houses in the area. These latest kit houses are anti-cyclonic by definition, although it must be noted that the term “anti-cyclonic” refers only to the wind speeds that they can withstand. There are no set regulations for elevation height or wave resistance and large waves still present a danger. The kit houses considered in this analysis are the modern MTRs, recommended by the Fond de Developpment des Archipels. These MTR houses are elevated on rectangular columns; the floor of the building standing 1.5 m above the ground level, with a width and depth of 40 cm by 40 cm. They are built using cement with iron supports inside the columns and foundations. Each column extends 1.5 m of above the ground surface, and the cement foundations reach over 30 cm below the ground surface. The average lifespan of one of these MTR buildings without maintenance is 20 years (Engineers, Fond de Developpment des Archipels, personal communication, 2012 and Engineers, SOPAC, personal communication, 2013). During the mission to Rangiroa only one of the kit houses observed was raised to this height, the rest only sitting about 1 m above the ground level (Figure 7).

Figure 7: Kit house on Rangiroa with small elevation. Image: Anna Rios Wilks (Dec, 2012).

Kit houses can withstand storm surges to a certain point due to their elevation but clearly for larger storm surges that inundate to depths of more than 1.5m, the houses will flood. Water is unlikely to do damage to elevation columns but floating debris and sand washed by the waves could cause considerable damage. Tree trunks and sand banks propelled by storm surges would damage and perhaps destroy columns. If the water level rises above the height of the columns, the houses would likely flood and may be seriously damaged or destroyed.

Although kit houses would offer some protection, it is possible that inhabitants of kit houses (as with any other type of house) would need to evacuate to cyclone shelters if a cyclone was to hit Rangiroa.

The procedure for purchasing the houses can vary. Often, when a family income is below a certain threshold, the kit house is subsidised (perhaps only contributing a total of about 10 per cent of the price of the MTR house). Alternatively the full or subsidised payment of the house can be done by a scheme in which the house is initially provided free of charge, the inhabitants pay rent each month and once the rent covers some proportion of the price of the house, the house becomes property of the inhabitants. In order to make certain that all rent is paid and that the population understand the conditions of having the houses, all of the parties involved, the ministry, political parties and the media must ensure that consistent, correct and sufficient information about the scheme is provided to the population.

Elevation

The elevation of houses is not new to the Tuamotu Islands. For generations many of the homes have been built on stilts to protect homes from flooding and to reduce moisture entering the buildings through the floor.

Two options exist to elevate houses for the mitigation of coastal inundation: to enforce minimum floor heights for new buildings, or to enforce an immediate elevation of all existing buildings by dismantling and rebuilding all buildings or lifting them on cranes and inserting elevation column underneath. Both these options would likely be more expensive than elevating a house as part of its design and construction, unless the building was already built with very expensive materials. In addition, the transport of a crane to the islands would prove extraordinarily costly.

The elevation option analysed here will be the raising of floors to 1 m above ground level. Both immediate elevation of all existing buildings and the gradual elevation of buildings (in the year buildings are rebuilt) will be considered.

3 METHODOLOGY

This document reflects a LCA of the adaptation options in response to the coastal inundation threats to Rangiroa. A LCA is an assessment of the most affordable option that may achieve some level of a set outcome, in this case a reduction in storm surge damage.

Least cost analysis

In this LCA, only the material costs incurred in the provision of risk reduction options will be included in the analysis. These are the factors such as the materials purchased and the cost of labour employed both during the initial implementation of the options and in any maintenance and replacement costs that need to be undertaken throughout the life span this analysis focuses on. The time span for conducting an economic analysis is usually equal to the engineering life of the longest lasting component used in a project (Woodruff 2008). In this case, the seawall is the longest lasting structure, with an expected life span of 50 years. For the purpose of this analysis, a time frame of 50 years is adopted (2 generations).

No evaluation of environmental impacts will be made although they may be flagged. Indirect costs such as ripple effects on the economy will not be included in the cost analysis.

The costs for this LCA will be reported using constant rather than nominal prices and in 2 forms: the total costs over time and the costs over time with social time discounting.

It must be emphasised that the LCA only provides an analysis of the cost of implementing each option. The cost of implementing each option completely ignores any benefit from implementing the option and any savings that would be made by implementing an option. For example, in the MTR option, only the cost of constructing MTR's is included in the LCA, the savings made by society from not having to construct other forms of housing are not included. The benefits and savings that each adaptation option produces are analysed in the benefit part of the full CBA (Rios Wilks, 2013).

The treatment of time

Some costs of the risk reduction options will be incurred over time, in future years. Economic theory observes that individuals generally prefer to incur costs later rather than sooner and to enjoy benefits sooner rather than later. Discounting adjusts values (in this case costs) incurred in the future so that they provide an estimate of the present value that society would place on them. The relative weight placed on costs incurred in different time periods is determined through discounting. This discounting of future utility can be modelled in many different forms and there is debate as to which best represents social time preferences (see Bateman and Henderson (1995) or Cruz Rambaud and Muñoz Torrecillas (2006) for a discussion). The exponential form of discounting will be employed in this analysis.

The decision as to which discount rate to use, is also a much disputed topic (see Holland (2008) for a discussion on discount rates in the Pacific Island countries (PICs)). Environment and development projects still use highly variable discount rates; these can range between 3 and 12 per cent. Due to the high level of uncertainty in the Pacific environment, a discount rate of 10 per cent seems to be the most common value used in pacific development projects and this figure is also consistent with the Asian Development Bank (2006) guidelines (Holland 2008). The use of this discount rate will also allow this analysis to maintain consistency with other SOPAC analyses.

4 DATA AND ANALYSIS

General information used in LCA analysis

The threat of storm surges

According to an extreme value analysis carried out by Scott Stephen, NIWA, (Herve Damlamian, Coastal Numerical Modeller, SOPAC, personal communication, 2012) for Tahiti, a significant wave height of 12 metre has a return interval of approximately 50 years; i.e. a 2% chance of occurring in any one year. This event will be the hazard focused on throughout this analysis.

