An economic analysis of **ecosystem-based adaptation and engineering options** for climate change adaptation in Lami Town, Republic of the Fiji Islands

Technical report

FRONT COVER

Informal settlement along the river in Lami Town, Fiji © Nalini Rao

BACK COVER

Replanting mangroves in Lami Town, Fiji © Lami Town Council.

An economic analysis of ecosystem-based adaptation and engineering options for climate change adaptation in Lami Town, Republic of the Fiji Islands

Technical report

A technical report by
the Secretariat of the Pacific Regional Environment Programme

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Project overview

This cost-benefit analysis is part of the UNEP Ecosystem-based Adaptation Flagship Program and UN-HABITAT Cities and Climate Change Initiative and is intended to guide decision makers in their consideration of various options for climate change adaptation. While the scope of the research and analysis is confined to Lami Town, Fiji, a town adjacent to the capital Suva, general lessons and considerations may also be informative at the national level. Furthermore, the lessons learned will be useful for future comparison of options for Ecosystem-based Adaptation (EbA) to climate change in the Pacific region.

The cost-benefit team consisted of staff from SPREP, Conservation International (CI), and UN-Habitat in close consultation with the Lami Town Council (LTC). At the time of the Lami Town site visit an early draft of the Lami Town Climate Change Vulnerability and Adaptation Assessment was available to provide general guidance on vulnerable areas and adaptation measures. The findings presented in this report were further specified through participatory research with the LTC, which included two focus group sessions, informal follow-up meetings, one day of guided site visits, and a survey of coastal infrastructure, such as sea walls, and mangrove areas.

The first step of the site visit involved a meeting with the LTC. The purpose of this meeting was to identify specific locations within, or adjacent to, Lami that have experienced problems, related to extreme weather events, focusing on storm surges. A large city map was used to spatially record these sites of concern identified by the LTC and to begin discussing possible adaptation options. This participatory process resulted in the identification of several sites and three categories of adaptation responses. The map produced in collaboration with the LTC guided a series of specific site visits within, and just outside, Lami Town. All site locations were photographed, recorded with GPS and discussed with members of the LTC. Furthermore, the town's coastline was visually surveyed and mapped using GPS. The maps included in this document show various types of coastline including mangroves, sea walls and natural coastline.

For the economic analysis, the team took the adaptation responses suggested by LTC and estimated the costs and benefits associated with each. The team categorised the adaptation responses into a) Ecosystem-based Adaptation (EbA) options, b) Social/Policy options and c) A least-cost analysis was presented, which examined and ranked the different adaptation options one by one. Additionally, avoided damages were calculated, and the ecosystem service benefits in Lami Town were estimated.

Different sets of actions were categorised further into Scenarios, ranging from ecosystem focused actions to building/engineering actions to protect Lami from storm damage, and two "hybrid" scenarios which represented a combination of EbA and engineering actions. Net Present Value, the Annualised Net Present Value and cost-benefit ratios were calculated for the scenarios and results were presented with a sensitivity analysis. Finally, the limitations of the study were discussed, along with conclusions to inform for Lami Town in next steps of action prioritization or further analysis.

The authors of this report received and incorporated comments and suggestions from a diverse group of economists, planners and researchers. Comments were received from SPREP, Conservation International-Headquarters, Conservation International-Field Division, SPC-SOPAC, UNEP and UN-Habitat. These reviewers from many organizations, in the Pacific as well as researchers in international organizations, helped improve the report through a period of about nine months.

Lami Town: a description

GEOGRAPHICAL SETTING

Lami Town is a formally incorporated town located at 18° 7′ 0″ South and 178° 25′ 0″ East in Rewa Province, on the island of Viti Levu, Fiji (Figure 1). It is flanked by Suva City to the southeast and extensive mangroves and urban area to the west. Steep mountainous terrain, Draunibota Bay and Suva Harbour constrain potential sprawl to the north and south, respectively. Along with Suva, Navua, Nasinu and Nausori, Lami is part of the greater Suva area that is home to approximately half of Fiji's urban population. It is divided into the Eastern ward (the Delainavesi area), and the Western ward (which extends from the commercial centre to Wailekutu). There is also a central section which includes the commercial centre and industrial subdivision. However, it is also influenced by surrounding urban populations and informal settlements.

Lami is located on the eastern side of Viti Levu, the largest and most populated of Fiji's islands. Like much of Fiji, Viti Levu is volcanic in origin and is characterised by heavily populated coastal plains and a less inhabited mountainous interior, which reaches its apex with Mt Tomanivi's 1,323 m peak. The main rivers are the Sigatoka, Rewa and Ba, the deltas of which contain a significant portion of the island's arable land. Within Lami itself the elevation rises quickly, making its rivers (the Tamavua, Lami and Wailada) prone to flooding.

These geographical features make Lami Town an appropriate setting for a case study of ecosystem-based adaptation (EbA) to climate change, including this cost-benefit analysis. Because the area is located in a mountainous coastal zone, it is particularly vulnerable to flooding from heavy rains and storm surges. Additional challenges result from Lami's urban context, and opportunities from the large areas of intact mangrove and other coastal features. Its geospatial situation presents decision makers with several options for climate change adaptation including a range of engineering and ecosystem-based adaptation solutions.

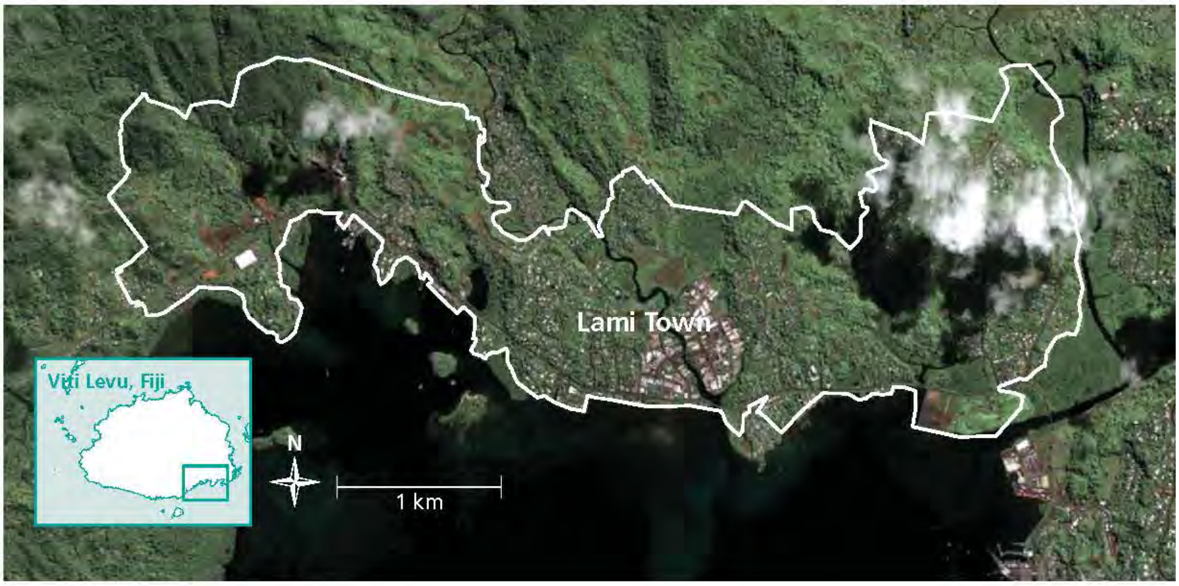


Figure 1. Lami Town, Fiji, is situated close to Suva City and near a large expanse of mangroves.

CLIMATE AND EXTREME WEATHER EVENTS

The air temperature for Suva area, adjacent to Lami Town, ranges from 12–34°C. The wet season lasts from November to April, and is characterised by heavy yet brief local showers that contribute most of Fiji's annual rainfall. These rainfall patterns are strongly influenced by El Nino/La Nina patterns and Fiji's larger topography. For instance, the windward areas of mountainous islands tend to be wetter than leeward areas. In general, the average rainfall in the Suva area, to which Lami Town belongs, is 3,060 mm, with average monthly rainfall varying from 150 mm in July to 384 mm in March, some of this rainfall results in flash flooding in Lami Town. The dry season lasts from May to October with air temperatures ranging from 23–25°C (Figure 2). Lami Town and Suva City, for example, experience more rain than the distinctly drier western side of the island, which includes Nadi. There is evidence, furthermore, that rainfall over the last decade has been higher than past averages.

