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

SPC Applied Geoscience and Technology Division (SOPAC)

September 2013

Anna Rios Wilks

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Natural Resources Economics Section
Ocean and Islands Programme

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DISCLAIMER

IMPORTANT NOTICE

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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
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 benefit 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 m.

This document analyses 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 15 illustrative scenarios in order to provide an indication of which type of adaptation might be more suitable and cost effective for the Tuamotu environment, and as a basis for the Government of French Polynesia to discuss the implications and design specifications to inform further dialogue.

Types of costs and benefits considered in this analysis

This analysis quantifies only the material costs of each option and the reduction in damage to buildings in its benefits. The summary tables below outlines all the values that could be considered in a BCA. Those in green 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 coasts affects tourism and fishing		

Summary of analysis

The results of the full analysis are displayed in Table 3. A discount rate of 10 per cent is used throughout the analysis.

Options are divided into 15 illustrative scenarios. A scenario has larger benefits than costs if the benefit-cost ratio (BCR) is greater than unity.

The scenarios are ranked by efficiency (or "cost effectiveness") with "1" being the most efficient.

The total costs of implementation are taken from the LCA and show the total funds required (in millions of XPF) over the 50 years of this analysis[1]. The affordability ranking ranks these implementation costs with "1" being the least cost option.

[1] A social discount rate of 10 per cent was applied in order to compare and aggregate costs over time.

Note that elevation and MTR options that are only implemented in the setback zone are always cheaper than if they are implemented over the whole area; this is simply due to the scale of the intervention. The next column asks which parties might be expected to pay for the adaptation options assuming current social norms.

Table 2: Summary of benefits for each adaptation option.

	Setback zone	Seawall	Elevation	Kit houses (MTR)
Building damage	Slight reduction in velocity and depth of inundation	Velocity of inundation reduced	Depth of inundation reduced	Depth of inundation reduced
Household goods	Possible small reduction in damage		Significant reduction in damage	Significant reduction in damage
Fatalities/injuries	No change expected as shelters are already under implementation to accommodate all inhabitants during emergencies			
Service provision			Reduction in inundation of equipment	Reduction in inundation of equipment
Business			Reduction in inundation of stock and equipment	Reduction in inundation of stock and equipment

Summary of results

From this preliminary analysis, the categories that appear likely to reduce damage significantly are the elevation of buildings and the use of MTR houses, both of which would result in higher floor heights. This is an encouraging result because if these options are implemented on a gradual basis, they are likely to produce overall benefit to society once their full benefits are quantitatively taken into account. Furthermore, if these options are gradually implemented, they pose much fewer challenges to society than a seawall or setback zone would, and are consequently much more likely to be accepted by the community.

A seawall is expected to provide little reduction in the depth of inundation and due to its high cost is a relatively inefficient option for reducing damage. It might also produce environmental effects and could impact tourism by reducing the aesthetic qualities of the coast.

Table 3: Summary of analysis of the adaptation scenarios.

Adaptation scenario		BCR	Efficiency rank	Total cost of implementation (million XPF)	Affordability rank	Who might pay?
Seawall	Assuming wave force reduced by 25%	0.0021	15	6,787	11	Government
	Assuming wave force reduced by 50%	0.0061	14			
	Assuming wave force reduced by 75%	0.0149	13			
Immediate MTR implementation	Whole area	0.2129	10	21,040	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.
	Setback zone only	0.2134	9	603	6	
Gradual MTR implementation	Whole area	0.9867	2	4,528	9	
	Setback zone only	0.9874	1	130	1	
Immediate elevation to 1 m	Whole area	0.2876	5	14,691	12	
	Setback zone only	0.2874	6	421	3	
Gradual elevation to 1 m	Whole area	0.9391	4	4,740	10	
	Setback zone only	0.9396	3	136	2	
Immediate implementation of setback zone	Relocated to concrete building	0.0469	12	2,505	7	
	Relocated to MTR	0.0512	11	2,526	8	
Gradual implementation of setback zone	Relocated to concrete building	0.2326	8	546	4	
	Relocated to MTR	0.2334	7	549	5	

A setback zone is found to provide little reduction in storm surge damage to buildings. This is because the storm surge hazard model predicts that the majority of the area of study, regardless of its distance from the coastline, is at risk of significant depths and speeds of inundation. Also, there are other unquantified costs associated with the setback option such as cultural attachment to the land that inhabitants would be forced to give up and social challenges in finding new land for the displaced.

MTR produce the highest benefits, but their immediate implementation is a relatively inefficient option because it leaves current buildings unused. The gradual implementation of MTR means that inhabitants only replace their current homes once they are no longer of use, producing the highest benefit to cost ratio.

Elevation of buildings also significantly reduces damage, although their immediate elevation of the current buildings is relatively costly due to the engineering challenges in elevating buildings that are already constructed. The gradual elevation of buildings seems much more advantageous, producing a benefit to cost ratio almost as large as the gradual use of MTR.

Likely overall effect to society

Aside from those analysed, there are also other costs and benefits that must be taken into account. Column 2 in Table 4 first shows the expected return of each adaptation option when only the construction costs and reduction in damage to buildings benefit are taken into account. This column summarises the quantitative findings of this report. Then, the remainder of the table lists the other costs and benefits that may be incurred if the adaptation options are put into place. The final column displays the likely overall effect to the community when all of these costs and benefits are taken into account.

Table 4: Overall expected impact of options to society.

Adaptation scenario	Expected return	Other costs	Other benefits	Likely overall effect to society
Seawall	For every 100 XPF spent, only 1 is recouped.	Environmental impacts? Effects on tourism?		Negative
Immediate MTR implementation	For every 100 XPF spent, only 21 are recouped.	Buildings currently in use will go to waste.	Reduces damage to household goods and the stock or machinery of businesses. Likely will allow for quicker return to normal business post cyclone. Potential for more benefits due to less wind damage to MTR buildings as they are “anti-cyclonic” and withstand winds of up to 204 km/hr.	Negative
Gradual MTR implementation	For every 100 XPF spent, 99 are recouped.			Positive
Immediate elevation to 1 m	For every 100 XPF spent, only 29 are recouped.		Reduces damage to household goods and to the stock or machinery of businesses. Likely will allow for quicker return to normal business post cyclone.	Negative
Gradual elevation to 1 m	For every 100 XPF spent, 94 are recouped.			Positive
Immediate implementation of setback zone	For every 100 XPF spent, only 5 are recouped.	Cultural attachment to land given up. Social costs of relocation. Current buildings in setback zone area go to waste.	May be some further reduction in damage due to less buildings being in the area where the wave is breaking and most turbulent.	Negative
Gradual implementation of setback zone	For every 100 XPF spent, only 23 are recouped.	Cultural attachment to land given up. Social costs of relocation.		Negative

The most efficient option

The most efficient option is found to be the gradual replacement of buildings with MTR. Nevertheless, when only the value of the reduction in damage to buildings is quantified in the benefit analysis, the benefit-cost ratios for all adaptation options are still slightly below 1, implying that no option generates enough savings to cover their costs in this minimum benefit case.

On the other hand, both the elevation and MTR options also generate benefits that were not quantified in this analysis such as the reduction in damage to household goods and reduction in post disaster losses to business and services that may otherwise see their stock or machinery inundated. Furthermore, it is likely that there would also be a reduction in damage from other smaller, more frequent events by implementing these options.

Consequently, it is likely that once these other elements are included, analysis will demonstrate that adaptation options which allow for elevation of buildings will provide an overall gain to society.

Key overall findings

- From this preliminary analysis, the only categories that appear likely to reduce damage significantly are the elevation of buildings and the use of MTR houses, both of which would result in higher floor heights. This provides clear support for the building of cyclone shelters like those currently being implemented by the Government of French Polynesia.
- The adaptation options which raise the floor heights (MTR and elevation options) produce a reasonable benefit to cost ratio if they are implemented gradually in order to minimise the waste of assets already in place in Rangiroa.
- When only the minimum damage reduction values (reduction in damage to buildings only) are included in the benefits, none of the adaptation scenarios analysed could produce benefits that outweighed their costs after 50 years. Nevertheless, in the case of the gradual implementation of the MTR and elevation of buildings options, if their other benefits (such as reduction in damage to household goods, business assets and business interference) are quantified and included, it is likely that overall gain to the community would be produced if they were to be implemented.
- The analysis shows that there are many benefits in using MTR and elevating buildings, and if the options are implemented gradually over a number of years their cost is relatively low. This demonstrates that possible adaptation options have been found for Rangiroa and may be used as a basis for the government to continue its work in community protection.

Recommendations

- The government should focus future analysis on options which elevate the floor level of buildings to at least 1 m. If building regulations are to be imposed, then support has been found for the use of elevated MTR buildings and concrete buildings elevated to 1 m or above.
- For any adaptation option that is considered, there is a need to take into account the implications for the community and their ability to afford the intervention. There may be a need for cost sharing with the government providing subsidies or favourable loan repayment systems.
- The government should continue its work in the provision and maintenance of cyclone shelters for the inhabitants of Rangiroa to ensure that they have access to good protection during cyclone and storm surge events.