Prices of land and buildings

Information on the cost of land was obtained through the Direction des Affaires Froncières. Data for the price of 105 Rangiroa land sales, made between the years of 1995 and 2012, show that the average price per metre square of land is 2415 XPF. An independent real estate expert, who specialises in Rangiroa was also consulted and the figures provided for the sale value of land in Rangiroa were very close to those given by the Direction des Affaires Froncières. The approximation for the price of land in the Avatoru (Rangiroa) village was 3000 XPF/m^2, whilst that in Avatoru (Rangiroa) rural areas was 550 XPF/m^2.

An estimate of the average value of buildings in Rangiroa was also provided by the Rangiroa real estate expert. Almost all the houses seen in Rangiroa were one storey concrete structures and the values provided are for one story houses. The purchasing value for a concrete house is 100,000 XPF/m^2. To calculate the cost of construction of this type of concrete building, it may be noted that that the economic value of a building is the cost of its construction plus a normal rate of return. Consequently, the cost of construction could be estimated by taking its market value and discounting this by the rate of market interest that would be earned over the duration of its construction. Due to a lack of data on how long this type of construction may take, and the relatively small rate of interest that would be earned during this time, the market value of 100,000 XPF/m^2 is taken as a proxy for its cost of construction.

The engineers at the Fonds de Développement des Archipels provided the total value of constructing an MTR (kit house) as between 5 and 6 million XPF. The house that costs 5 million XPF is 56.5 m^2, making the cost per square metre 88,496 XPF. Table 5 presents the costs of assets used this analysis.

Table 5: Cost of assets

Asset	Minimum	Average	Maximum	Source
Rangiroa Land	88 XPF/m^2	2415 XPF/m^2	12,000 XPF/m^2	DAF
Concrete House (single storey)		100,000 XPF/m^2		Rangiroa real estate expert
MTR House (single storey)		88,496 XPF/m^2		FDA

The net replacement cost

Due to the fact that buildings are not often sold in Rangiroa, there is insufficient data on the value of buildings in order to construct values for houses of different ages. For this reason the net replacement cost (NRC) of a building will be employed in order to estimate their value. This measurement takes into account the age of the building and how long this type of building is expected to last (Jean-Michel Corteel, Rangiroa real estate expert – personal comm. December 2012).

The coefficient of durability (COD), which is calculated as the current age of the building divided by the expected life of building, can be used in the estimation of the net replacement cost (NRC) of a building. The NRC (value of a building depending on its age) can be calculated by taking the value of the building when new (VN) and subtracting from this the value of the building when new multiplied by the coefficient of durability: NRC = VN – VN*COD.

Area of land and buildings existing in the study zone

The study zone for this analysis can be seen in Figure 1. The setback zone refers to the area of land which currently prohibits all maintenance and building work. The setback zone covers the area of land up to the line running 30 metre back from the first vegetation line on the sea side of the *motus*, and the area of land up to the line 10 m back from the coastline on the lagoon side. This area is displayed in red in Figure 5. The remaining land, shown in yellow makes up the evacuation zone, which is currently seen by the government as less at risk from storm surge damage.

The land and building areas included in the analysis are displayed in Table 6.

Table 6: Land and building areas used in the analysis.

	Area of land (metres square)	**Area of buildings (metres square)**
Total area under study	4,435,600	203,078
Setback zone only	796,300	5,815

Source: SOPAC, SPC (2013).

The durability of buildings in Rangiroa

Maintenance does not usually seem to be undertaken in the majority of properties in Rangiroa. (Alain Timiona, Secretary General of Avatoru, and Jean-Michel Corteel, Rangiroa real estate expert, personal communication Dec 2012). An expert from the Direction de l'Equipement stated that it was unusual for maintenance to be undertaken on homes due to the lack of resources available. For this reason maintenance is assumed to be zero.

Without maintenance the real estate expert suggested that a concrete, one story building would last about 50 years. Engineers from SOPAC and from the Direction de l'Equipement suggested that the kit houses (MTRs) would last between 10 and 25 years with no maintenance. The estimate that was most frequently provided was of 20 years duration until the building would need to be replaced. Consequently, it is assumed that concrete buildings have a replacement rate of 50 years and that MTRs have a replacement rate of 20 years.

Assumptions used in the analysis

The analysis will first evaluate each option using undiscounted costs. Later a comparison will be made using a discount rate of 10 per cent. All prices and costs reported in this analysis are in constant terms, this means that costs incurred in the future are not inflated in order to accommodate future increases in prices as this would distort the analysis[1].

All construction and implementation costs have labour costs included automatically.

Throughout the analysis, the age of the houses that are currently present in Rangiroa must be assumed. It will be assumed that the houses currently on site are single storey, concrete buildings and so will have a duration/lifespan of 50 years. The actual age of each individual house is unknown so for illustrative purposes it is assumed that the ages of the houses are evenly distributed between 0 and 50 years of age. This means that even if no risk reduction options were implemented, in any one year 2 per cent of the houses should reach 50 years and need to be rebuilt.

Using the data and information gathered, the analysis will assume certain values for the costs, maintenance and durability of each solution. These will now be outlined. Four options for risk reduction will be considered:

- Set back zone with compensation (assuming land can be purchased)
- Seawalls
- The elevation of existing and new buildings to 1 m
- Kit houses (all elevated to 1.5 m)

Setback zones

The setback zone area is the area running between the lagoon and the point 10 m inland from the first vegetation line on the lagoon side, and the area running between the ocean and the point 30 m inland from the first vegetation line on the coast side (Figure 1).