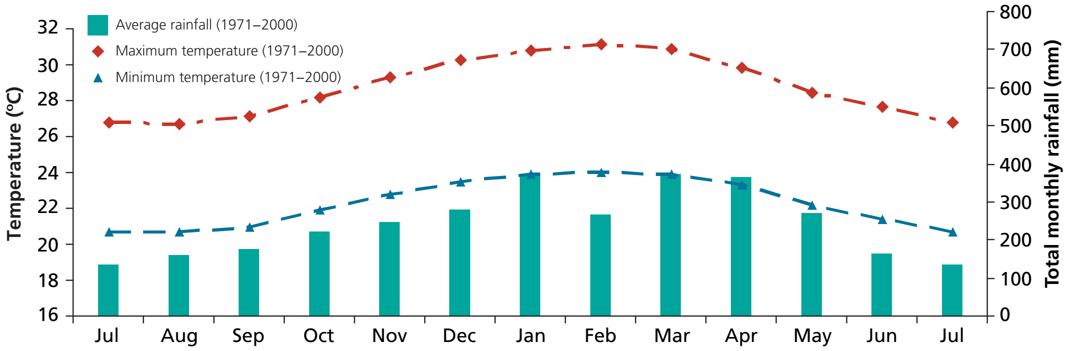


Figure 2. Maximum and minimum temperature ranges, and average rainfall records for Laucala Bay (Suva) from 1971–2000. Adapted from Fiji Islands Climate Summary Nov 2011.

Tropical cyclones in the Pacific Islands, especially in Fiji, Tonga and Samoa exhibit high interannual variability, which is in part due to the El Nino Southern Oscillation activity. Very high rainfall and wind speeds are characteristic of storms in this region, which includes the Lami Town area. Furthermore, river flooding from increased runoff and storm surge are common consequences of cyclones. Storm surges are the increase or decrease in water level caused by factors other than tides and other seasonal water level changes. These factors consist of a combination of changes in atmospheric pressure, winds and waves affecting basin geometry, as well as other factors such as flooding from rivers and cyclone-induced storm surges. Storm surges already affect many coastal areas around Fiji, and because of climate change and sea level rise, are anticipated to increase in intensity and frequency. In addition, the mountainous terrain surrounding Lami and its relatively small river systems make flooding likely. Specifically, the areas in Lami prone to flooding are the Lami/Qauia and Wailada river flats, as well as the flat land on the Delainavesi side of the Tamavua river. Extreme rainfall events, associated with cyclones and other storms, can result in river flooding, erosion, landslides, and damage to property, infrastructure or even loss of human life.

One projection on climate change for Fiji between 2001–2100, using different scenarios, shows that the atmospheric temperature will increase by 0.5°C by 2050 and 1.6°C by 2100, while sea level will increase by 10.5 cm by 2025 and 49.9 cm by 2100. The UNFCCC National Communication Report for Climate Change also projects an increase in temperature of 0.5–0.6°C by 2025 and 1.6–3.3°C by 2100 for Fiji, with changes in precipitation expected but uncertainty as to whether there will be an overall increase or decrease. Sea level is also projected to increase by 11–21 cm by 2025, 23–25 cm by 2050 and 50–103 cm by 2100. The UNFCCC projections agree with the assessments made by Feresi et al (2000). Studies performed specifically on Fiji project an increase in the intensity and frequency of days of extreme rainfall and an increase in wet season rainfall. While this CSIRO report also projects that cyclone numbers in Fiji are projected to decrease, there is only moderate confidence in this projection AND cyclones were described as a key issue for Lami Town Council, cyclones and related storm surge were considered as a major exposure in this report.

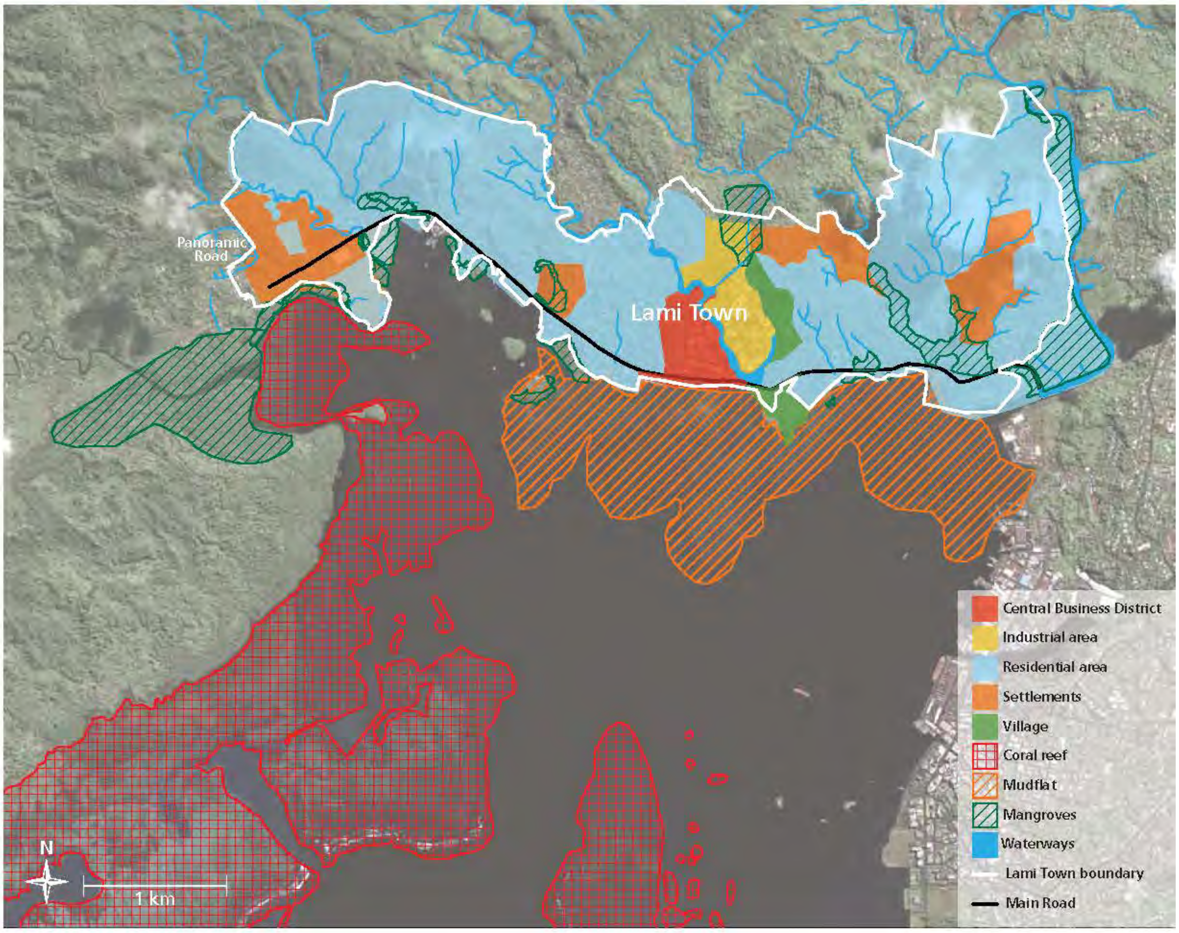
ECOLOGICAL CONTEXT OF LAMI TOWN

Lami Town is surrounded by significant natural capital including large areas of mangrove forest, seagrass beds and coral reef that are still present directly along the Lami Town shoreline, as well as further out into Suva Harbour. These ecological resources provide a range of ecosystem services to Lami Town, both in terms of coastal protection and support of subsistence and commercial fisheries (Figure 3).

Fiji has 51,700 ha of mangrove forest, the third largest area of mangroves for a country within the Pacific Island region.* The largest mangrove areas are on the South East and North West shoreline of Viti Levu and the northern shore of Vanua Levu covering an area of 38,543 ha. This habitat type has long been important in Fiji as a source of food, construction materials, fuel, dyes and traditional medicine. Additionally, approximately 60% of Fiji's commercially important coastal fish species are directly associated with mangrove environment, and the contribution of subsistence fisheries to total catch supported by mangroves in Fiji was estimated at 56%. This habitat type, moreover, provides protection from extreme weather events such as cyclones, storm surges and flooding.