1 INTRODUCTION

The disaster risk reduction project

The EDF 9 C Envelope funded by the EU aims to reduce risk from natural disasters in 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; the purpose of this project is to define this hazard more accurately and inform risk mitigation solutions.

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 the second part of the complete economic analysis of this project, providing a preliminary assessment of the efficiency 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 this analysis

In response to the threat of cyclones and the storm surges they produce, French Polynesia, including Rangiroa and its neighbouring atolls, have 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 m of the first vegetation line on the coast side, and 10 m 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.

To inform future considerations, this document outlines the potential cost and benefit 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 the payoffs from 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 this BCA, the assumptions made on each of the adaptation options considered and their illustrative scenarios analysed in the BCA. Section 4 displays the results of the least cost analysis with section 5 detailing the analysis of the benefits produced by each scenario and the results. Section 6 brings together the benefit and cost results in order to form the overall benefit-cost measurements of each scenario and also runs some sensitivity analysis. Section 7 discusses the feasibility and implications of each adaptation option.

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 a vast 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).

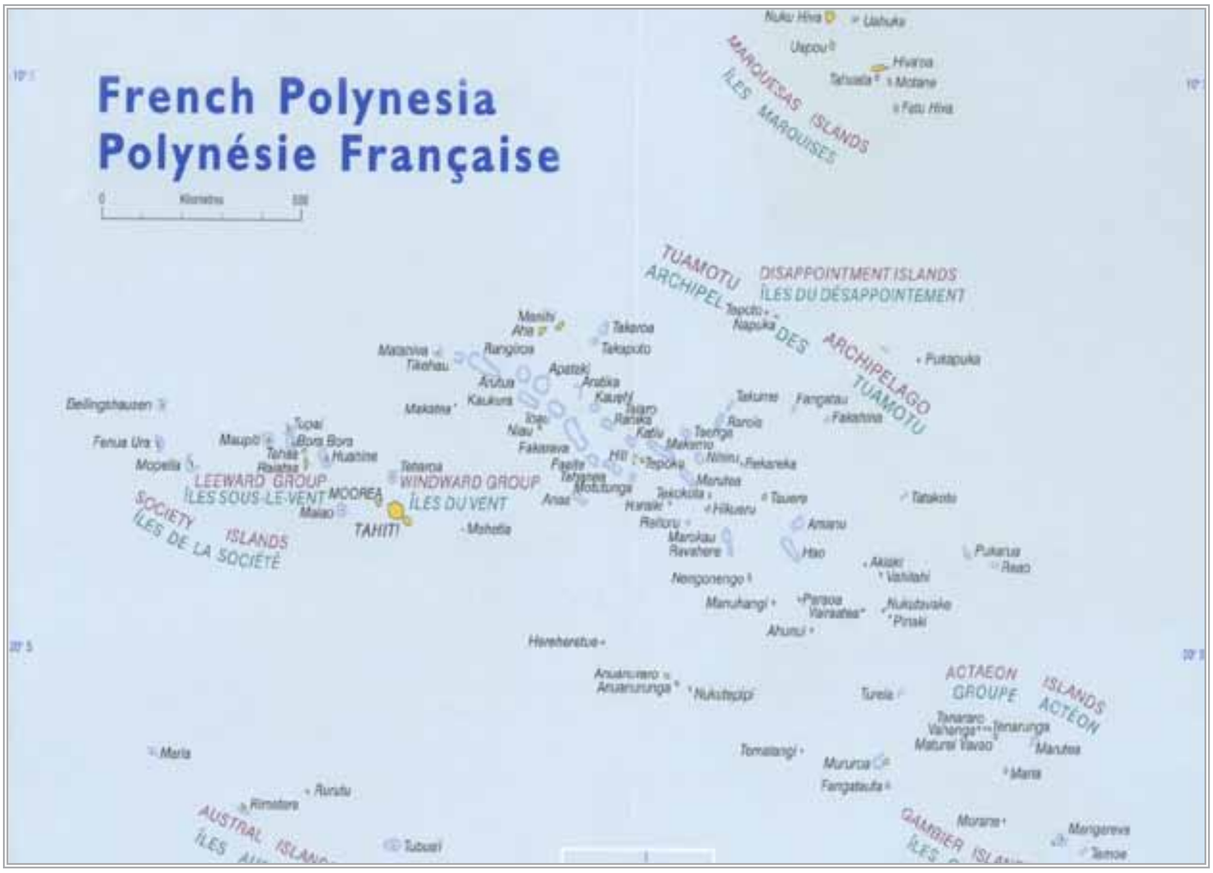

Figure 2: French Polynesia . Source: SOPAC, SPC (2013).

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 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. Nonetheless, the fishing sector has seen increasing returns over the recent years with the value of fisheries exports increasing 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) expected 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 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 Niño 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 5). In total, these 11 events resulted in 56 fatalities and created major housing, infrastructure and crop damage.

Table 5: 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 Table 6, 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 6: 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	5,050	
TC – Orama	1983	16,000	6		
TC – Arthur	1991				
TC – Osea	1997			5,600	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 has 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.

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

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.

Figure 4: Rangiroa. Source: SOPAC SPC, 2013.

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). In Figure 5, the red zone boundaries can be observed for the most populated segment part of Avatoru.

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. Consequently, 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 (picture taken at site).

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 on site) 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 1983-1984 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 during normal times uses the shelter as the high school and 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 had 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 300 km/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 m2 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 of 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 1100 m2 and will double as a new medical centre, while the other will be used as a municipality building (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 bought 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, Fonds de Développement 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, providing some flood protection also.

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 windspeeds 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

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

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 SOPAC engineers, ersonal 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).

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 1.5 m, 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 ten per cent of the price of the MTR house). Alternatively, the full or subsidized payment of the house can be done by a scheme in which the house is initially provided by the government 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 ascertain 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

The study takes the form of a preliminary benefit cost analysis (BCA) of setback zones, elevation and kit housing along the most inhabited area of the Rangiroa coast. This BCA is the second part of the full economic analysis of this project. The study draws on to consider the frequency and severity of past coastal flooding arising from storm surges and cyclones.

The Government of French Polynesia is interested in reducing the risk posed by storm surges with a significant wave height of 12 m. According to an extreme value analysis carried out by Scott Stephen, NIWA, (Coastal Numerical Modeller, SPC SOPAC, personal communication, 2012) for Tahiti, a significant wave height of 12 m has a return interval of approximately 50 years, or a 2% chance of occurring in any one year.

Drawing on scientific data generated as part of the project's modelling of storm surges, the potential area, depth and velocity of inundation related to this type of storm surge is inferred. Based on documentation of previous floods and a recent report carried out by an engineering company (Worley Parsons, 2013) on the potential damage to the study area due to storm surges, the benefit of each adaptation option is estimated. This information will be compared with the costs of applying the adaptation options along the same area of Rangiroa. These costs were estimated in the LCA which is the first part of this study in which the reader will find details of all costing assumptions and results (Rios Wilks, 2013). Based on analysis, preliminary recommendations are made.

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). This means that the analysis assumes that each adaptation option is in place for 50 years, and analyses the costs and benefits produced by each, over this time period.

Benefit cost analysis (BCA)

A BCA values the economic cost and benefit of each of the options in monetary terms, including the option of doing nothing (the "without" option, or the "baseline" option). These benefits and costs are then aggregated in order to construct the net present value (which could be negative) of each option and the benefit-cost ratio of each option. The Government of French Polynesia will be able to use these measurements to see which of the options provides the most efficient risk reduction during different stages of the 50 year period evaluated in order to make informed decisions on how best to reduce storm surge risk.

Each option will reduce the damage from storm surges by different amounts, and so will provide different amounts of benefit to society. Each adaptation option is assessed against the "without option" (the current status quo). The economic benefit of implementing the risk reduction option will be the reduction in damage and loss caused by storm surges if the option was not to be implemented; the "without option".

For this project a static rather than a stochastic analysis will be undertaken. Static analysis assumes that there is only one magnitude of cyclone event possible, in this case, a one in 50 year event. In reality, there exists all types of storm surge, from those that occur on average once per year, to those that only occur every millennia. Consequently, every year there is a possibility of any of these types of events occurring, and even that multiple events occur. But, undertaking an analysis which accounts for all of these possibilities would be too complex for the time allocated to this project, and so, a static analysis will provide an initial sense of costs and benefits of the options open to the government.

Adaptation scenarios analysed

The Government of French Polynesia are presently open to the idea of alternative means of adaptation to storm surges; however the specific methods have yet to be determined. To provide an indication of possible implications for design, several options for how adaptation might be implemented are provided. These are not exhaustive and could still take other forms. Nevertheless, they will hopefully provide sufficient information to guide further dialogue. There are 13 options for the implementation of the various adaptations that the government might consider. Although there is only one option for the implementation (construction method) analysed for the seawall, the amount by which the seawall would reduce the force of the storm surge is unknown and so the seawall option is split into 3 hypothetical scenarios when analysing its benefits. In total then, 15 possible scenarios are analysed in the BCA and are summarised below [2].