There are many possible ways to implement a setback zone, but for the purpose of this assessment, two ways will be costed:

- Establishing a 'No-Go Zone', where all households are required to immediately move out of the zone in the first year.
- Establish a 'No Maintenance or Building Zone' in which households are gradually required to relocate out of the zone. This is the type of zone currently in place, and prohibits inhabitants to maintain or rebuild property in the zone. This means that they must relocate once their house is no longer useful (because the houses are assumed to be concrete, this would mean the houses are no longer of use once they reach 50 years). This type of setback zone is likely to be the more socially acceptable of the two setback zone scenarios. Given that the existing buildings on Rangiroa have been assumed to be concrete houses, with a life span of 50 years, if the age of houses is assumed to be uniformly distributed between 1 and 50 years, then the probability of a house reaching 50 years of age and being replaced is 2 per cent per annum. Consequently, for this gradual implementation the relocation rate of existing houses is assumed to be 2 per cent per annum.[2]

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[1] For further explanation on CBA economic valuation, one may refer to the Green Book, UK, available at http://www.hm-treasury.gov.uk/data_greenbook_index.htm

[2] There are only 38 houses in the setback zone, and 2 per cent of this would be approximately ¾ of one house that would be moved per annum. The movement of ¾ of a house per annum is clearly not realistic but will give an accurate estimate of the expected cost that would be incurred each year if there is a two per cent probability per annum of a house reaching 50 years of age. This gradual movement of houses is purely for illustrative purposes.

Reallocation costs

In order to make the setback zone feasible, displaced inhabitants would need to reallocate and buy new land and a home; otherwise they would have nowhere to live. This cost of alternative housing and land was calculated by measuring the area of the land and homes currently in the zone, and multiplying these areas by their market prices. The vast majority of homes observed whilst in Rangiroa were one storey, concrete buildings.

In the analysis, two scenarios for the purchase of new homes will be put forward:

- All new houses that must be bought in order to re-house the inhabitants of the setback zone are concrete.
- All new houses that must be bought in order to re-house the inhabitants of the setback zone are MTR houses.

Because the analysis spans a 50 year period, the replacement of these new buildings at the end of their functioning life must be included in the costing.

It must be noted that the cost of the setback zone is likely to be an underestimation of the full costs because these do not include the value of sanitary and electric infrastructure which would be foregone and would also need to be reinstalled after relocation.

The implementation scenarios analysed

The different implementation techniques (immediate and gradual relocation of inhabitants) and the two types of housing structures bought for those displaced (concrete and MTR) are analysed producing 4 adaptation scenarios for the setback zone:

a) Establishing a 'No-Go Zone' (immediate relocation of those in the zone) using concrete single storey replacement houses.
b) Establishing a 'No-Go Zone' (immediate relocation of those in the zone) using MTR replacement houses.
c) Establish a 'No Maintenance or Building Zone' (gradual relocation of those in the zone)[3] using concrete single storey replacement houses.
d) Establish a 'No Maintenance or Building Zone' (gradual relocation of those in the zone) using MTR replacement houses.

Recouped value of forgone assets

Although implementing a setback zone will mean that the land and houses currently in this area will be given up, it may still be possible to use these assets for another purpose. For example, some of the value of the forgone buildings could be recouped by selling the materials they are made of. Nevertheless, as legislation prohibits maintenance or rebuilding on the area inside the setback zone, the market value of this real estate (value obtained for selling the real estate) would be expected to be low; the only use for the land once the legislation is implemented is the growing of coconut trees for copra, or of crops that can survive in the sandy, saline earth.

Because it is likely that inhabitants would only be able to recoup a small value of their forgone assets and that any attempt to quantify this recouped cost would be mere speculation, in this analysis it is assumed that the recouped costs are zero.

[3] This is the type of zone currently in place, and prohibits inhabitants to maintain or rebuild property in the zone.

Values used in the calculations

As detailed earlier in Table 5, the price of a new concrete house is 100,000 XPF/m^2 and the price of a new MTR house is 88,496 XPF/m^2. As explained earlier, it will be assumed that no maintenance of houses takes place. Without maintenance, the lifespan of a concrete house is 50 years and the lifespan of an MTR is 20 years.

The average value of land in Rangiroa is 2415 XPF/m^2 (see Table 5), this is the value used throughout this analysis.

Savings

The cost of maintenance or replacement of the new houses of the relocated inhabitants over the 50 year period analysed must be included in the costs of the implementation of the setback zone option. Nevertheless, it must be noted that without the setback zone, and the relocation to new houses, the inhabitants would be incurring costs of replacing their old properties within the setback area at the end of their functioning life. By implementing the setback zone inhabitants no longer need to maintain these forgone houses which they are no longer using, so this cost is saved. This saving will be included in the benefit section of the CBA (Rios Wilks, 2013).

Seawall

Material costs

The seawall considered is the same as the one currently used in Tahiti, which stands 5 m in height and has a width of around 1.2 m at the top and over 5 m at the base of the wall. The price per metre of the seawall used in Papeete was 170,000 XPF/m, which in current value would be 560,691 XPF/m (using inflation rates reported by ISPF, 2013).

The durability of the wall with basic maintenance is about 50 years (John Tagiilima, SOPAC engineer, personal communication, January 2013). This means that this analysis will finish in the year just before the wall would have to be replaced. The ASCE manual (2001) suggests that walls should be assessed every 5 years.

It is assumed that the seawall has a 50 year life span (John Tagiilima, SOPAC engineer, personal communication, January 2013) and that the government would maintain the wall in five year intervals. The maintenance needed is likely to gradually increase until the replacement of the wall, so for illustrative purposes it is assumed that maintenance costs are zero for the first thirty years of the life of the wall, then increase to 1 per cent of the cost of establishment until the wall reached 40 years of age when the cost increases to 3 per cent, and then once the wall reached 45 years of age the cost increases to 5 per cent. After 50 years (50 years into the future) the wall would need to be replaced, but the analysis will end just before this year (50 years after it is established). The seawall costs incurred over time are summarized in Table 7.

Table 7: Costs of seawall.

Cost type	Year incurred	Cost in XPF/m length	Total cost for 1 km wall
Establishment	1	560,691	560,691,615
Maintenance	1-30	0	0
Maintenance	31-40	5,607	5,606,910
Maintenance	41-45	16,821	16,820,748
Maintenance	46-50	28,035	28,034,581

The length of the seaward side coastline of the study site is 11.99 km. This analysis will use this as the length of wall needed in order to offer some degree of protection to the whole study site. Figure 8 displays the likely location of a seawall for a short section of this coastline.

Figure 8: Example of a 1 km seawall. Source: SOPAC SPC, 2013.

Costs of foregone assets

The opportunity cost of the foregone land on which the seawall would be built has not been valued. It is unclear what the value of this land would be; currently it is at least partially submerged below the sea and does not have a market value.