* Fiji is home to eight true mangrove species (*Rhizophora stylosa, R.samoensis, Bruguieria gymnorhiza, Lumnitzera littorea, Heritiera littoralis, Excoecaria agallocha, Xylocarpus granatum*) and one hybrid (*R. selala*).

Figure 3. Location of ecological resources surrounding Lami Town.



Lami Town has significant mangrove assets both along the coast and just outside the town's western border. Adjacent to Lami in the west is the extensive Tikina Navakavu mangrove forest (91 ha) which, although outside the town boundary, is likely to provide ecological services to Lami, in terms of provision of fish nursery areas and improvement of water quality. Much of this area is protected by the Yavusa Navakavu Locally Managed Marine Area. During the site visit, a large area was being cleared for a new cement factory in close proximity to the mangrove forest.

Mangrove forests line the rivers in Lami Town. © SPREP

Within the larger Suva area, seagrass beds are widespread in the reef flats, back reef regions and mud flats, often in a mosaic of patchy meadows along Laucala and Suva Bay. They also cover much of the intertidal reef platform surrounding Suva Point and surrounding the shores of Laucala Bay and in small patches along the shores of Lami area. These areas are exposed to various impacts such as waste runoff from industries and residents, coastal erosion, siltation from rivers, storm surges, litter and coastal development that affect the distribution and growth of seagrass meadows. This habitat type, however, also provides wave attenuation and sediment stabilization, helping to maintain water quality, and providing habitat for species of important economic and subsistence value. Seagrass meadows are efficient recyclers of nutrients and help support a large biomass of consumers, especially those of fisheries importance. Additionally, they provide nursery and breeding grounds for many juvenile and adult fish species. For example, green turtles and many predatory fish use seagrass meadows as a feeding habitat. These areas are often used by local fishermen and women who glean the shallow inshore mudflats, seagrass beds and reef tops for shellfish and other marine organisms. Therefore, the loss of seagrass meadows can affect the food availability for many coastal communities.

Like mangroves, mudflats and seagrass meadows, the reef habitats adjacent to Lami Town may offer protection from extreme events and provide ecosystem services such as local fisheries and coral products for use in septic systems. In other locations, when reefs are damaged or destroyed, the absence of this natural barrier has been shown to increase the damage to coastal communities from normal wave action and violent storms. Coral reefs minimise the impact of storms by reducing wind action, wave action and currents and coral reef structures buffer shorelines against waves, storms and floods. Coral reefs also provide natural beach maintenance, as sand is calcium carbonate broken down from nearby reefs. Reefs are increasingly under human and climatic threat due to water pollution, increasing sea surface temperature and ocean acidification, regional studies have shown that the threats faced by coral reefs affect their ability to provide ecosystem services. In Lami Town, in addition to storm protection, corals are collected for various direct uses such as for septic tanks, and can be seen being sold on the roadsides. While this activity represents a service provided by the ecosystem, it is likely damaging to the coral reefs if undertaken at an unsustainably high rate. The coral reef area of Lami Town was determined to be 1387 ha, as determined through spatial analysis.

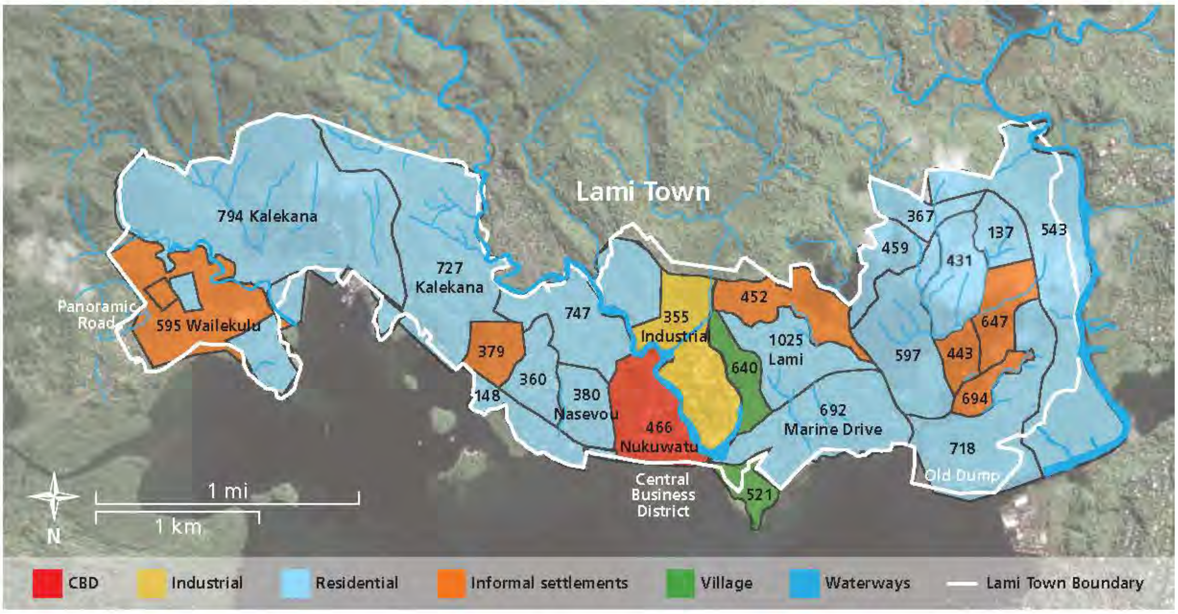
Although impacts from Suva city on the environments in and surrounding Lami were beyond the scope of this analysis, it is important to mention that they are potentially significant. While further investigation is needed to understand other effects, studies have shown that industrial pollution has increased marine heavy metal concentrations in the Lami-Suva area. Furthermore, it seems likely that factors such as shipping and waste disposal have some impact on the resilience of important ecosystem services. The presence of high population density and urban pollution makes the preservation of habitats such as mangroves, which filter pollutants, even more important. In general, it is important to begin to consider how adaptation to climate change can most appropriately utilise the existing and potential ecological and hard infrastructure systems of Lami Town.

SOCIO-ECONOMIC CONSIDERATIONS

Fiji is becoming increasingly urbanised. Approximately half of the country's population resides in urban areas, which also produces about 60% of the national Gross Domestic Product (GDP). Lami Town is part of the greater Suva area, along with Navua, Suva, Nasinu, and Nausori, which makes up approximately 50% of Fiji's urban population. While the urban growth rate for this area is relatively slow (about 2% per annum), growth in the other urban areas is faster. These populations, including those residing in informal settlements, utilise services within Lami Town and often work in urban areas. Lami is a good example of growth in informal low-income settlements on the economic fringes of an urban center (Figure 4). These settlements highlight that Lami, and towns like it, tend to absorb the urban overspill from Suva and indicate that Lami's urban situation, including impacts of urbanization on climate change adaptation, cannot be isolated from the greater Suva area.

The 2007 census reported an even distribution of population between Lami's Eastern and Western wards with the surrounding urban area accounting for almost 50% of the total population. Because the urban population utilises services in Lami, and makes up part of the work force, it will become more important if current growth trends for these areas persist. Additionally, informal settlements are also susceptible to projected climate change impacts for Lami. This indicates that not only the urban, but also the context of population in surrounding areas is important when considering climate change adaptation options for Lami Town. Most residential areas are located on freehold land while some are located on crown land that is leased for 99 years. Industrial subdivisions are often leased for 30 years and can be renewed.

Figure 4. Population of residents by enumeration area for Lami Town, Fiji.



Residential areas in Lami are mostly located on hilly terrain with permanently established structures and mostly accommodate average and high income earners. The residential areas are well serviced with street lights, regular public transport, rubbish collection and water supply. Most of the residential areas are unsewered so residents have to install private septic tank systems. Most settlements are occupied by average to low income earners, most have access to services such as water supply, public transport, and rubbish collection while electricity is only available in some settlements.

According to the 2007 census, ethnic Fijians are the dominant ethnic group in the Lami area.* Lami is unique in this respect from the majority of other urban areas in Fiji, as Indo-Fijians generally live in higher numbers in the urban areas. This may be due to the native lands within close proximity to Lami including two large villages, Lami Village and Suvavou Village. This has aided the establishment of large ethnic Fijian settlements within Lami. Other settlements within the town boundary are situated on either State-owned or freehold land.