[2] More detailed explanation of the assumptions behind each form of implementation can be found in the LCA (Rios Wilks, 2013).

Seawall

There is only one type of seawall, and method by which it is implemented, considered in this analysis. It 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 wall would run along the whole length of the study area (1199 km) on the side of the sea coast. At this time, there is no data as to how much this seawall would be expected to reduce the force of a storm surge with a significant wave height of 12 m. For this reason, the benefit analysis breaks down the seawall option to include three illustrative scenarios in order to analyse the expected benefit of this seawall:

a) The seawall is able to reduce the storm surge force by 25 per cent.
b) The seawall is able to reduce the storm surge force by 50 per cent.
c) The seawall is able to reduce the storm surge force by 75 per cent.

If the seawall was to be considered more seriously, further modelling of the storm surge with a seawall present would need to be undertaken. Nevertheless, if results find that even with a 75 per cent force reduction, the seawall is not economically viable then it is suggested that this option be discarded.

Kit houses (MTR)

In this analysis, 4 different MTR 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.

Elevation

In this analysis, 4 different elevation scenarios are considered:

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

Set back zone

In this analysis, 4 different setback zone scenarios are considered:

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.

Assumptions used in cost and benefit analysis

The risk of storm surges per annum

Throughout the analysis the risk per annum of a storm surge event is taken to be 2 per cent. This means that each year, the average expected damage the area would incur due to a storm surge is 2 per cent of the total estimated damage due to this event.

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. The relative weight placed on costs or benefits incurred in different time periods can be determined quantitatively through

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

"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 is 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 also allows this analysis to maintain consistency with other SOPAC analyses. This analysis will evaluate each option using discount rates of 10 per cent. For sensitivity analysis the options will also be analysed using rates of 7 per cent and 3 per cent.

Values and Prices

The values for costs and benefits will be reported using constant rather than nominal prices. All costs of construction and implementation have labour costs automatically included.

The values of land and buildings were obtained through interviews and data collection in Tahiti and Rangiroa, full details can be found in the LCA (Rios Wilks, 2013) but a summary table for values used in this analysis is given in Table 7.

Table 7: Cost of assets.

	Minimum	Average	Maximum	Source
Rangiroa Land	88 XPF/m^2	2,415 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
Elevated concrete house (single storey)		107,000 XPF/m^2		Rangiroa real estate expert and estimates of cost of elevation[4].

Data on the study area

From aerial images and geographic information system data, the land and building areas in the study zone were calculated and summarised in Table 8.

Table 8: Land and building areas used in the analysis.

	Area of land (m^2)	Area of buildings (m^2)
Total area under study	4,435,600	203,078
Setback zone only	796,300	5,815

Source: SOPAC, SPC (2013).

Data on the houses currently in Rangiroa

Observations made in December 2012 showed that the majority of buildings in Avatoru and Tiputa are single story and concrete. The exceptions to this were the very few two story buildings, MTR's and wooden houses and the shelter constructed in Tiputa under the cyclone shelter program. Throughout the economic analysis, it is assumed that all buildings currently in Rangiroa are single storey, concrete structures. The expected life span of a concrete building of this kind is 50 years. See LCA document for more details (Rios Wilks, 2013).

Throughout the analysis the age of the houses that are currently present in Rangiroa must also be assumed. It has been assumed that the houses currently on site are single story, concrete buildings with a duration/lifespan of 50 years. As the actual age of each individual house is unknown, it is assumed that the ages of the houses are evenly distributed between 0 and 50 years of age[5]. The values of houses of different ages are calculated using the net replacement cost formula, detailed in the LCA report (Rios Wilks, 2013).

[4] The value of an elevated single storey concrete house is assumed to be the value of an non-elevated single storey concrete house, plus the value of assets used when elevating this type of house during its construction. As detailed in the LCA, the extra cost of elevating this type of structure during its construction is 7 per cent of the value of the non-elevated structure. Consequently, the value of an elevated single storey concrete house is 107 per cent of the value of a non-elevated single storey concrete house.

[5] Note that this also means that in the "without scenario", even if no risk reduction options were implemented, in any one year 2 percent of the houses should reach 50 years and need to be rebuilt.

4 COST ANALYSIS

The preliminary least cost analysis (LCA) of risk reduction options is described in Rios Wilks (2013a) and the cumulative costs over time are summarised in Figure 8. These costs have been calculated with social discounting at 10 per cent.

Figure 8 shows the total discounted value of the cost of implementing each adaptation scenario after the full 50 years lifespan of the analysis. All of the seawall scenarios cost the same, and are displayed in a single column.

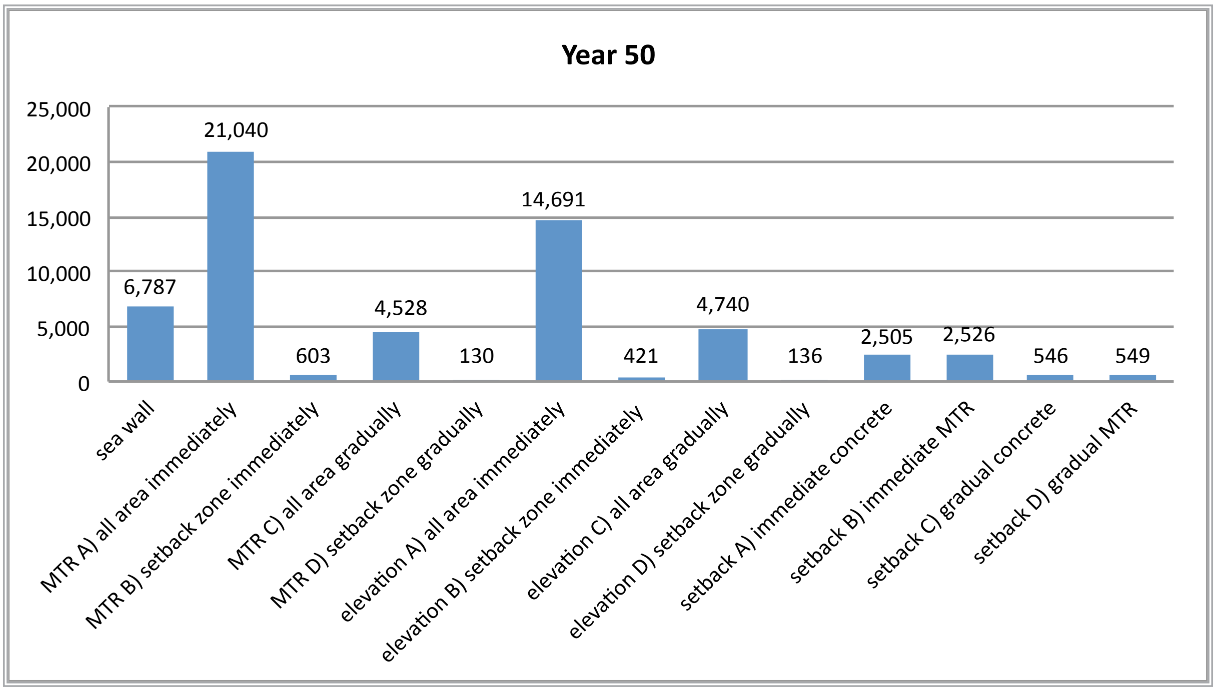

Figure 8: Total discounted costs after 50 years (in millions of XPF).

The most costly adaptation scenario is the immediate replacement of all buildings in the study area with MTR houses. This is likely due to the fact that a large proportion of the costs are incurred in the first year rather than in the future. The further into the future the costs are incurred, the lower their social value will be after time discounting has been applied. Nevertheless, it could be the case that the more expensive options also produce the most benefit and in order to make an informed decision about which option is most efficient, the benefit-cost ratio must be studied.

5 BENEFIT ANALYSIS

The benefit of implementing each adaptation option, is the reduction in damage and loss incurred by the community due to a storm surge event once these options are in place. Due to time and data restrictions this preliminary analysis includes only the material costs and benefits of each option. Impacts on the economy and the environment are briefly discussed.

The storm surge model for Rangiroa

Although a storm surge with significant wave height of 12 m has a 2 per cent probability of occurring per annum in the region of the Pacific where Rangiroa is located, this does not mean that Rangiroa itself would suffer a surge of this magnitude. There are many other factors such as the direction of the surge and the height of the tide which would affect the height of the wave. For the French Polynesia project, a probabilistic analysis for the future occurrence of the specific storm surge modelled in Rangiroa was not undertaken. For this reason, the simple 2 per cent probability estimate is employed throughout this analysis.

From the models constructed by the SOPAC team, it is possible to see the depth and velocity of inundation that different areas of land would face in such a storm surge event, and from this, infer the likely damage caused.

Inundation depth map

Figure 9 displays the different depths of inundation that areas in the study region are likely to experience in this storm surge event.