Costs such as changes to marine life, biodiversity and damage to sea views or natural beauty are not included in this analysis. If a seawall was found to be a viable option, then a full environmental impact analysis would need to be undertaken before decisions could be made on its implementation.

Elevation of houses

The implementation scenarios analysed

To consider the cost of elevating buildings, four elevation scenarios will be analysed:

a) All houses existing in the whole area are elevated immediately.
b) All houses existing in the setback zone are elevated immediately.
c) All houses existing in the whole area are elevated gradually, in the year that they would be rebuilt.
d) All houses existing in the setback zone are elevated gradually, in the year that they would be rebuilt.

The elevation costs are for the raising of floors to 1 m above ground level.

Material costs

Currently there is little or no experience in elevating existing structures on Rangiroa. It is possible to estimate the cost of elevating existing structures by using the values obtained by Williams (1978). These costs have been calculated as a proportion of the full cost of the building and therefore are assumed not to have varied significantly over time. The costs are for the elevation of the floor level (for structures of less than 150 m^2 in area) to 1 m above ground level.

Table 8: Cost of elevating floor (per cent of total construction cost).

Structure type	New structure			Existing structure		
	Min	Mean	Max	Min	Mean	Max
Single storey	2	7	12	11	30.5	50
Multi-storey	2	3	4	2	3	4

Source: Williams (1978) cited in Woodruff (2008).

Any experts who were asked about the possibility of elevating existing structures on Rangiroa were unable to provide an estimate of the cost, stating that they thought it unfeasibly expensive to undertake such an operation. In light of this, and the large costs involved in transporting material and equipment to Rangiroa, the upper limits of these estimations will be used, but it must be emphasised that these costs may still underestimate the costs of elevation, due to the distance that a crane would need to be transported to the atoll. The vast majority of homes observed in Rangiroa were single storey, concrete buildings, so this will be assumed in the analysis and maintenance is assumed to be zero.

Because the analysis is for a 50 year period, the replacement of the elevated buildings at the end of their functioning life must also be included in the cost of this option.

As detailed earlier the elevation can be either implemented immediately or gradually when the houses need to be rebuilt anyway.

For those scenarios where the buildings are elevated gradually, houses would only be elevated once they have to be rebuilt at the end of their life. This makes the average net cost of elevating these houses only 7 per cent more than building an un-elevated house. So each year the cost of gradually elevating houses will be 7 per cent of the cost of construction of the two per cent of houses which happen to be rebuilt that year.

Where the houses are elevated immediately, the calculation of the cost of elevation will differ. It has already been assumed that each year 2 per cent of the houses currently in Rangiroa would have to be rebuilt because they have reached 50 years of age. For this reason if the elevation of houses occurs immediately, 2 per cent of the houses would be rebuilt anyway, so it would only cost an average of an extra 7 per cent of the construction cost to elevate them. The other 98 per cent of the houses would not be rebuilt in this year, so for these the cost of elevating them would be 50 per cent of the cost of constructing a concrete house. In each future year 2 per cent of houses would be rebuilt as they reach the end of their life, and these will also be elevated, costing an extra 7 per cent of the construction cost of these houses. Similarly, where houses are elevated in the year they would be rebuilt anyway (due to old age) the costs calculated still include the actual cost of rebuilding the houses, as well as the cost of their elevation.

Costs of foregone assets

The elevation of the buildings currently on Rangiroa should not cause any reduction in the value of these buildings and they would still be used as before. There may perhaps be an argument of damage to visibility, or natural beauty by elevating the houses but this will not be analysed here.

Savings

It is important to note that in the situations, where houses are only elevated in the year they are going to be rebuilt anyway, the actual extra cost that inhabitants must incur in order to have the building elevated is only 7 per cent of the cost of building. In other words, without the elevation of houses, the inhabitants would still be incurring costs to replace the old, non-elevated properties at the end of their functioning life as usual[4]. The fact that the rebuilding costs as well as the elevation costs will be included in the cost of implementing the elevation option (the fact that the *net* costs of rebuilding and elevation are provided in the LCA), means that in the benefit part of the CBA, the cost of rebuilding those houses that were to be rebuilt in any case will be treated as a saving.

Kit house (MTR)

The implementation scenarios analysed

In this analysis 4 different MTR implementation scenarios are considered:

a) Replace all homes in the whole area studied immediately.
b) Replace only those homes in the setback zone immediately.
c) Replace all homes in the whole area studied gradually, once the current houses reach the end of their life.
d) Replace all those homes in the setback zone gradually, once the current houses reach the end of their life.

[4] These costs of replacing houses at the end of their functioning life are not related to damage from storm surges, they are just the basic costs of maintaining a house which would be incurred even without any cyclone hazards.

Because the analysis is for a 50 year period, the replacement of MTR buildings once reaching the end of their life must be included in the analysis. Consequently after 20 years all houses will need to be replaced again.

Material costs

As detailed by the engineers at the Fonds de Développement des Archipels, the Secretary General of the Avatoru, and an independent real estate expert:

The Fonds de Développement des Archipels stated that the cost of a new 2 bedroom kit house, elevated to 1.5 m is 5 million XPF and for a three bedroom kit house, elevated to 1.5 m the cost is 6 million XPF. Using the prices and areas of these buildings the cost per square metre is calculated to be 88,496 XPF.

Providing that the kit houses are constructed with good foundations and to the correct regulations, they would likely last 20 years until they need to be replaced even without maintenance (John Tagiilima, SOPAC engineer, personal communication, Jan 2013).

After interviewing engineers from both the Fond de Développement des Archipels, and SOPAC, estimates of the durability of the MTRs ranged from 10 to 25 years, with the majority agreeing that without maintenance, an MTR would last 20 years. In this analysis, the 20 year durability is assumed. As previously explained, it is assumed that no maintenance is undertaken.

Recouped costs of forgone assets

If all inhabitants are required to replace their current homes with MTR houses, then their current houses will become much less useful, just as in the setback zone option, and could only be sold as storage facilities or for scrap material. The inhabitants may be able to recoup some of their value, but, as with the setback zone analysis, any intent to quantify this would be speculation and for simplicity it is therefore assumed to be zero.