* For more information on Lami Town population, ethnicity statistics or climate details, please see this report: *UN-Habitat. 2011. Cities and Climate Change Initiative: Lami Town Climate Change Vulnerability Assessment. 121pp."*

There are a diversity of land uses in Lami Town and adjacent lands; these include informal settlements, residential, industrial and business. Due to social, political and economic reasons, these different land uses have some specific implications for assessing potential adaptation options. No informal or squatter settlement has been formalised in Lami. There are identified settlements under a "City-Wide upgrading" programme guided by the Department of Housing in partnership with a local NGO. Vulnerability to flooding and other hazards may necessitate resettlement, of some of these communities, or the most vulnerable areas within settlements. When listed as informal settlements, the national government is not legally bound to aid these populations during disaster events, which increases the vulnerability of these inhabitants as they can rely less on external support. While formal residential areas contain approximately the same number of residents as informal settlements, formal settlement communities earn more on average than the inhabitants of the informal settlements (see Figure 4), occupy land that is less vulnerable to extreme weather events (further from the coast), and have better access to government aid and services. The Lami Town industrial area occupies 56 ha along 800 meters of the Lami River and primarily contains light industry. However, some heavy industry exists in the form of a cement factory in western Lami and a new cement factory just west of the Lami Town boundary that was in early construction at the time of the site visit. Finally, the Central Business District (CBD) occupies 6.5 ha, much of which is less than 50 m from the current coastline. The location of the CBD makes it vulnerable to events such as storm surges. Planned adaptation measures will be important for securing the CBD's important services.

Informal settlement along the river in Lami Town, Fiji. © SCOPE Pacific Limited

Although little is known about the links between climate change vulnerability and socio-economic marginalization in Lami Town, the social science literature has consistently demonstrated that these populations are less resilient to extreme weather events and other disasters than those with access to more economic, political and social resources. Women, children, and informal and ethnically marginalised populations are generally less resilient to disaster and, while detailed consideration of this issue is beyond the scope of this analysis, a comprehensive adaptation plan needs to consider the relatively greater vulnerability of marginal populations. This means that issues of income inequity, discrimination based on race, ethnicity or gender are integral to climate change adaptation. For these reasons, the costs or benefits of adaptation actions will almost certainly not be evenly distributed throughout the population that lives or works in Lami Town.

GOVERNANCE

Lami was established as a town by Ministerial declaration through the Local Government Act in March 1977. The town has general powers that relate to the promotion of health, welfare, convenience of inhabitants of the municipality and development of amenities. The council is governed by the Local Government Act, which details the provision of limited public utility services, road maintenance, streetlight, drainage and the making of by-laws on subjects prescribed to it by law (e.g. rubbish collection). The Council is headed by the Special Administrator who is tasked with ensuring that policies and appropriate guidelines are incorporated within the Local Government Act and other appropriate by-laws to achieve a standard of service delivery that is both efficient and effective. The Chief Executive Officer is responsible for the implementation of all Council's policies and procedures and also ensures that the operations of the various departments are managed in an orderly and timely manner. Furthermore, each department of the Council is assigned a manager who is responsible for the effective and efficient running of their individual section.

The Lami Town Council is divided into five departments which include: 1) Town Planning and Building Services, 2) Health and Environment Services, 3) Public Works and Services, 4)

Enforcement and Parking Meters, and 5) Finance and Administration Department. Significantly, none of these departments are tasked with dealing with climate change issues since the Lami Town Council's Five Year Strategic Plan does not contain any specific objectives that address climate change. However, these considerations are now becoming recognised as key concerns for cross-sectoral collaboration, coordination, and better management of resources among key stakeholders. Furthermore, key adaptation concerns, such as coastal protection, infrastructure or mangroves, are not under the direct authority of the Lami Town Council but are instead administered at the national level.

In addition to the roles and responsibilities of Lami Town, land tenure systems affect the governance of the resources and vulnerabilities that are important to climate change adaptation. There are two general types of land tenure system (customary land tenure and western land tenure) divided into four land holding units (native land, native lease, state land, and freehold land). All land tenure systems exist within either the Lami Town boundary or adjacent to it. Land tenure within the Lami's administrative boundary is: 11.72% crown lease, 31.7% freehold and 56.2% native/iTaukei.

The customary land tenure system refers to those land units owned by the indigenous Fijians according to their customs and traditions and are referred to as Native Land. Native lands can be used for subsistence purposes, commercial needs, native/iTaukei reserves (land set aside to be used exclusively by indigenous Fijians) or leased under the customary, or vakavanua, arrangements. Furthermore, native/iTaukei land ownership is vested in the mataqali, or tribal group, which is registered in the Register of Native/iTaukei Land (NRL) and the individual membership of the land owning tribal group. Once a Native/iTaukei Land is leased it becomes a Native/iTaukei Lease and will be classified into the western land tenure system until the duration of the lease expires.

The western land tenure system includes Native/iTaukei Lease, State Land and Freehold Land. Freehold Land is held individually (private freehold) or corporately under a fee system (state freehold). State Freehold lands are surveyed, mapped and registered. Tenure over these lands is guaranteed by the government. State Land, also referred to as Public Land, is held by the State for public purposes such as roads, reservoirs, dams, drains and can be leased for residential, commercial, industrial or agricultural purposes. They also include lands that are: below the high water mark referred to as State Foreshore (which includes mangrove swamps and foreshores); have not been claimed by Fijians when Fiji became a British colony in 1874 (State Schedule B Land); and Native/iTaukei Lands for which the mataqali owning that land have since become extinct (State Schedule A Land). However, lands under schedule A and B are in the process of being reverted back to ownership by indigenous Fijians. State Land cannot be sold but can be leased, usually for 99 years with periodic reviews every 10-years.

Furthermore, the governance of resources and infrastructure within Lami Town is made even more complex by the division of roles and responsibilities between the village, town and national scales. In addition to the powers of the LTC and various land tenure systems, many areas of concern, which were identified in partnership with the LTC, are governed at the national scale. These include non-locally managed mangrove areas and actions (such as protection, management and replanting), the protection of other natural systems (such as coral reefs, forests, river buffer areas, and seagrasses/mudflats), the improvement of bridges, the relocation of vulnerable populations from riverbank or coastal settlements, and the formalization of informal settlements. Furthermore, many of these are the responsibilities of different ministries at the national level. Therefore, because climate change effects cross sectors and scales of governance, adaptation will require collaboration between national ministries and between the national, town and village scales. For example, in terms of policy and planning, the Lami Town Council's five year strategic plan makes provision Environmental management which addresses disaster risk reduction, climate change planning and "greening" operations.

Overview of adaptation options and economic analysis

The economic analysis of actions to protect Lami Town involved the following steps.

1. A participatory meeting with the Lami Town Council was held, and it was determined that the main threat posed by climate change is higher frequency and intensity of storms. Hence the economic analysis focused primarily on storm protection. The storm protection actions proposed by the Lami Town council and the Vulnerability Assessment (VA) were listed. Actions were classified into the general categories of ecosystem-based adaptation options, social/policy options, and engineering options (Table 1).

2. For each of these options, costs over the entire implementation area were researched and estimated; costs included the installation, maintenance, labor, and opportunity (associated) costs,* to the extent that this information was available.

3. A least-cost analysis on the results to summarise the cost implications of the different options was performed.

4. The cost of inaction, that is, the cost of not pursuing any of the adaptation options, referred to as the "status quo", was calculated. These costs include health, business, and household costs, resulting from storms, some of which can be avoided by adaptation actions. To estimate these flood damages, we used flood damage information from floods in relatively nearby Ba and Nadi and information about Lami to estimate the value of storm damages in Lami.† These damages include losses to households and businesses, the cost of government repairs, provision of flood relief supplies, health and education costs. These damages result when insufficient action is taken to protect the community. However, when action is taken, then some proportion of the storm damage is reduced. Economists consider these "avoided damages" from storms to be a benefit of storm protection.

5. Four scenarios ranging from ecosystem-based adaptation options to engineering options for storm protection were developed with included actions defined in each scenario.

6. A cost-benefit analysis of the four scenarios and the avoided damages was performed. Net present value,‡ the annualised net present value∞ and the benefit-cost ratio, which is the ratio of the present value of benefits to the present value of costs, were calculated. A sensitivity analysis was performed to examine the effects of different time horizons and discount rates.