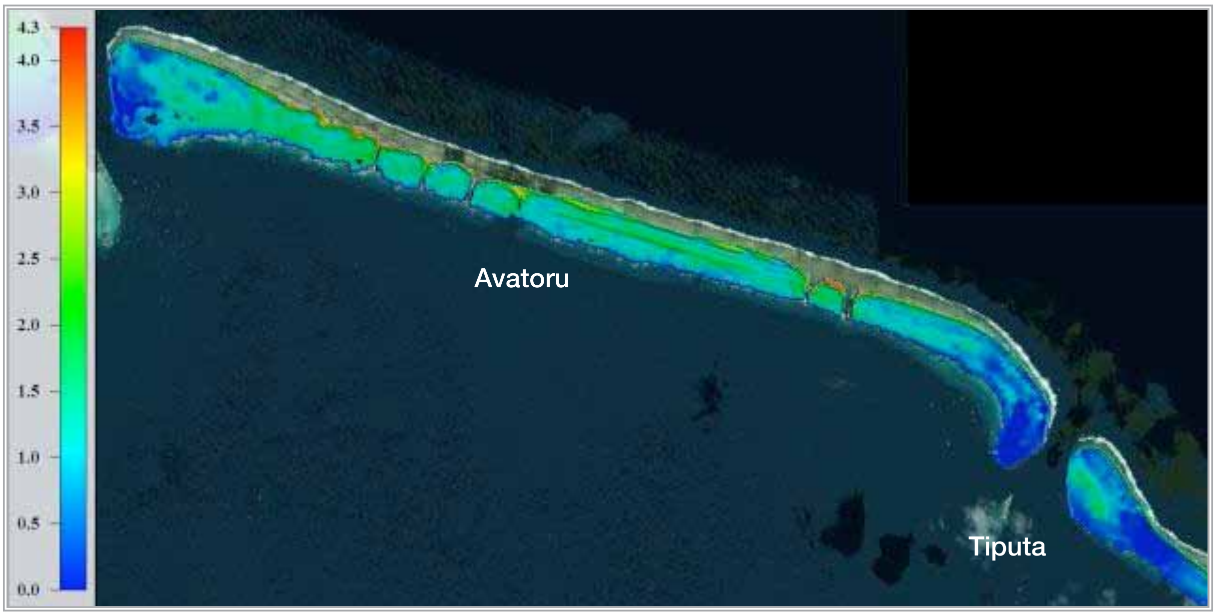

Figure 9: Inundation depth (metres) during a storm surge event with significant wave height of 12 m. SOPAC SPC, 2013.

A significant proportion of the region is expected to be inundated to depths of 1 m. and above, some areas experiencing inundation levels over 3 m.

Inundation speed map

Figure 10 displays the different speeds at which the inundation wave is expected to hit areas in the region during this storm surge event.

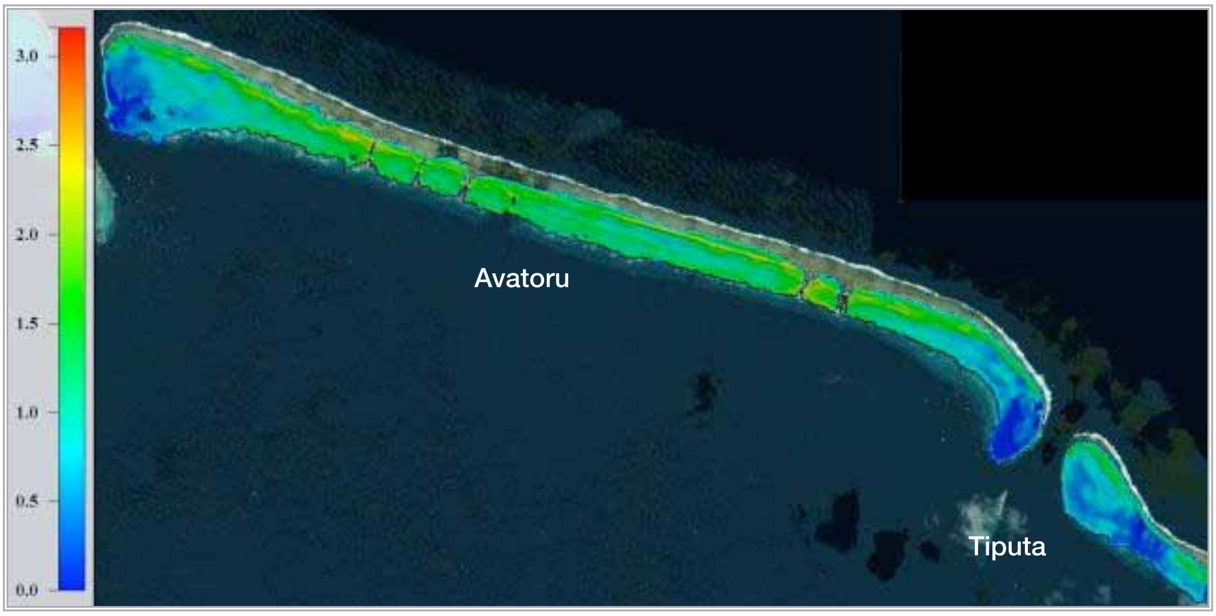

Figure 10: Speed of wave (m/second) during a storm surge event with significant wave height of 12 m. SOPAC SPC, 2013.

For much of the region the speed of the wave would reach over 1.5 m per second.

Risk category map

A risk map shows the category of risk each location would face if a one-in-fifty year event was to occur. The categories shown here correspond to those suggested by the Government of French Polynesia. The storm surge risk is categorised based on the maximum depth and speed of the water in a given area, as shown in Table 9.

Table 9: French Polynesia categorisation of risk from storm surge.

	Speed < 0.5 m	0.5 ≤ Speed
Depth < 0.5	Category 1 (Weak)	Category 2 (Intermediate)
0.5 ≤ Depth < 1.0	Category 2 (Intermediate)	Category 3 (Strong)
1.0 ≤ Depth	Category 3 (Strong)	Category 4 (Very Strong)

The colours shown in the above table correspond to those in Figure 11, each signalling the risk category of any given point in the area.

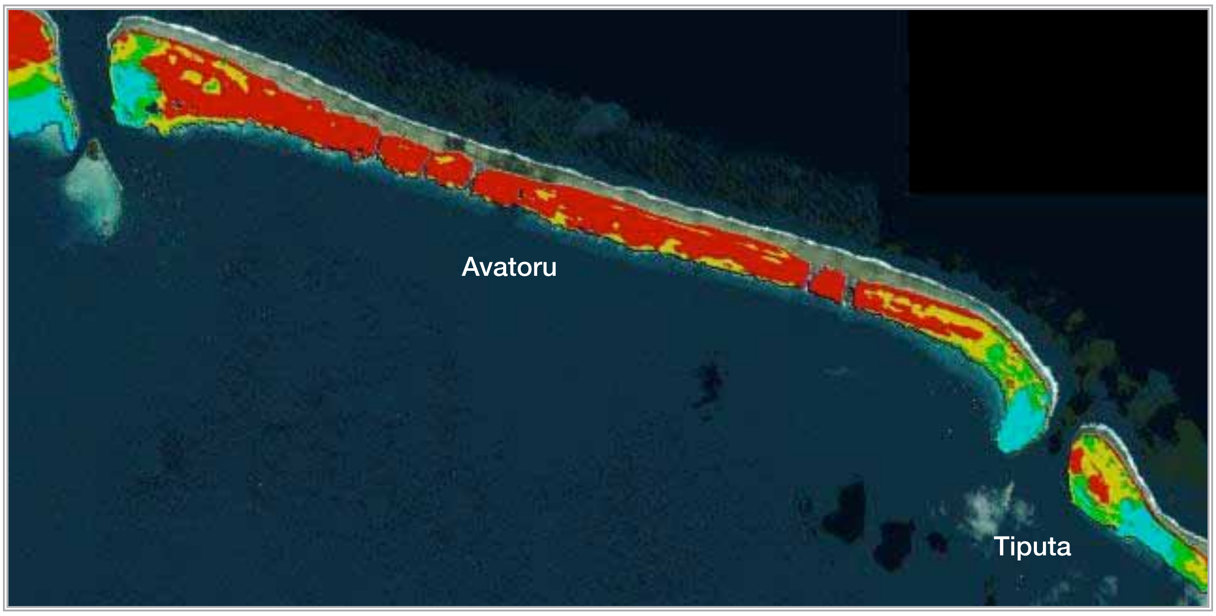

Figure 11: Risk category map. SOPAC SPC, 2013.

Housing density map

This map shows the location of the houses in the area of the Avatoru and Tiputa *motus* studied in this project.

Figure 12: Housing density map. SOPAC SPC, 2013.

As shown above, there exists a high density of households in the study area, with slightly more on the lagoon side of the *motus*.

Damage and losses expected

In the past, damage and loss assessments of storm surges have never been undertaken in the Tuamotus, with efforts focusing on providing assistance to inhabitants and the restarting of normal life. For this reason, there is no official data that may be used in order to evaluate the loss caused by storm surges.

The most obvious damage caused is to infrastructure, the damage or destruction of homes, roads, public buildings, businesses. Other losses are due to loss of life, livelihoods and ongoing problems due to a reduction in service provision such as hospitals or power plants. Due to time restrictions, not all of these elements are quantified in this analysis.