Savings

It must be noted that without the building and replacement of MTR's, the inhabitants would be incurring costs of replacing the old properties at the end of their functioning life in the zone areas by other houses. By implementing the MTR option this cost is saved. This saving will be included in the benefit section of the CBA (Rios Wilks, 2013).

Summary of costs included in this analysis

Table 9 summarises the costs that would likely be incurred for each adaptation. The costs in black ink are estimated and included in the LCA, those that are in grey are those that may exist but that will not be valued for this analysis.

Table 9: Summary of costs for each adaptation option.

	Setback zone	Seawall	Elevation	Kit houses (MTR)
Material	Relocation costs (purchase of new land and construction of houses)	Construction costs	Construction costs	Construction costs (purchase of MTR houses)
Social	Cultural attachment to location in setback zone. Increased crowding of other areas.	Reduction in natural beauty		
Environmental		Marine biodiversity		
Service provision	Implementation of power lines and plumbing to the new houses			Implementation of power lines and plumbing to the new houses
Business		Disruption of coast affects tourism and fishing		

5 RESULTS OF THE LCA

Due to the large number of scenarios analysed in this LCA, Table 10 shows the labels used in the charts and tables displaying the results.

Table 10: Table of risk reduction options analysed.

Adaptation scenario	Chart label
Seawall − a 11,900 m wall	Seawall
Kit house (MTR) − A) replacing all of the buildings in the whole area studied immediately	MTR A) all area immediately
Kit house (MTR) − B) replacing buildings in the setback zone immediately	MTR B) setback zone immediately
Kit house (MTR) − C) replacing all of the buildings in the whole area studied gradually	MTR C) all area gradually
Kit house (MTR) − D) replacing buildings in the setback zone gradually	MTR D) setback zone gradually
Elevation − A) elevate all of the buildings in the whole area studied immediately	Elevation A) all area immediately
Elevation − B) elevate all existing buildings in the setback zone immediately	Elevation B) setback zone immediately
Elevation − C) elevate any new buildings in the whole area studied (2% per year)	Elevation C) all area gradually
Elevation − D) elevate any new buildings in the setback zone (2% per year)	Elevation D) setback zone gradually
Setback zone − A) immediate implementation of the setback zone using concrete house replacements	Setback A) immediate concrete
Setback zone − B) immediate implementation of the setback zone using MTR house replacements	Setback B) immediate MTR
Setback zone − C) gradual implementation of the setback zone (2% of houses moved per year) using concrete house replacements	Setback C) gradual concrete
Setback zone − D) gradual implementation of the setback zone (2% of houses moved per year) using MTR house replacements	Setback D) gradual MTR

Material cost analysis

The costs of each option are presented below. These have been left without discounting in order to show the actual values that would be incurred. A short section on the discounted costs is presented in the following pages. The costs provided indicate any costs that would need to be incurred in order to implement each option. These figures must be treated with caution as they do not demonstrate the overall monetary impact to society which would be experienced if an option was to be implemented because savings and benefits of implementing options are not included in the LCA. For this reason it is critical that these results are complemented by the CBA.

Establishment costs (year 1)

Figure 9 allows easy comparison of the costs incurred in the first year of the analysis, during the establishment of each option (all costs are in millions of XPF).

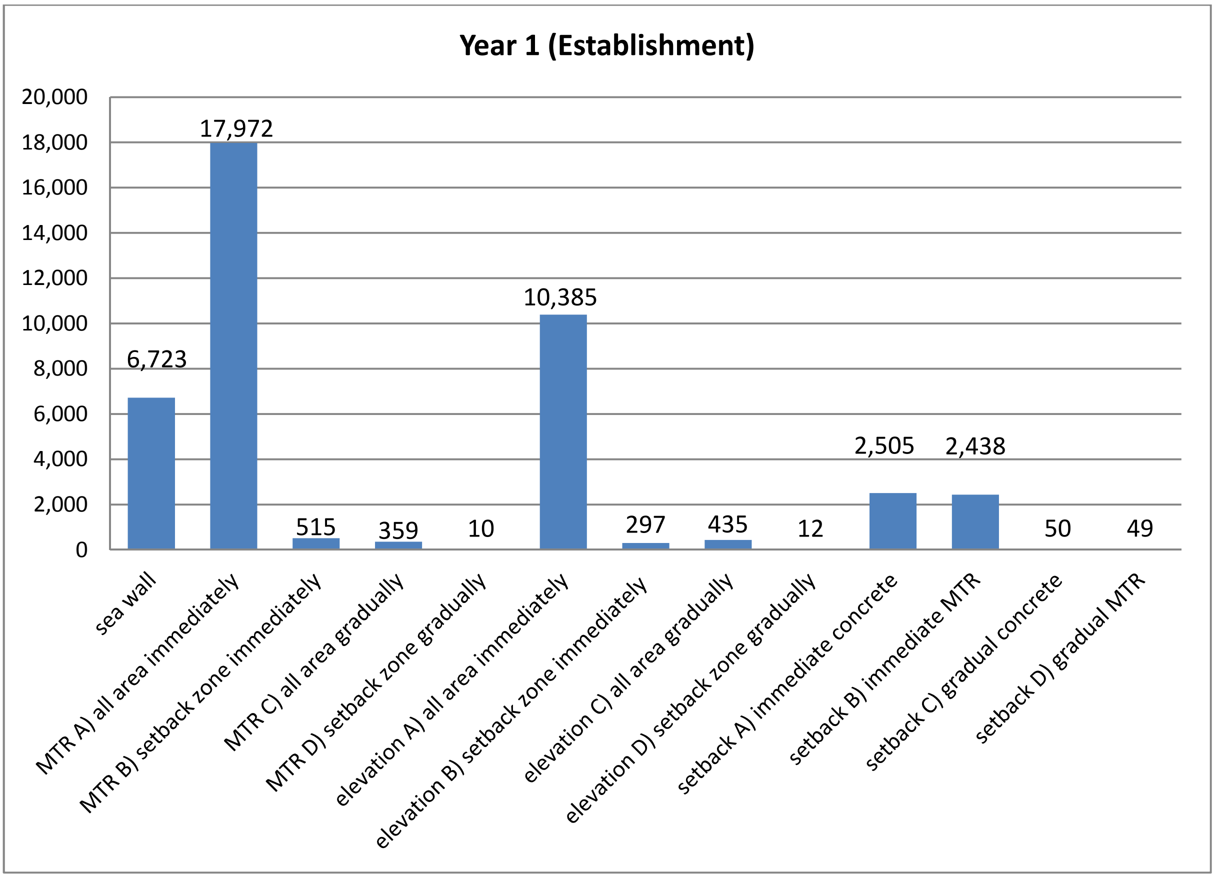

Figure 9: Establishment costs.