7. The baseline ecosystem service value of Lami Town's natural areas was estimated. Lami Town has mangroves, coral reefs, seagrasses/mudflats and upland forests. An estimate of the ecosystem service value was calculated for each of these natural systems by using a combination of global and local economic valuation studies. Spatial analysis was used to determine the size and extent of the habitats, and the economic value of this extent of natural habitat was then estimated based on the economic valuations and benefit transfer, which is the procedure of estimating an ecosystem service value by transferring a valuation estimate which has been calculated in a similar ecosystem. For each of the options, it was determined whether there were any benefits over and above the "avoided damages" described above.

8. A cost-benefit analysis of the four scenarios was performed using the estimates of avoided damages and estimate of ecosystem service benefits. Finally, the implications of the three economic approaches are discussed and presented as overall conclusions. The limitations of the study are identified including some ways that future assessments could be improved.

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* Opportunity cost is the cost of the foregone alternative use, in this case, the use of the area.

† No climate projections were performed to estimate the avoided damages for this study. The avoided damages were estimated from the Ba and Nadi floods, recalculated for Lami, and different proportions of this total amount were tested in the economic analysis.

‡ NPV analysis estimates the difference in the present value of the benefits (accrued revenues or monetary savings from a proposed investment) minus the present value of the costs (accrued expenditures from a proposed investment).

∞ The annualized NPV (ANPV) is the average yearly net return over the lifetime of the suite of adaptation options, that is, the annualized cash flow.

Flooding and possible adaptation options

During a participatory exercise in Lami Town, a map was used to capture key areas of known vulnerability in Lami Town. Specific areas known to have experienced problems of flooding (Figure 5a) and erosion (Figure 5b) were noted on the map and the discussion identified possible adaptation options that may be beneficial in the different regions of Lami Town. These were combined into a map of generalised vulnerability throughout Lami Town (Figure 5c).

While climate change has several important predicted outcomes, such as drought, seasonality, increased precipitation and increasing dryness in different areas, residents of Lami Town highlighted the need to alleviate problems associated with coastal flooding from storm surges or large waves from Suva Harbour, flash flooding from rapidly rising rivers, especially where hillsides have been cleared of vegetation, and surface flooding where high rainfall pools in low lying areas (Figure 5a). From the vulnerability assessment, as well as this participatory mapping exercise, it was evident that flooding is considered the greatest threat to Lami Town, and will potentially be exacerbated by climate change. The record of damages caused by flooding alone in Fiji are extensive, and one study reports estimated damages of FJD 40 million and loss of six lives in floods during 1999. In 1992–1993, the estimated cost of the damages caused by cyclone Kina in the Rewa River watershed exceeded FJD 88 million. Floods caused by tropical cyclones

Figure 5a. Flooding risks in Lami Town.

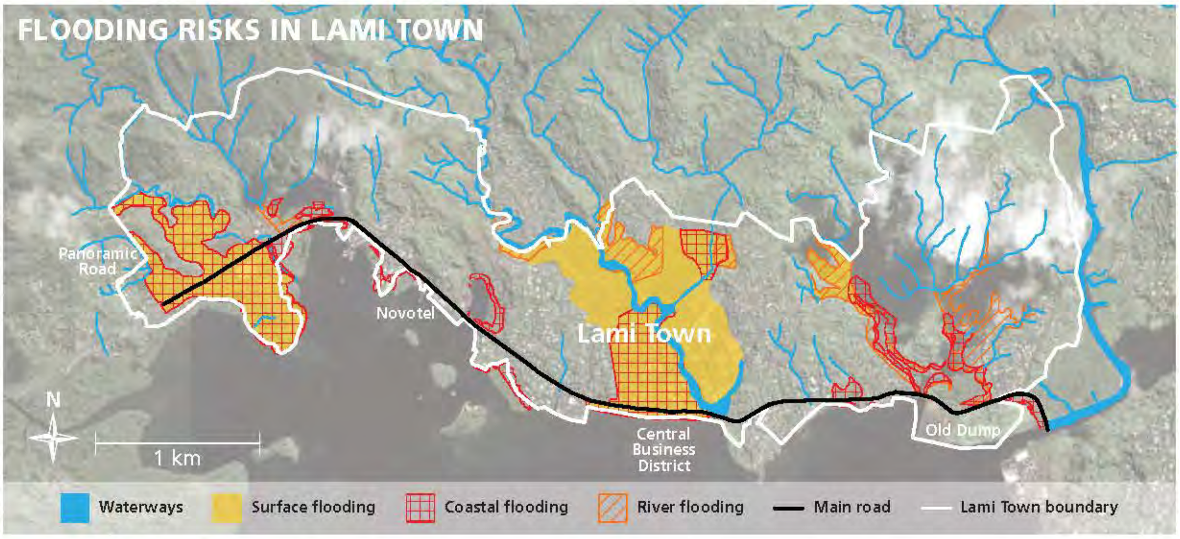
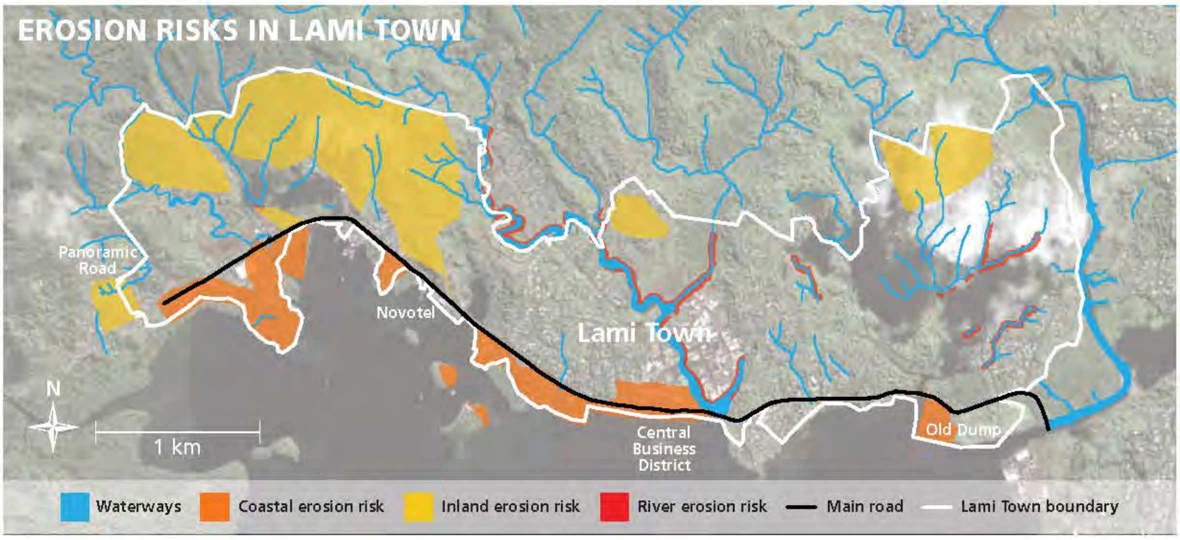


Figure 5b. Erosion risks in Lami Town.



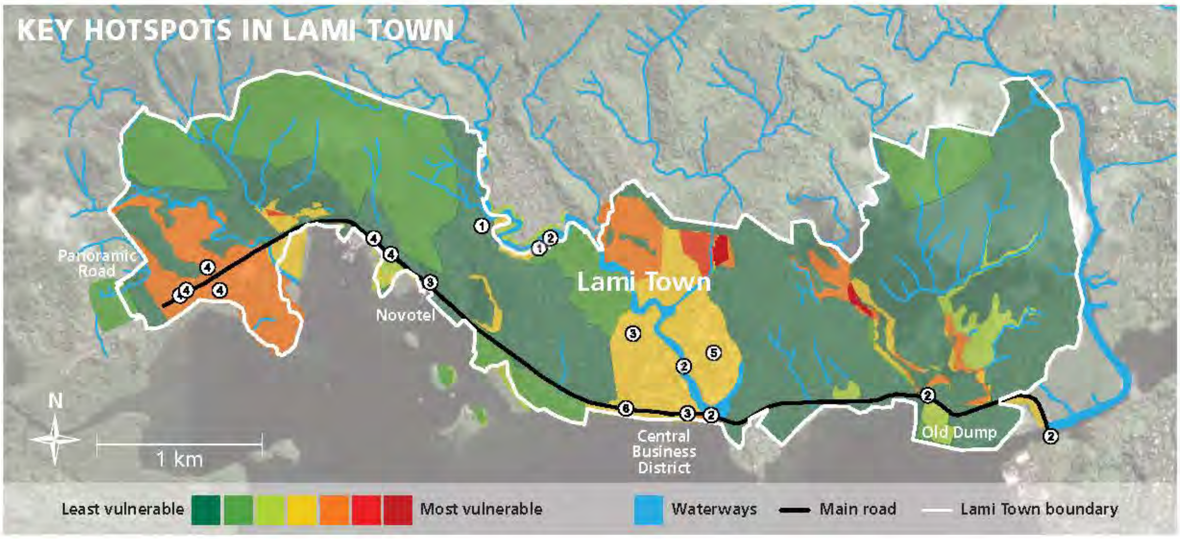


Figure 5c. Key hotspots in Lami Town.