Description of the adaptation benefits quantified in this analysis

Damage to buildings

Different magnitudes of storm surge will destroy buildings in larger or smaller areas and in more or less densely populated land. Using the storm surge models, and aerial photographs, it is possible to see the number and area (in square metres) of buildings that would be destroyed or damaged[6]. The cost of destruction of these buildings is then estimated.

An independent engineer report was undertaken for this analysis, which provided estimates of the damage that different building types may suffer after a storm surge with a significant wave height of 12 m, depending on which risk category

[6] Damage and destruction included in this analysis refers only to that which is due to the depth and speed of the storm surge itself. No wind damage or other possible forms of damage are included.

they are located in (Worley Parsons, 2013). The engineer analysis also estimated the new categories that buildings would be in if a seawall was able to reduce the force of the wave by 25, 50 and 75% (see Worley Parsons (2013) for more details). Table 10 displays the average expected damage to buildings as a percentage of their value for this storm surge event. These are the damage values used in this analysis.

Table 10: Expected damage to buildings for each risk category after a storm surge with a significant wave height of 12 m.

		Description of category		Average damage to buildings (as a per cent of the building value)		
French Polynesia category	New category for more accurate analysis[7]	Depth	Speed	Concrete (no elevation)	Concrete (elevated to 1 m)	MTR/kit house (elevated to 1.5 m)
1	1	depth < 0.5	speed < 0.5	0.045	0.02	0.02
2	2a	depth < 0.5	0.5 ≤ speed	0.045	0.02	0.02
2	2b	0.5 ≤ depth < 1.0	speed < 0.5	0.02	0.02	0.02
3	3a	0.5 ≤ depth < 1.0	0.5 ≤ speed	0.11	0.02	0.02
3	3b	1.0 ≤ depth	speed < 0.5	0.185	0.12	0.12
4	4	1.0 ≤depth	0.5 ≤ speed	0.575	0.51	0.51

Worley Parsons (2013)

Description of unquantified benefits

Although not all losses from storm surges are included in this preliminary analysis of the benefits of adaptation, it is important that they be noted. The main elements that would likely suffer from a storm surge are described below. Future more detailed analysis may focus on quantifying the losses that these sectors suffer during and after a cyclone, so that any reduction in losses that an adaptation option may provide, can be included in the benefits of these options.

Damage to household goods

Values of the basic goods that could be claimed by inhabitants who wished to be compensated by the government after damage caused by cyclone Oli (2010) were suggested by the French High Commission (Colonel Maxence Jouannet, personal communication, Dec 2012). This data provides an estimate of the value of the principle household goods that are expected to be found in a typical, four person household in the Iles du vent (eastern Society Islands which include Tahiti), the Australes and the Iles sous le vent (the western Society Islands). The seven goods included in the estimation were; a refrigerator, a freezer, a cooking stove, a washing machine, 4 beds, a 4 person wardrobe and a four person table and chairs. The value of these items in the Iles du Vent was 705,000 XPF, the value for the Australes and the Iles sous le vent was 885,000 XPF.

The average number of people per household is 3.7. Although of course no household would actually have 3.7 members, for statistical analysis it is possible to manipulate the values of the goods in order to calculate the value of goods in a representative household of 3.7 members. Out of the seven goods considered, only the number of beds, clothes and chairs would be expected to vary between households with slightly different numbers of inhabitants. The values of these is adjusted to calculate the cost that a representative household of 3.7 members rather than 4 members would spend.

In practice, the replacement cost for items such as those compensated by the government is likely to be dependent on their isolation and distance from Tahiti (which is the international port and economic centre of French Polynesia). The price of the goods in the Iles du vent (those closest to Tahiti) is lower than that for the other islands in this survey. The distance between Tahiti and Rangiroa is more similar to the distance between Tahiti and the Australes, and both Rangiroa and the Australes are serviced by an airport and by ship. For this reason, the price of the goods in the Australes is used as a proxy for the price of those in Rangiroa.

Finally, it might be expected that depending on the incomes of the inhabitants, the goods they will have in their homes will vary, and therefore so will their losses from damage to their properties. Due to time limitations, collecting data on the exact household goods located in Rangiora is not possible, and it is assumed that all houses have on average these seven items, although this is likely to underestimate the average value of goods for households.

[7] The categories used by French Polynesia were disaggregated into new categories for the analysis of damage in order to provide a more accurate measure of the impact of the storm surge on the buildings. In the future the government may wish to consider the use of these new categories in other analysis so as to increase accuracy of damage estimations.

The total cost of these seven items, for a representative household of 3.7 people in Rangiroa is calculated to be 846,000 XPF (or 5,528 XPF/m^2).

It is assumed that damage to household goods is suffered if the level of water comes above the floor level of the building the goods are in, and consequently would be able to reach any goods situated on the floor of the building.

Damage to business

Aside from damage to homes, business will also be affected. The three main business sectors in Rangiroa are tourism, pearl culture and copra production.

Tourism

The main hotel in Avatoru, the Kia Ora, is made up of 66 bungalows and can hold up to 120 clients. It has impressive reception, restaurant and bar buildings. There are also 17 rooms in which staff can reside. The minimum number of staff on site is 96, the maximum around 115.

Although the Kia Ora stated that some of its sturdier buildings could be used as shelters during a cyclone, the new emergency plan will require clients to be evacuated or to shelter in the new medical centre or municipality shelters in the event of a cyclone.

Within the last few years, 25 bungalows have been reconstructed to be anti-cyclonic. These bungalows are elevated 60 cm above ground level, with a further 120 cm of foundations pillars below ground. It can be expected that the remaining buildings would be completely destroyed in the event of a cyclone.

For those hotels and guesthouses that suffer damage during the storm surge, a loss of business and income should be expected post-disaster until the buildings can be reconstructed and service can resume.

Aside from damage to buildings, cyclones and storm surges often change and sometimes completely destroy the beaches. Although the change of beaches is a natural phenomenon[8] it will likely have negative consequences for the tourism industry if beaches are washed away.

Pearl production

Pearl production has plummeted in Rangiroa in the last years. There were 6-8 farms on Rangiroa, now there are only about 2.

The pearl business interviewed stated that a few years ago it employed over 80 people but now only 30.

The manager did not believe that there would be much direct damage caused to the shells that are kept in cage like structures in the lagoon. The main damage would be to the onshore buildings and workshops although most of these were made with low budget, low quality means so would be less costly to replace.

Past experience of cyclones in the Tuamotus suggests that the "spat" (young shells that are matured in the smaller lagoons) would likely be washed away in cyclones. This would have secondary effects on other pearl farms, which would not be able to obtain the supply of spats needed for their production. Rangiroa is a large lagoon and no spats can be nurtured within it. All farms on Rangiroa must buy the spats from neighbouring smaller atolls. If these atolls were also affected by the storm surges, then this would mean lower production for quite a few years after the cyclone, unless spats are bought in from unaffected lagoons.

One other danger explained by the manager was that often in post-cyclone months the lagoons can experience phytoplankton algae blooms, some of which are toxic for the pearl shells. But, the manager did explain that the last storm surges deposited organic material into the lagoon which, after a few years, may have been the cause of greater oyster harvests.

Overall it is very difficult to quantify the effects of a cyclone on the two remaining pearl farms on Rangiroa.

Copra production

Copra production on Rangiroa is the largest of all atolls. It has been profitable (sold at 140 XPF/kilo) and work on the plantations has also been used as a successful scheme to get the unemployed into work. It can be imagined that a storm surge could drastically shock copra production on Rangiroa. The way that coconuts are harvested means that the coconuts are left to fall onto the ground before they are collected. This means that waves could wash away the whole coconut harvest.

[8] Some atolls even have motus named "Motu Tere One" translated as "Motu of the sand that goes".

In order to estimate the economic impact of the storm surge on the copra industry, data would need to be obtained for the volume of copra that is supplied by Rangiroa. This might be a consideration if further analysis is to be undertaken.

Reduction in services

Reduction in the services provided to Rangiroa post-storm surge event may include reduced electricity, transportation, hospital, school and airport functionality.

Aside from flooding and damage to buildings, perhaps the most important determinant of whether hospitals, schools and the airport can function post cyclone is the electricity supply. An electricity generator, belonging to Tahiti's main electrical provider supplies the electricity. Around 80% of Rangiroa's electrical supply is provided through sub-terranean cables which should be unaffected by a storm surge. The remaining 20% runs through cables above ground some of which are likely to be destroyed. Any damage done to the electrical infrastructure will be repaired by the provider apart from that which is on private land. In this case, the land owner chooses whether to pay the provider to reinstate sub-terranean or above ground cables (the much cheaper option). Some inhabitants report to have solar powered electricity supply, but none were located during the visit to Rangiroa. No petrol reserves on Rangiroa were damaged in the 1983 cyclones and there are 3 companies which can supply petrol to the atoll.

Other damage

Before proceeding with decisions as to whether or not to implement an adaptation option, it is recommended that an environmental analysis for a storm surge event is undertaken and that this is compared with an environmental impact analysis for each adaptation option. This would be especially important in the case of seawall construction.