From this chart it is clear that the immediate replacement of all buildings in Avatoru and Tiputa with MTRs will be by far the most expensive risk reduction option. This is followed by the cost of immediate elevation of all buildings. This is of course as expected, given that any option that is immediately imposed on all buildings will incur a high cost in this first year.

The cost of the seawall is also relatively large as expected.

The costs of implementing the setback zone with either concrete or MTR replacements are relatively small, due to the relatively few houses in the zone. Due to the similarity in the cost of an MTR or concrete building, the tenth and eleventh options look similar, as do the 12th and 13th options. It will be informative to keep track of how the cumulative cost of these options changes over time, as the MTRs must be replaced much more frequently than concrete buildings.

Due to the fact that there are relatively few buildings in the setback zone area, for all possible risk reduction options, it will always be the case that those which are only implemented in the smaller setback zone area will be cheaper than when they are implemented over the whole area of the Avatoru and Tiputa towns.

Cumulative costs in year 10

Figure 10 allows comparison of the costs that would have had to have been incurred for each option once 10 years has passed since their initial implementation (all costs are in millions of XPF).

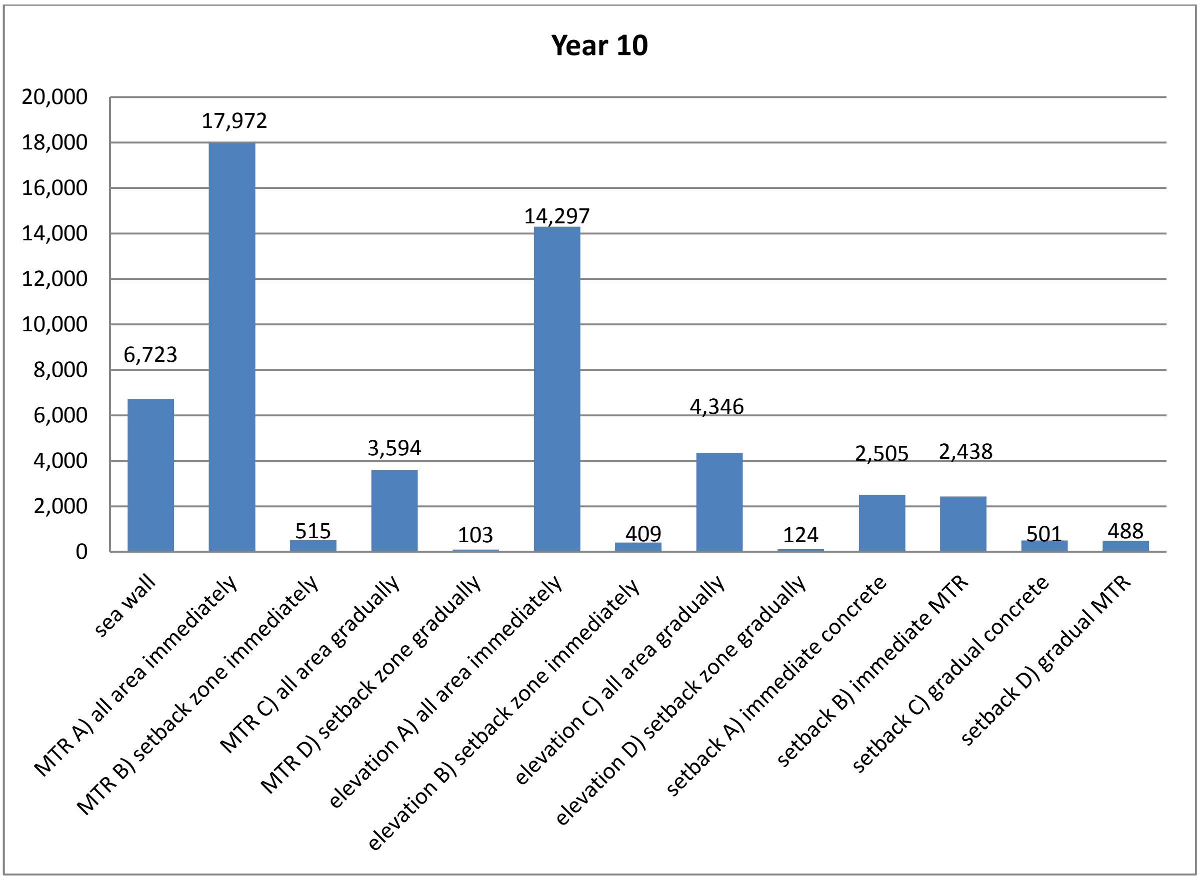

Figure 10: Cumulative costs 10 years after establishment.

Here it is possible to see how the options which are more gradually implemented, such as the elevation or replacement of 2 per cent of the buildings per year, will become more expensive as time goes on and the cumulative cost of their implementation can be observed.

Cumulative costs in year 25

Figure 11 allows comparison of the costs that would have had to have been incurred for each option once 25 years has passed since their initial implementation (all costs are in millions of XPF).