1. River bank erosion

These locations (including Powell Crescent, Nasevou Street, Wailada Industrial area, and Johnny Singh park) show severe river bank and soil erosion, or localised flooding with large rains and strong river flow.

2. Vulnerable bridges

Many of the strategic bridges throughout Lami Town have evidence of riverbank erosion exacerbated by being either too low (e.g., Quaiya Bridge) or being undergraded for the size and quantity of traffic (e.g., Lesi Bridge).

3. Coastal erosion

Evidence of coastal erosion resulting from storms and extreme tides is common along the Lami Town shoreline, but extreme in some areas such as Tikaram Park and the Bay of Islands Park.

4. Coastal flooding

Many of the informal settlements in and around Lami Town are particularly vulnerable to coastal flooding. These settlements are often located in mangroves, wetlands, or flood plains.

5. Wailada industrial subdivision

Being located on a flood delta region previously surrounded by mangroves, this area is highly vulnerable to flooding and erosion both from the rivers and the ocean.

6. Lami Town business district

This area is highly vulnerable, with sand overwash from the coast onto both commercial and residential properties along the Queens Highway, in addition to flooding and erosion. Very high impervious surface and low lying topography limit ability for water to dissipate.

are more extensive due to the intensity of tropical cyclone precipitation and the direction of movement of storms across the country. In January 2009, heavy rain resulting from a tropical depression caused severe flooding in the towns of Nadi, Ba and Labasa. There were reports of death, severe damage and major disruption to services. According to a government assessment of the cost of these floods by division, total recovery cost approximately FJD 113 million.

Based on historical records of cyclone damage in Fiji and scientific theory, a 20% increase in maximum wind speed could result in a 44–100% increase in cyclone damage. The impacts of sea level rise and increase in temperature from projected data is expected to have a large impact upon Fiji's coastal resources, when compared to agriculture, human health and water. Sea level rise will lead to increased coastal erosion while increased temperature will lead to increased coral bleaching events and reduction in reef productivity, thus contributing to shoreline erosion as experienced in many outer islands. All of these negative effects will reduce the natural habitat's ability to protect the shoreline from flooding and storm surges. Hence, the economic analysis concentrates on examining possible ecosystem-based adaptation and engineering options used for preventing storm surges and flooding associated with climate impacts.

Types of possible adaptation options

From the participatory exercise based around storm surge and flooding, a large set of possible adaptation actions were determined and described (Table 1). These actions were classified into three types:

1. Ecosystem-based Adaptation options;
2. Social/Policy options;
3. Engineering options.

Ecosystem-based adaptation options include revegetation, conservation, and preservation of natural habitats for their storm surge protection capabilities. One example of this is the conservation of mangrove areas that partially attenuate wave action that exacerbates storm surges. Social/policy options rely on legal, policy, or regulatory actions to mitigate the effects of storm surge. An example is the policy of issuing flood warnings to all members of a community. Engineering options encompass the range of adaptation actions that involve building structures, such as sea walls or drainage ditches, to prevent the impacts of storm surges on local assets. In general, a distinction is made between ecosystem-based adaptation options, which include ecosystem conservation activities, and social/policy options, and engineering options. This study focused on the economic implications of implementing ecosystem-based adaptation responses to storm surges in comparison to engineering responses.

After discussing this larger list of adaptation options with the Lami Town council, a smaller set of adaptation options were identified for inclusion in the economic analysis. The subset of options was determined through discussions with the Lami Town Council and on data availability on the particular options. Some of the options are beyond the control of Lami Town Council and would be undertaken by another level of government.

Uncertainties exist in the capacity to quantify the effectiveness of both ecosystem-based adaptation options and engineering options for storm protection, particularly in the pre-design stage given the number of variables in both contexts. Climate change is predicted to affect many aspects of the system in Lami Town, in terms of storm frequency, magnitude, the capacity for storm protection of ecosystem-based adaptation and engineering options. In addition, there are non-climate factors that will affect storm damages, such as human settlement patterns, demography, political situations and patterns of development in Lami Town. In such situations, in addition to examining the adaptation options one-by-one, alternative scenarios can offer insight into the future sustainability of proposed developments. In cases such as this, where long-term climate projections are often unavailable at local and regional scales suitable for local decision-makers, assessments examine issues of risk by identifying issues of vulnerability.

In the Vulnerability Assessment commissioned by UN-HABITAT, which preceded this economic analysis, areas at risk to storm surge in Lami were described (Figure 5a). In this economic analysis, we examined whether ecosystem-based adaptation or engineering options offer better economic outcomes to the potential impacts associated with storm damage. In the climate adaptation literature, there are many paradigms for understanding the differences, and these often categorise the differences in terms of such characteristics as their flexibility, outcomes, predictability and efficiency. Communities will decide what action, or set of actions, to implement for storm protection, based on the resources available, including a clear articulation of the uncertainties associated with each option. The options and scenarios presented in this analysis reflect a range of possible solutions for comparison, rather than a comprehensive list of all possibilities for Lami Town. In using this information with caution, it should be emphasised that approaches such as cost-benefit analyses should be considered as 'a filter and not a scoop' (World Bank, 2010) and such approaches are ideally applied to rank alternatives and nothing more. This suggests that most attention should be placed on the ranking of the alternatives in comparison to each other rather than on the numbers themselves.

Table 1. Possible adaptation options.

Action	Details of the Action	Positive aspects	Negative aspects
ECOSYSTEM-BASED ADAPTATION ACTIONS			
Coastal revegetation	Replant mangroves and other vegetation (such as riverbank and streamline vegetation) to buffer impacts from flooding and reduce erosion.	• Additional economic, environmental and social benefits; • Can involve community participation/education in restoration activities; • Low ongoing maintenance costs; • Can afford flexible protection from coastal and riverine flooding.	• Space requirements; • Success rate of wetland can be low if improperly designed; • Not as effective at protecting property from impact as hard barriers; • Difficult to reliably quantify multiple functions.
Conservation of mangroves, seagrasses/mudflats, coral reef, forests, river buffer areas	Protect natural systems through monitoring and enforcement to limit extractive activities.	• Additional economic, environmental and social benefits; • Can involve community participation/education in protection and maintenance activities.	• Need to have realistic understanding of protection service being received; • Forests and wetlands offer little protection from floods when soils are already saturated; • Difficult to quantify multiple functions.
SOCIAL/POLICY ACTIONS			
Rezoning areas	Rezone areas such that building industrial or residential areas in vulnerable zones would not occur.	• Highly effective at reducing property damage; • Maintains natural function of coastal ecosystems; • Recreation space.	• Will need to be periodically reviewed • Potential creation of conflict; • Needs to be based on good quality data.
Regulating land tenure of informal settlements	Design or implement policies to formalise the informal settlements, making them eligible for assistance and support.	• Can potentially resolve other livelihood/stewardship issues.	• Reduces options for planning in future; • Can be politically challenging.
Coastal relocation	Relocate people from the most vulnerable, coastal settlements to higher, drier areas.	• More chance of success if relocating to proximate lands that the relocating community has tenure over.	• Effective negotiation required to avoid political issues and conflict.
River relocation	Relocate people from the most vulnerable riverine settlements to drier areas.	• Can be successful if relocating to proximate lands that the relocating community has tenure over.	• Effective negotiation required to avoid political issues and conflict.
Flood warning systems	Provide an alert service for communities well in advance of the hazard impact.	• When designed well (including training of communities) can be extremely effective in reducing loss of life and in some cases property; • Allows installation of temporary barriers such as sandbags.	• Can be expensive; • Requires continuous monitoring and connections to regional/national meteorological service.
ENGINEERING ACTIONS			
Bridge improvements	Raise and upgrade bridges.	• If well constructed and maintained can support emergency service delivery.	• Capital and maintenance intensive.
Reinforce rivers	Reinforce river bank using gabion baskets and spall-filled reno mattresses.	• Relatively less expensive than other engineering solutions; • Baskets can be made using natural substances such as pebbles (thus decreasing costs).	• Labor intensive to construct, replace and repair; • May not be aesthetically pleasing; • May result in translation of erosion issues.
Dredge river	Remove extra sediments.	• Increases river capacity.	• Requires continued investment, may increase flooding in some areas.
Increase drainage	Clear out any blocked drains.	• Increases flow rates and improves drainage, so less chance of disease.	• Requires continued investment.