Quantitative analysis of benefits

It is important to understand that in reality, the benefit of each option will only come into effect once a hazard event occurs. As it is not possible to know the year the event will occur, it is necessary to calculate the expected value of the damage per annum from a storm surge[9]. As there is a 2 per cent probability of this event occurring in any one year, the expected damage per annum is calculated to be 2 per cent of the total estimated storm surge damage.

Benefits are calculated with a 10 per cent discount rate per annum, in order to convert all future benefits into present values.

The value of a house used in the benefit analysis is its net replacement cost (NRC)[10].

As previously detailed, the houses currently existing in Rangiroa (the "without option") are assumed to be single storey, concrete and with ages uniformly distributed between 1 and 50 years.

Under each adaptation option, if changes are made to the buildings, then the new value of those buildings must be used to quantify any damage to them.

The valuation of damage at present (the "without" analysis)

The estimated value of damage to the buildings currently in the study area after a storm surge with a significant wave height of 12 m is calculated to be approximately 2,864,951,883 XPF. The expected value of damage each year to buildings is therefore calculated to be approximately 57,299,038 XPF. This damage estimation is used as the status quo used to calculate by how much each adaptation option will reduce expected losses each year if they are implemented. When calculating damage in the "without option" the houses currently existing in Rangiroa are assumed to be single storey, concrete and with ages uniformly distributed between 1 and 50 years. This means that every year, there would be the same percentage of houses of each age, because those that reach 50 years of age are replaced by new houses.

[9] In economic terms, the "expected value" of the damage per year from a storm surge, is the total estimated value of damage incurred during a storm surge multiplied by the probability of the storm surge event occurring in any one year.

[10] Explained in the LCA report (Rios Wilks, 2013a).

The likely benefit of each risk reduction option (the "with" analysis)

The amount by which each option will reduce damage and loss is now analysed.

Seawall

According to an independent report carried out by an engineering consultancy for this project (Worley Parsons, 2013), a seawall will reduce the velocity of a storm surge but will not reduce the depth of flooding to houses. The reduction in the velocity of the surge will cause to some houses to be in lower risk categories, and so some damage reduction will take place. As the seawall is implemented in the first year of analysis and maintained throughout, the expected damage reduction will be present from the first year and will continue to hold its value throughout the duration of the 50 year analysis.

Because without further data it is not possible to quantify by how much the seawall will reduce the force of the storm surges, for illustrative purposes three scenarios are analysed: a force reduction of 0, 25, and 75 per cent.

Kit houses (MTR)

MTR/kit houses have been recommended as a likely option for the reduction in storm surge damage because of their high elevation and anti-cyclonic structure.

The immediate implementation scenarios would see all houses replaced in the first year. Although the number of MTR houses in the area will not vary over time, the value of damage will vary over the duration of this analysis. This is due to the fact that analysis takes into account the actual yearly values of the buildings that would be present in the area, which varies (decreases) over the lifespan of buildings. For example, in the first year when all houses are new MTR buildings, the value of the houses will be at its greatest, as the houses begin to age, the value of these assets will depreciate, until they are replaced by new MTR after their 20 year lifespan is up.

The values of buildings of different ages are calculated using the net replacement cost formula detailed in the LCA report. (Rios Wilks, 2013). In the gradual implementation scenarios, due to the fact that there will be different numbers of houses that have been replaced by MTR houses at different points throughout the 50 year timespan of this analysis, the reduction in damage (benefit) will also vary over time. This analysis also takes this into account.

Without the implementation of kit houses (the "without option") the current houses (assumed to be single story and concrete) would still be in use and need to be replaced at the end of their functioning life by the inhabitants during the period analysed. Because this replacement of the current buildings would no longer be necessary once kit houses are used, it is necessary to treat this amount as a saving or benefit. As explained earlier in the assumptions section, for illustrative purposes it is assumed that the houses currently in Rangiroa are single storey concrete with ages evenly distributed between 0 and 50 years of age. This means that in the "without option", in any one year 2 per cent of the houses should reach 50 years and need to be rebuilt. Because the forgone concrete houses are no longer being maintained, these costs are saved and are consequently seen as a benefit of the MTR option.

The total expected benefit per year is the sum of the benefits discussed above.

Elevation

Elevation is expected to reduce the damage to buildings due to the reduction in inundation above floor level.

Like the MTR option, the analysis of damage takes into account the ages of the buildings' different points throughout the analysis and the number of houses elevated each year in the gradual implementation scenarios.

Without the elevation of houses (the "without option"), the inhabitants would still be incurring costs of replacing the old, non-elevated properties at the end of their functioning life as usual. By implementing the elevation (which includes full rebuilding costs in its analysis[11]) this cost is saved and are seen as a benefit of the elevation option.

The total expected benefit per year is the sum of the benefits discussed above.

Setback zone

As with the other options, the analysis of damage takes into account the ages of the buildings different points throughout the analysis and the number of houses relocated each year in the gradual implementation scenarios.

[11] See LCA document (Rios Wilks, 2013a) for full details of costs included in the analysis.

Without the setback zone (the "without option"), the inhabitants would still be incurring costs of replacing the old properties at the end of their functioning life in the zone areas as usual. By implementing the setback zone (which includes relocation costs in its analysis) this cost is saved.

The total expected benefit per year is the sum of the benefits discussed above.

Benefit results

The total value of the expected benefit from each of the 15 adaptation scenarios is calculated for each year of the analysis. As in the cost section, the expected benefits each year are discounted at 10% to reflect time preferences.

Figure 13 shows the total discounted value of the expected benefit from each adaptation scenario after the full 50 years lifespan of the analysis.

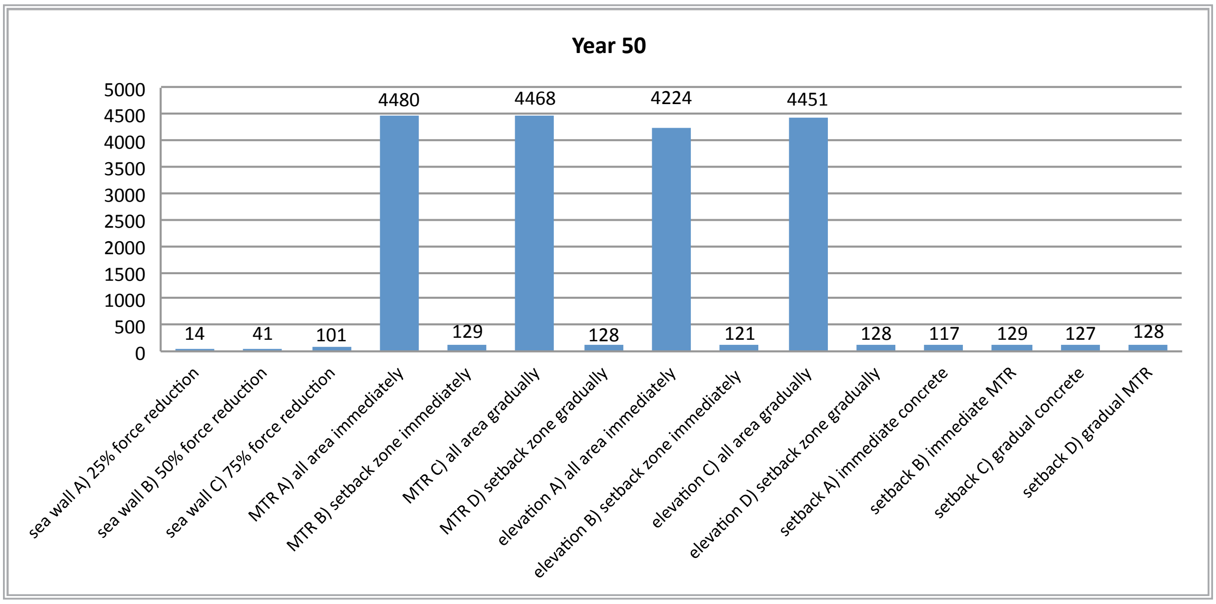

Figure 13: Total discounted expected benefit after 50 years (in millions of XPF).

Here, it is possible to see that the benefits of elevating buildings either by elevating concrete houses or using the MTR houses, are very great in comparison to using a seawall (even if it is assumed that the wall can reduce the storm surge force by 75 per cent) or to implementing a setback zone. The low benefits from implementing a setback zone are due to the fact that the risk categories within the setback zone are very similar to the risk categories of the buildings in the rest of the atoll. This is likely to be a consequence of the whole atoll being at a very similar level above the sea. Consequently, the moving of inhabitants out of the setback zone would do little to reduce damage.

6 OVERALL BCA

Net present value

For each adaptation scenario the net present value (the present value of benefits minus the present value of costs) is calculated for each year. These are then aggregated to produce the cumulative net present values of each adaptation scenario at different points throughout the 50 year period analysed. These cumulative net present values, show the overall benefit society would have experienced from each option after different having had them in place for 1, 10, 25 and 50 years.

Table 11: Cumulative net present value of each scenario at different points in time (in millions of XPF).