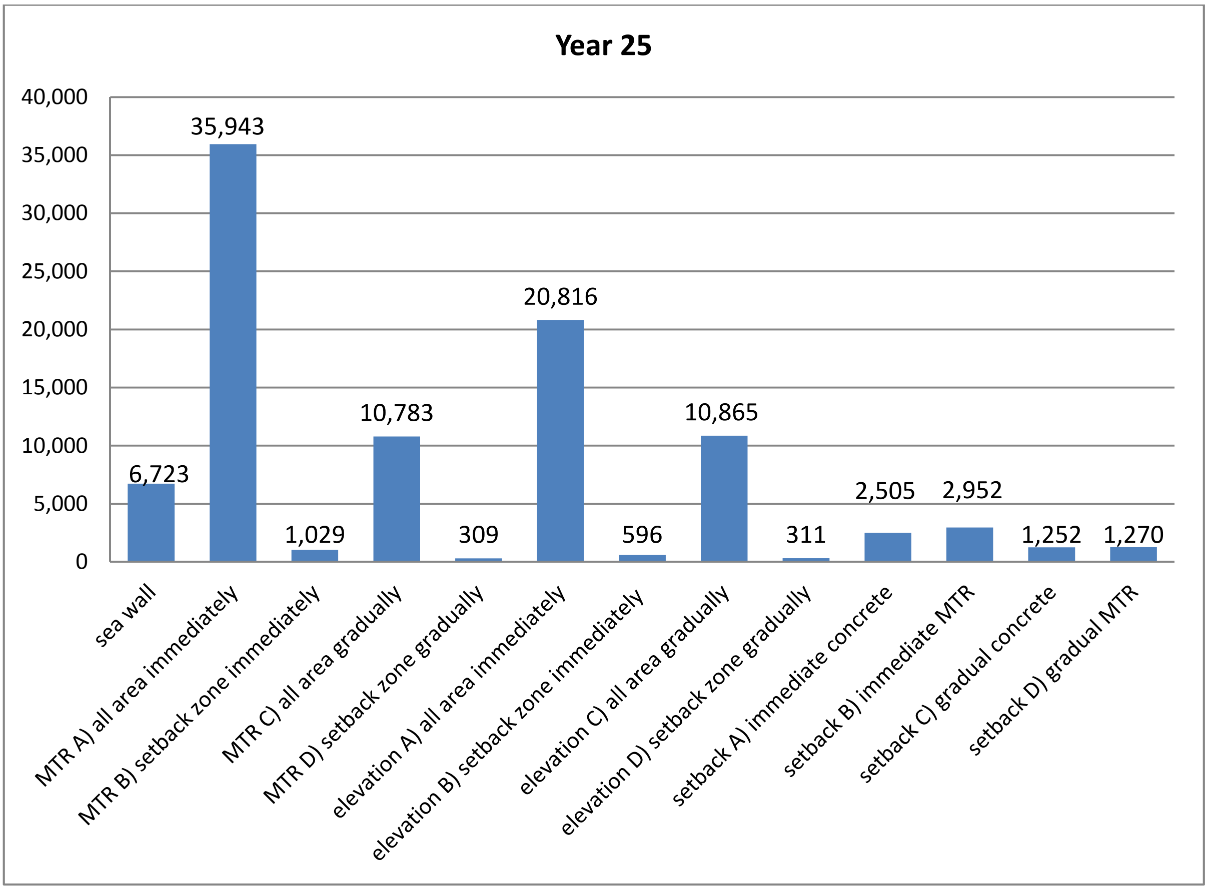

Figure 11: Cumulative costs 25 years after establishment.

It is possible to see a jump in the cost of the options where MTRs are used, 25 years after the establishment of the options,. This is because after 20 years, an MTR building will reach the end of its life and must be replaced, incurring large capital costs.

The cumulative cost of the seawall is still exactly the same as in year 1, because maintenance was only assumed to begin after 30 years (if this assumption was changed then this result would not hold).

Cumulative costs in year 50

The chart below allows comparison of the costs that would have had to have been incurred for each option once 50 years has passed since their initial implementation (all costs are in millions of XPF).