Table 1. Possible adaptation options.

Action	Details of the Action	Positive aspects	Negative aspects
ENGINEERING ACTIONS (continued)			
Build sea walls	Build sea walls with concrete, rock, or tyres.	• High degree of protection against coastal flooding, lower space requirements than other options, possible to progressively upgrade.	• Potential scour at foot can cause stability issues, impacts sediment availability, continued investment in maintenance, reduction in area of intertidal habitat, overtopping causing instability.
Flood mapping	Designing for creating evacuation zones and planning boundaries - e.g. areas would be above a 1 in 100 year flood.	• Can be useful when accompanied by early warning systems in preventing loss of life.	• Requires good quality data and modelling for accuracy.
Beach nourishment	Adding imported sediment to a beach area that has a sediment deficit.	• Provides a buffer for beach erosion, can be designed for ecological benefits.	• Periodic nourishments will be required, increased turbidity and burial risk for local organisms.
Sea dikes	Building high volume structures which helps to resist water pressure.	• Often the cheapest hard defense, offer greater wave energy dissipation and less scour than vertical structures	• Requires high volumes of building material and space, requires constant maintenance, may encourage settlement patterns that increase risk in the long term, can prevent natural costal processes.
Storm surge barriers	Building hard engineered structures with a primary function of preventing coastal flooding. Typically a solid movable barrier across the mouth of a tidal inlet or estuary.	• Provide a high degree of protection	• Very expensive to establish and maintain, movable systems need Early Warning Systems, can cause flooding on landward side, change estuarine system.
Land claims	Creating new land areas that were previously below high tide.	• Additional coastal land for agriculture of development	• Expensive to establish, requires high volumes of building material
Flood proofing (elevating)	Reducing avoidance of the impacts of coastal flooding on structures by elevation, innovative building materials or designs.	• Does not require additional land or resettlement, will facilitate cheaper clean up after flooding.	• Requires careful communication, does little to reduce high velocity flooding, may not be aesthetically pleasing.
Managed realignment of the shoreline	Altering flood defenses to allow flooding of a presently defended area.	• Reduces incident wave energy, reduces costs of other defenses, can support conservation on intertidal habitats.	• Requires land to be yielded to the sea and may require relocation of infrastructure and communities.

Theoretical overview of least-cost analysis, benefit-cost analysis, and net present value

For the economic analysis of the storm surge adaptation options, least-cost analysis and benefit-cost analysis were performed. Analyses were carried out on selected adaptation options, as well as on suites of adaptation options (denoted action scenarios). In the analysis, the costs of implementation were calculated, as well as the avoided damages and the ecosystem service benefits retained. The uncertainty will build from the least-cost analysis, for which there is likely less uncertainty, to an analysis which includes ecosystem service benefits, for which the uncertainty is higher. The economic approach, allowed the ranking of options and scenarios, as a guide for decision making to policy development.

Least-cost analysis provides the specific sum of costs of each of the chosen adaptation options over a period of years, and has been used often in development projects to support decision-making for infrastructure and water projects. The least-cost analysis is presented first, in order to show what a basic level of economic analysis might reveal to decision-makers. For a least-cost analysis, only the costs of any options are included, so that the costs of implementing the different actions are clear.

The advantage of using least-cost analysis is that there is a minimum level of uncertainty associated with the figures that are integrated into the analysis. The costs of each activity in the suite were determined through interviews in Lami Town, published records, technical papers and general estimates from local experts. The values used for the analysis are all specific to Lami, and in a couple of cases, more broadly to Fiji. Due to limited availability of data, in the later analyses, it was necessary to also include estimates from around Fiji and then estimates from outside the Pacific Islands in an attempt to show what the benefits of adaptation to climate change could be.

The formula used for the least-cost analysis was as follows:

$$C = \sum_{1}^{T,N} c_{t,n}(1+i)^{-t} \qquad (1)$$

In Equation 1, C is sum of costs, c is the set of individual costs per action, i is the discount rate, n is the adaptation option, and t is the time period, in years.

Benefit-cost analysis (BCA) is a method used to evaluate the economic desirability of a proposed action that has certain benefits and certain costs associated with it. It is a technique used to analyze policy alternatives, and is commonly used by the United States Environmental Protection Agency (US EPA) and many other organizations to analyze the economic feasibility of alternative projects or proposed investments. A net present value (NPV) BCA was used to analyze the economic consequences of ecosystem-based adaptation and engineering options for storm protection in Lami Town. NPV analysis estimates the difference in the present value of the benefits (accrued revenues or monetary savings from a proposed investment) minus the present value of the costs (accrued expenditures from a proposed investment). It incorporates the initial project investments, which for practices to mitigate storm damage, can be quite large. A NPV analysis also accounts for changes in inflation and payments made across the lifetime of the project being evaluated. A NPV benefit-cost analysis "can provide an exceptionally useful framework for consistently organising disparate information," and is advocated for use in analysing public policy measures.

A NPV analysis requires quantification of the costs and benefits for the action in terms of dollars, expressed in Equation 1:

$$NPV = \sum_{1}^{T,N} b_{t,n}(1+i)^{-t} - \sum_{1}^{T,N} c_{t,n}(1+i)^{-t} \qquad (2)$$

where b are the benefits, c are the costs, t is year, T is the timeframe of the project, and i is the discount rate. For this study varied time frames and discount rates were used (main results are presented in the main body of this report, and sensitivity analyses are presented in the Appendix). The result of applying this equation will reveal whether the discounted value of the future benefits is greater or less than the discounted value of future costs, added up over a defined time period T. Hence the choice of the discount rate can greatly affect the results.

The annualised NPV (ANPV) is the average yearly net return over the lifetime of the suite of adaptation options, that is, the annualised cash flow. To calculate the ANPV, we use Equation 2 below:

$$ANPV = [\frac{i}{1-(1+i)^{-T}}]NPV \qquad (3)$$

This ANPV will allow the decision maker to decide whether, over a chosen time frame and discount rate, the action is economically desirable. If the ANPV is greater than zero, then the project is considered to be desirable, and if the ANPV is less than zero, then the action is not desirable. This calculation does not take into account the equity of the action, whether more vulnerable populations are protected, and local vs. regional benefits. These issues were interpreted by comparing different maps of the segments of Lami Town to the results.

The benefit-cost ratio (BCR) is the ratio of the present value of discounted benefits to the present value of the discounted costs for the action. This outcome of the analysis can provide decision-makers with an intuitive answer regarding the desirability of the project. If the ratio is greater than one then the project is desirable, and the ratio itself will give the benefits per dollar spent on the project.

$$BCR = \sum_{1}^{T,N} b_{t,n}(1+i)^{-t} / \sum_{1}^{T,N} c_{t,n}(1+i)^{-t} \qquad (4)$$

The discount rate is used in economic analysis in order to take into account productivity of capital and the preferences of the population. Economists have varying opinions on the appropriate discount rate to use, and these suggestions range from negative discount rates to discount rates of infinity. The reason to use discount rates is to determine whether the present value of the project is positive or negative in every time period, and whether the aggregated NPV is positive. This will allow decision-makers to design policy based on consideration of current and future generations and the benefits and costs that will accrue to them in future time periods. For example, some projects have long term benefits, such as tree planting, and some projects have long term costs, such as environmental waste facility maintenance. One thing to note is that using a specific discount rate will place a lower value on benefits and costs as they occur further in the future, that is, as the time horizon increases. Hence the present value of these activities will be lower as the time horizon increases as well. A range of discount rates are used for economic analysis in the Pacific Islands, ranging from 3% to 15%. The discount rate chosen for an analysis reflects the society's preference at a discount rate of 3%.