Adaptation scenario		Year 1 (establishment)	Year 10	Year 25	Year 50
Seawall	Assuming a 25% wave force reduction	-6,721	-6,714	-6,710	-6,773
	Assuming a 50% wave force reduction	-6,719	-6,697	-6,685	-6,745
	Assuming a 75% wave force reduction	-6,713	-6,660	-6,630	-6,686
Immediate MTR implementation	Whole area	-17,586	-15,267	-16,551	-16,560
	Setback zone only	-504	-437	-474	-474
Gradual MTR implementation	Whole area	47	326	271	-60
	Setback zone only	1	9	8	-2
Immediate elevation to 1 m	Whole area	-10,016	-10,345	-10,462	-10,466
	Setback zone only	-287	-296	-300	-300
Gradual elevation to 1 m	Whole area	-28	-186	-268	-289
	Setback zone only	-1	-5	-8	-8
Immediate implementation of setback zone	Relocated to concrete building	-2,494	-2,434	-2,398	-2,387
	Relocated to MTR	-2,427	-2,360	-2,396	-2,396
Gradual implementation of setback zone	Relocated to concrete building	-38	-260	-384	-419
	Relocated to MTR	-37	-251	-376	-421

The only adaptation options which produce an overall benefit (shown in bold) are the gradual implementations of MTR houses and even these two cases begin to see overall losses towards the end of the 50 year period.

Benefit-cost ratio

The benefit-cost ratio allows policy makers to see the value of benefits they should expect to obtain for each XPF spent on an adaptation option.

Here it is calculated as the total discounted stream of benefits divided by the total discounted stream of costs over 50 years of the analysis. Figure 14 displays the benefit-cost ratio of each adaptation scenario. All discounting is done at 10 per cent.

The similarity between benefit-cost ratios means that it is more informative to examine them using the more detailed Table 12, which ranks each option from the most efficient (ranked number 1) to the least efficient (ranked number 15).

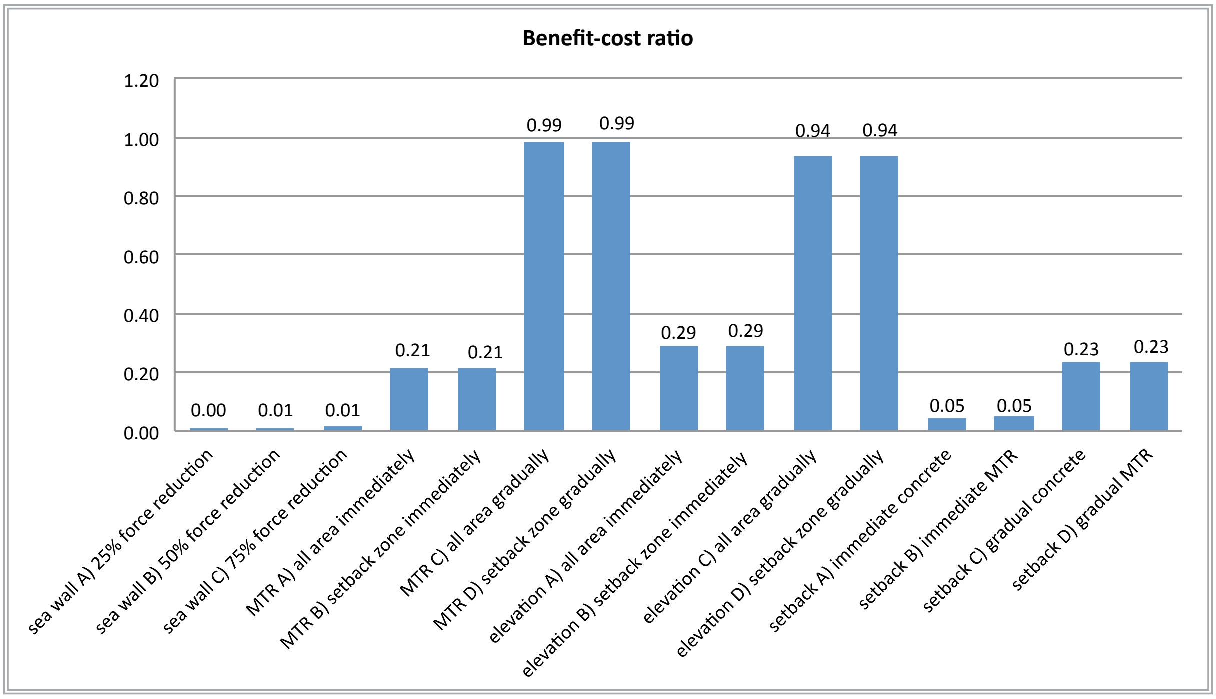

Figure 14: Benefit-cost ratio of each scenario after 50 years.

Table 12: Benefit-cost ratio of each scenario after 50 years.

Adaptation scenario		Benefit-cost ratio (with 10% discounting)	Rank
Seawall	Assuming a 25% wave force reduction	0.0021	15
	Assuming a 50% wave force reduction	0.0061	14
	Assuming a 75% wave force reduction	0.0149	13
Immediate MTR implementation	Whole area	0.2129	10
	Setback zone only	0.2134	9
Gradual MTR implementation	Whole area	0.9867	2
	Setback zone only	0.9874	1
Immediate elevation to 1m	Whole area	0.2876	5
	Setback zone only	0.2874	6
Gradual elevation to 1m	Whole area	0.9391	4
	Setback zone only	0.9396	3
Immediate implementation of setback zone	Relocated to concrete building	0.0469	12
	Relocated to MTR	0.0512	11
Gradual implementation of setback zone	Relocated to concrete building	0.2326	8
	Relocated to MTR	0.2334	7

No adaptation option offers an expected benefit-cost ratio above 1 in this preliminary analysis. This means that for each XPF spent on adaptation, less that 1 XPF will be expected to be returned in benefit. In the case of a seawall for example, even if this 5 m wall was able to reduce the force of the storm surge (with a significant wave height of 12 m) by 75 per cent, the benefit-cost ratio would still only be 0.015 XPF, so for every 1 XPF spent, only 1.5 cents would be expected in return.

The adaptation options with the highest expected benefit-cost ratio are those for the gradual implementation of MTR. The highest benefit-cost ratio is that of the gradual implementation of MTR in the setback zone only. For this scenario, every 1 XPF spent will give an expected return in benefits of 0.9874 XPF, or approximately 99 cents. The benefit-cost ratio for the gradual implementation of MTR over the whole study area would be marginally lower, at 0.9867.

The only other adaptation options that provide an expected benefit-cost ratio close to that of the gradual MTR options are those of gradual elevation of concrete houses to 1 m.

Although no adaptation option gives a benefit-cost ratio greater than 1 when only the damage to buildings is included in the benefits, by estimating the damage reduction to household goods in the 2 best cases (gradual implementation of MTR in the setback zone only or the whole study area), it may be possible to obtain a benefit-cost ratio larger than 1, this will be analysed in the sensitivity analysis section.

Sensitivity analysis

Including household good damage reduction

Household goods are damaged by inundation. If the storm surge never reached the floor level of an MTR (1.5 m), then it can be assumed that the household goods suffer reduced damage. The proportion of households that only experience from the inundation data, it is possible to see which households will have inundation of less than 1 m. This is far below the floor height of an MTR building. In the setback zone area, 58% of the buildings have an inundation depth below 1 m; in the whole study area 59% of the buildings have an inundation depth below 1 m. If minimal damage is suffered to the goods in these buildings, then an extra benefit of approximately 32,148,000 XPF in the setback zone scenario and 1,122,642,000 XPF in the whole study area scenario may be estimated for the 50 year duration of the projects. If these are added to the benefits of reduced damage, the benefit-cost ratios become 1.041 and 1.040 for implementing the MTR gradually in the setback zone and whole study area respectively.

For the gradual elevation of concrete houses to 1 m scenarios, which are the only other two scenarios with a benefit-cost ratio close to 1. Any damage reduction to household goods is likely to be lower than damage reduction of the MTR scenarios because the elevated concrete houses have a floor level of 1 m, whereas the MTR floor level is 1.5 m.

For the adaptation options where the floor levels are not elevated (the seawall and the setback zone options), not only are the benefit-cost ratios far lower than those for gradual MRT options, but no damage reduction to household goods can be assumed because all houses are likely to suffer inundation above floor level in these scenarios.

For this reason, the gradual implementation of MTR, both in the setback zone only and the whole study area seem to be the most beneficial options.

Also, in addition to the gradual MTR implementation scenarios having the highest benefit-cost ratios, the most likely reduction in damage to household goods, they are also the only form of adaptation option which uses anti-cyclonic housing structures. As detailed earlier in the report, MTR houses are described as “anti-cyclonic” meaning that they can withstand wind speeds of up to 204 km/hr.

Discount rate

Because there is ongoing debate as to which discount rate to use in benefit-cost analysis, the benefit-cost ratios have also been calculated with a three and seven per cent rate. Here, it is possible to compare the rankings of each adaptation scenario when a 10, 7 and 3 per cent discount rate is employed.

Table 13: Benefit-cost ratios and adaptation scenario rankings using alternate discount rates.