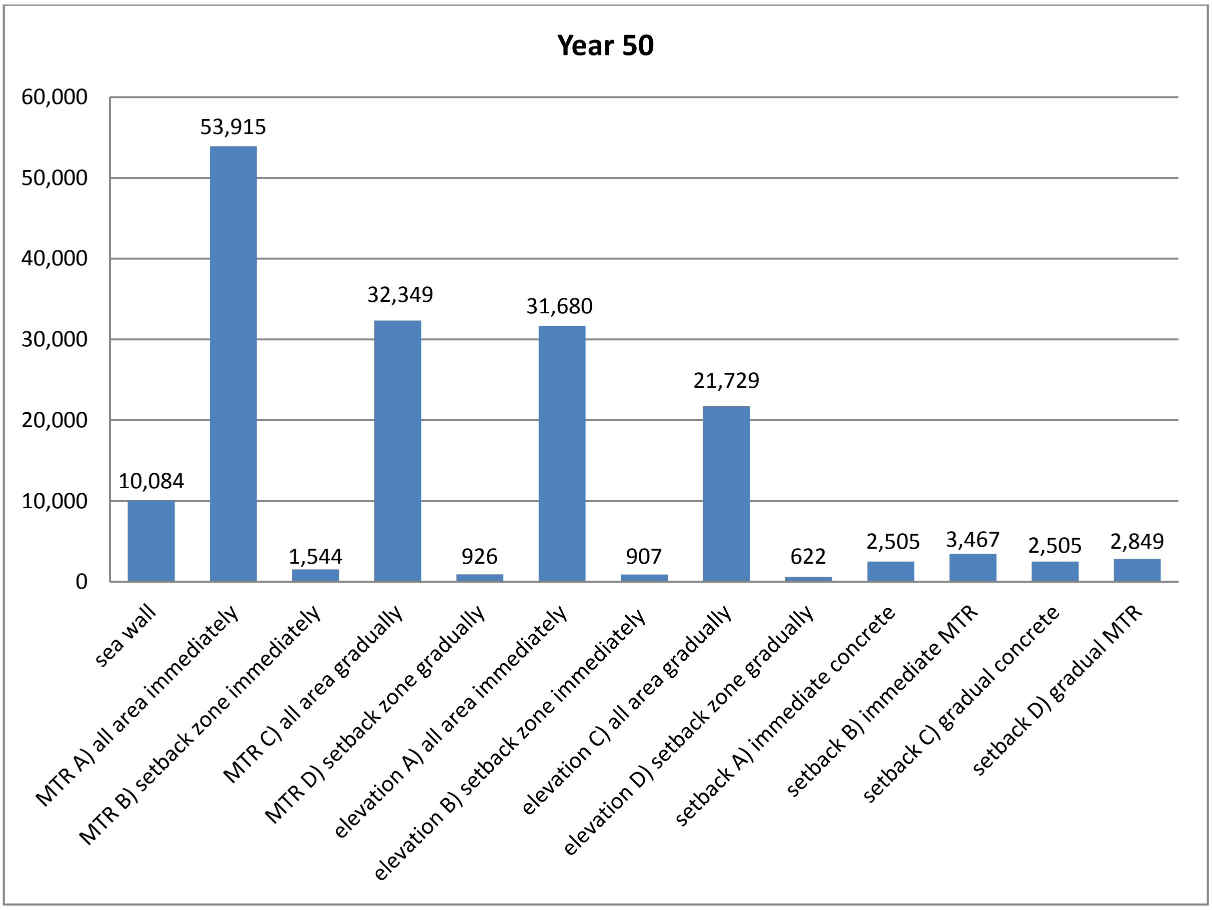

Figure 12: Cumulative costs 50 years after establishment.

In this final year of the analysis, the second option (immediate replacement of all buildings with MTRs) is still the most expensive, followed by the gradual implementation of MTR. The elevation of all buildings are the next most expensive options, with the gradual elevation less expensive than if all buildings are elevated immediately in year one. This is because the cost of elevating an existing building is so much higher than the cost elevating a building while it is being built. The cost of the seawall has risen slightly due to the maintenance which was assumed to be needed every 5 years. The least cost option overall is the gradual elevation of the buildings in the setback zone.

Ranking of the cost of options over time

Table 11 shows how the costs and rankings (in terms of affordability where 1 is the cheapest) of options change over time. Costs are in millions of XPF. From this table it is possible to see that the least cost option after 50 years is the gradual elevation of houses in the setback zone only. Although this is the least cost option, this may not be the most effective option, and this will be analysed in the full CBA (Rios Wilks, 2013).

Table 11: Cost rankings over time.

	Cost in year 1	*Rank*	Cumulative cost at year 10	*Rank*	Cumulative cost at year 25	*Rank*	Cumulative cost at year 50	*Rank*
Seawall	6723	*11*	6723	*11*	6723	*9*	10084	*9*
MTR A) all area immediately	17972	*13*	17972	*13*	35943	*13*	53915	*13*
MTR B) setback zone immediately	515	*8*	515	*6*	1029	*4*	1544	*4*
MTR C) all area gradually	359	*6*	3594	*9*	10783	*10*	32349	*12*
MTR D) setback zone gradually	10	*1*	103	*1*	309	*1*	926	*3*
Elevation A) all area immediately	10385	*12*	14297	*12*	20816	*12*	31680	*11*
Elevation B) setback zone immediately	297	*5*	409	*3*	596	*3*	907	*2*
Elevation C) all area gradually	435	*7*	4346	*10*	10865	*11*	21729	*10*
Elevation D) setback zone gradually	12	*2*	124	*2*	311	*2*	622	*1*
Setback A) immediate concrete	2505	*10*	2505	*8*	2505	*7*	2505	*5*
Setback B) immediate MTR	2438	*9*	2438	*7*	2952	*8*	3467	*8*
Setback C) gradual concrete	50	*4*	501	*5*	1252	*5*	2505	*6*
Setback D) gradual MTR	49	*3*	488	*4*	1270	*6*	2849	*7*

Social (discounted) cost analysis

Discounting the future, means that options which must incur more of their costs in the future rather than in the first year, will become less costly. This can be seen by comparing Table 11 (which demonstrates the undiscounted costs) to Table 12 (which shows the discounted costs). Costs are in millions of XPF. The most useful points to note from these ranking tables is how some risk reduction options change ranking in later years after discounting. Those scenarios which incur relatively more of their costs in the future will become more affordable when discounting is used. Nevertheless, the rankings do not change considerably although the least cost option is now the gradual implementation of MTR in the setback zone.

Table 12: Discounted cost rankings over time.

	Cost in year 1	***Rank***	**Cumulative cost at year 10**	***Rank***	**Cumulative cost at year 25**	***Rank***	**Cumulative cost at year 50**	***Rank***
Seawall	6723	*11*	6723	*11*	6723	*11*	6787	*11*
MTR A) all area immediately	17972	*13*	17972	*13*	20643	*13*	21040	*13*
MTR B) setback zone immediately	515	*8*	515	*6*	591	*6*	603	*6*
MTR C) all area gradually	359	*6*	2429	*7*	3812	*9*	4528	*9*
MTR D) setback zone gradually	10	*1*	70	*1*	109	*1*	130	*1*
Elevation A) all area immediately	10385	*12*	12888	*12*	14290	*12*	14691	*12*
Elevation B) setback zone immediately	297	*5*	369	*5*	409	*3*	421	*3*
Elevation C) all area gradually	435	*7*	2937	*10*	4339	*10*	4740	*10*
Elevation D) setback zone gradually	12	*2*	84	*2*	124	*2*	136	*2*
Setback A) immediate concrete	2505	*10*	2505	*9*	2505	*7*	2505	*7*
Setback B) immediate MTR	2438	*9*	2438	*8*	2514	*8*	2526	*8*
Setback C) gradual concrete	50	*4*	339	*4*	500	*5*	546	*4*
Setback D) gradual MTR	49	*3*	330	*3*	493	*4*	549	*5*

6 FUTURE ANALYSIS

The LCA is only half of the CBA story. It may well be that once the benefit part of the CBA is undertaken; the options which seem more expensive in the LCA are in fact cheaper to society in the long run. For this reason it is critical that this LCA report be complemented by the CBA before optimal policy can be discussed.

Considerations which are not included in the LCA but will be included in the CBA are the following:

1) Benefits from implementing adaptation options.
2) Savings from implementing adaptation options.
3) The feasibility of implementing each option in the specific community involved (Rangiroa).
4) Consideration of which parties will pay for their implementation.

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This report may also be referred to as SPC SOPAC Division Published Report 170

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