Adaptation scenario		Benefit-cost ratio (10% discount rate)	Rank	Benefit-cost ratio (7% discount rate)	Rank	Benefit-cost ratio (3% discount rate)	Rank
Seawall	Assuming a 25% wave force reduction	0.0021	15	0.0027	15	0.0044	15
	Assuming a 50% wave force reduction	0.0061	14	0.0081	14	0.0130	14
	Assuming a 75% wave force reduction	0.0149	13	0.0198	13	0.0319	13
Immediate MTR implementation	Whole area	0.2129	10	0.2565	8	0.3306	8
	Setback zone only	0.2134	9	0.2571	7	0.3315	7
Gradual MTR implementation	Whole area	0.9867	2	0.9021	4	0.7535	4
	Setback zone only	0.9874	1	0.9029	3	0.7545	3
Immediate elevation to 1 m	Whole area	0.2876	5	0.3545	6	0.4990	6
	Setback zone only	0.2874	6	0.3545	5	0.4997	5
Gradual elevation to 1 m	Whole area	0.9391	4	0.9404	2	0.9429	2
	Setback zone only	0.9396	3	0.9410	1	0.9439	1
Immediate implementation of setback zone	Relocated to concrete building	0.0469	12	0.0646	12	0.1200	11
	Relocated to MTR	0.0512	11	0.0677	11	0.1108	12
Gradual implementation of setback zone	Relocated to concrete building	0.2326	8	0.2327	9	0.2329	9
	Relocated to MTR	0.2334	7	0.2288	10	0.2189	10

The scenario with the highest benefit-cost ratio when a discount rate of 10 per cent is used is the gradual implementation of MTR in the setback zone. If a discount rate of 10 per cent is used by the government, the gradual implementation of MTR is expected to give the highest benefits for each XPF spent. Nevertheless, if only the damage to buildings is considered in the benefit analysis, the costs still slightly outweigh the benefits of implementing the adaptation option.

When the lower discount rates are used, the gradual implementation of MTR becomes less cost effective, because the relatively frequent replacement rate of MTR means that relatively more of the MTR option costs are incurred in the future. With lower discount rates, these future costs now become more significant. The highest benefit-cost ratio becomes that of the gradual elevation of buildings in the setback zone, which need to be replaced less frequently. Table 14 highlights this change in ranking between the gradual MTR and gradual elevation options.

Whichever discount rates are used, any options which are gradually implemented and increase the floor height of buildings (either by the gradual elevation options or the gradual MTR options) always produce the highest benefit-cost ratios, far above any of the other adaptation options.

Nevertheless in this preliminary analysis, which only includes reduction in damage to buildings in its benefits, none of the options have benefits which outweigh their costs. For this reason, before the government decides on whether to implement any of the adaptation options analysed, it is advisable that a deeper analysis is conducted on the options which use the elevation of buildings as their method of damage reduction.

Transport costs

For all of the adaptation options, construction materials must be sourced from other locations and shipped into Rangiroa. According to data from the Central Bank of French Polynesia (ISPF, 2013a) there have been steady increases in fuel prices recently, with fuel prices increasing by approximately 20 per cent during the last 6 years (from 2006 to 2012).

For illustrative purposes, Table 14 displays the benefit-cost ratios if oil prices were to increase costs of implementation by 10 per cent.

Table 14: Benefit-cost ratios if implementation costs increase by 10 per cent.

Adaptation scenario		Benefit-cost ratio (with 10% discount rate)	Rank
Seawall	Assuming a 25% wave force reduction	0.0019	15
	Assuming a 50% wave force reduction	0.0055	14
	Assuming a 75% wave force reduction	0.0135	13
Immediate MTR implementation	Whole area	0.1936	10
	Setback zone only	0.1940	9
Gradual MTR implementation	Whole area	0.8970	2
	Setback zone only	0.8976	1
Immediate elevation to 1 m	Whole area	0.2614	5
	Setback zone only	0.2613	6
Gradual elevation to 1 m	Whole area	0.8537	4
	Setback zone only	0.8542	3
Immediate implementation of setback zone	Relocated to concrete building	0.0426	12
	Relocated to MTR	0.0465	11
Gradual implementation of setback zone	Relocated to concrete building	0.2114	8
	Relocated to MTR	0.2122	7

The ranking of each adaptation option is unchanged but as table shows, now even the most efficient option (the gradual implementation of MTR in the setback zone) only has a benefit-cost ratio of 0.898.

Exchange rate

The French Polynesian currency (XPF) is pegged to the Euro (Veyroon, 2007). The current decreasing trend in the strength of the Euro at present will mean that imports from other countries may become more expensive, unless their own currency also depreciates by the same amount or more.

All of the options except that of the MTR could source their construction materials nationally, so avoiding this increase in costs. The MTR suggested for Rangiroa by the Fonds de Développement des Archipels, would be sourced internationally, and so the MTR option could subsequently be subject to cost increases if the weakness of the Euro continues.

If a cost increase of 10 per cent is applied to the MTR option, even the MTR option with highest benefit-cost ratio (the gradual implementation of MTR in the setback zone) would decrease to 0.898 and would consequently make the gradual elevation of concrete houses in the setback zone the most efficient scenario (have the highest benefit-cost ratio of 0.94).

7 FEASIBILITY AND IMPLICATIONS

This document analyses different adaptation scenarios that the Government of French Polynesia may consider implementing in order to reduce the negative impacts of a storm surge with a significant wave height of 12 m. These scenarios can be grouped into 4 categories of adaptation option; 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).

Setback zone

This analysis concludes that the setback zone adaptation option currently in place is not the most efficient form of adapting to the threat of storm surges. Implementing the option is only expected to produce approximately 0.23 XPF for every 1 XPF spent, and would consequently cost the community around 400 million XPF over the 50 year time period of this analysis. In addition, the imposition of legislation which prohibits inhabitants to live on or maintain their property will present considerable challenges. Given that it is unlikely that inhabitants have the funds necessary to buy new land and homes when they are unable to sell their current properties, the government may need to consider providing them with compensation. Even if compensation for the loss of value of property was provided to the inhabitants by the government, it is likely that the purchase of new land on the atoll will still present issues given that land is usually owned by whole families and passed down through the generations. Not only does this mean that families are usually unwilling to sell land, but even if all of the family members agreed to see their land, it will take time for all the legal documents to be signed by each family member, many of whom no longer live in Rangiroa. Nevertheless, due to the scale of damage expected if a storm surge of this size was to hit the atoll, providing inhabitants with more information on the threat they face may increase compliance rates.

Seawall

The seawall option is also not an efficient form of adaptation. The shape of the atoll, with a long stretch of coast inhabited by the population, means that the wall would need to stretch a considerable distance if it was to be built between the houses and the ocean, making it costly to construct. Also, the seawall would do little to reduce the depth of inundation of buildings and infrastructure, which, if at ground level would forgo significant damage. There is also the question of whether the building of a seawall on the coastal side of the atoll would reduce the incidence of storm surges coming from the lagoon side. If it is the case that storm surges from the lagoon side are initiated by surges first washing into the lagoon from the ocean and then rebounding from the lagoon side, the wall might aid reduction of storm surges from both the ocean and lagoon side. Otherwise, risk of damage from lagoon side storm surges would not be reduced by implementing this option.

Elevation

The immediate elevation of houses is relatively costly due to the challenges in elevating pre-existing buildings. The experts from the Direction de l'Equipement who was consulted was unaware of any retrofitting of houses in order to raise them and notes that such elevation of existing buildings could be largely unrealistic for people to undertake (personal communication, Dec 2012).

The elevation of houses may be a feasible option if it is undertaken gradually when the houses are to be rebuilt anyway. This would only require a comparatively small cost to be spent (7 % of the cost of construction) in order to make the homes less at risk from flooding. Nevertheless, given that kit houses have been built specifically with anti-cyclonic materials, would also be elevated to 1.5 m, and would be cheaper to replace than a concrete house, many inhabitants might find the use of a kit house a more affordable choice.

Kit houses (MTR)

MTR (kit houses) do seem to offer protection against cyclones, and once elevated are likely to reduce the incidence of inundation. They are cheaper than concrete houses, but, importantly, do have a shorter expected life span and so are likely to need replacing more frequently.

Recommendations

From this preliminary analysis the only categories that are likely to reduce damage significantly are those which elevate the floor level of buildings (either by the elevation option or the use of MTR). Nevertheless, when only the value of the reduction in damage to buildings is quantified in the benefit analysis, the benefit-cost ratios for these adaptation scenarios are still below 1, meaning that their costs would outweigh their benefits if they were implemented. Going forward the government may wish to conduct a more detailed analysis which includes other benefits of the adaptation options, such as the reduction in damage to household goods and reduction in economic loss due to building damage post-disaster. It is possible that once these other elements are included, the analysis might demonstrate that adaptation options which allow for the elevation of buildings using a gradual implementation method can give overall benefit to society. Nevertheless, it may still be challenging to impose these restrictions on the community, as some may not have sufficient funds to purchase the new houses outright. Consequently, successful take up of the initiative may benefit from the government providing either a subsidy or a flexible method of payment to aid their implementation.

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