A sensitivity analysis was performed on the economic analysis. There are several ways to perform a sensitivity analysis, such as varying the discount rate, time length of the project, selected prices or the amount of the physical quantities of the different inputs. By varying some of the key parameters and measuring the results—one parameter at a time—we can examine to what parameter the NPV outcome is sensitive. When the parameter to which the NPV outcome is sensitive is determined, then the researchers can direct effort into forecasting these parameters into the future, policy makers can design policy or assign funds to manage these specific parameters as the project is implemented. In this report, sensitivity analyses were performed by varying the discount rates (from 1% to 10%) and the time period (from 10 to 20 years).

Economic analysis Part One: least-cost analysis

The cost for different climate adaptation options was determined during a site visit to Lami Town in 2011. From sources ranging from discussions with local engineers, town council representatives, local governmental estimates, conservationists and project reports, the general costs (installation, maintenance, labor and opportunity) of the actions were estimated. The least-cost analysis will give decision-makers the ability to determine the desirability of specific actions at a Lami-wide scale. In addition, it could suggest to decision-makers how to implement the actions at different sites for a more targeted intervention, and the indicative cost implications. These results, coupled with the spatial results of the Vulnerability Assessment, identify where planners can potentially design interventions and also provide information on potential costs of these actions.

Estimating the benefits of adaptation options includes a high degree of uncertainty. This arises from using estimates of benefits and avoided damages or ecosystem services, which are spatially and temporally different from the site area, among other reasons. However, integrating these estimated benefits can also help inform potential positive consequences of actions, and can demonstrate the general range of expected benefits. Later analysis presented below will build upon the least-cost analysis and integrate both avoided damages and ecosystem service benefits.

The list of adaptation options from Table 1 was narrowed down to a set of ecosystem-based adaptation and engineering options shown in Table 2 below. The costs chosen for this analysis can be modified, but those used for this analysis reflect the costs determined on the site visit in August 2011.

Table 2. Selected adaptation options for least-cost analysis.

Action	Details of the Action	Description of action in Lami Town
ECOSYSTEM-BASED ADAPTATION OPTIONS		
Replant mangroves	Replant mangroves to buffer impacts from flooding and reduce erosion.	• Full revegetation of coastline where mangroves are currently not present (64 ha).
Replant stream buffer	Replant riverbank and streamline vegetation to buffer impacts from flooding and reduce erosion.	• Full revegetation of riverine areas (32.5 ha).
Monitoring & enforcement	Protect natural systems through monitoring and surveillance to limit extractive activities.	• Surveillance of replanted areas every day.
Reduce upland logging	Limit extractive activities and curtail upland logging.	• Logging curtailed on 50% of area.
Reduce coral extraction	Limit extractive activities and curtail coral extraction.	• Coral extraction curtailed by 100%.
ENGINEERING OPTIONS		
Reinforce rivers	Reinforce river bank using gabion baskets and spall-filled reno mattresses. Dredge the river to remove extra sediments.	• Constructing gabion baskets (120 m^3); • River realigning (150 m); • Protecting river with spall-filled reno mattress (1000 m); • Dredging of selected areas of rivers (30,000 m^3).
Increase drainage	Clear out any blocked drains.	• Building drainage ditches along Lami Roads (82750 m).
Build sea walls	Build sea walls with concrete, rock, or tyres.	• Building sea walls along currently unprotected area (7410 m).

Table 3. Calculation of costs for each option implemented throughout Lami Town, calculated over 10-years and 20-years, at a 3% discount rate.

Adaptation option	Cost (1000 FJD) 10-years	20-years
Replant mangroves	$1,781	$3,016
Replant stream buffer	$935	$1,584
Monitoring & enforcement	$89	$155
Reduce upland logging	$65	$114
Reduce coral extraction	$44	$78
Build sea walls	$12,377	$15,188
Reinforce rivers	$1,975	$2,424
Increase drainage	$1,348	$1,655

The analysis presented here used Equation 1 presented above. The costs of implementing the following options throughout Lami Town were collated, and summed over a 10-year and 20-year time period at a discount rate of 3%. The sum of the costs is presented in Table 3.

These costs can be compared better if they are ranked in terms of low to highest cost of the action. In Figure 6, we present the costs of these options ranked for a 10-year period and a 20-year period, at a 3% discount rate.

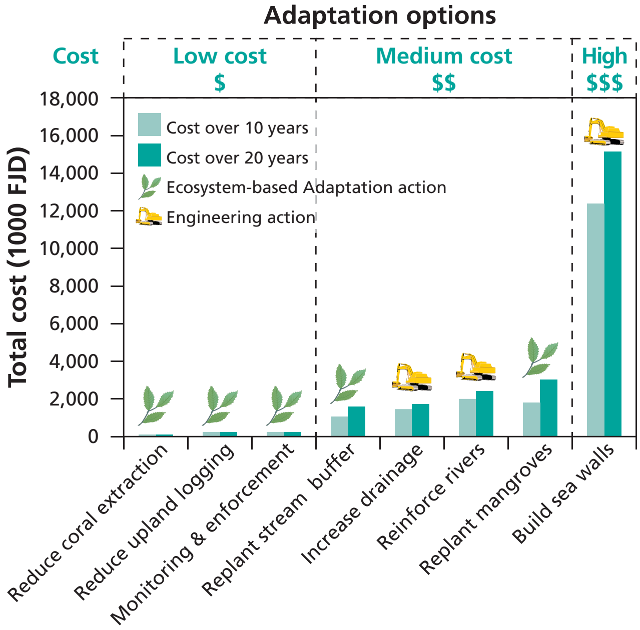


Figure 6. Total cost to implement adaptation options for all identified sites throughout Lami Town.

DISCUSSION OF LEAST-COST ANALYSIS

Table 3 shows the costs over a 20-year time period for each adaptation option, and this analysis examines all of the available life-cycle costs of the adaptation options. Studies have been performed on some of these different options listed in Table 3, to determine their effectiveness for storms of different intensities or surges of varied heights. For example there has been work on sea walls, green infrastructure versus engineering solutions, the effects of infrastructure on storm surge effects, community responses to climatic events, and coastal ecosystem management strategies. However, specific spatial information comparing different adaptation options—effectiveness and costs—is not available for many vulnerable sites. Therefore this analysis presented the costs of each of the selected adaptation options only. There are five ecosystem-based adaptation options and three engineering options. The equivalence in effectiveness of these adaptation options is not assumed, but we compare these eight options to determine their cost implications. Decision-makers can use this information, along with local knowledge regarding storm surge protection measures, especially their effectiveness in different locations, over different time periods, to determine what action, or set of actions to take when designing local policy, conservation or construction.

Figure 6 indicates that the sum of costs over 20-years exceeds the costs for 10-years, and the ranking of the alternatives from lowest to highest cost is the same irrespective of the time horizon. The least-cost alternatives for storm protection include reducing coral extraction, reducing upland logging, and monitoring and enforcement, while the most expensive option is to build sea walls. The medium cost options include replanting stream buffers, increasing drainage, reinforcing rivers, and replanting mangroves.

Building sea walls is expensive due to the cost of materials and labor required to build the structures. There are a variety of types of sea walls, and thus a variety of associated costs needed to establish them. There exist quite a wide variety of types of sea walls in Lami, from cement structures to tire walls, and it is recognised that the costs associated with these different building techniques varies. The costs used in this study were obtained from a report of the Ministry of Land and Water Resource Management Division (MLWRMD) of the Fiji Islands in December of 2010. Additionally, the labor costs associated with building a sea wall contribute significantly to the total costs, but they represent an opportunity for jobs in Lami Town. Hence while the labor component enters into the least-cost formulation strictly as a cost, there may nevertheless be a small, temporary positive effect on job creation in Lami Town.

Mangrove restoration project costs can vary from inexpensive to expensive. The mangrove replanting cost estimates here are obtained from the OISCA site estimates. The cost estimates associated with mangrove restoration in this project are relatively high compared to the lower range estimates used by TEEB, however, it should be noted that the failure rate is extremely high for low cost projects. For example, the majority of mangrove restoration/replanting projects in Indonesia (following the Indian Ocean Tsunami of 2004) have experienced high or even complete mortality due to the use of blind planting methods, without regard to the hydrological and ecological needs of various mangrove species. However, proper attention to site characteristics and ecological engineering principles are necessary so the restoration will not fail as outlined in engineering and wetland studies. Replanting mangroves is also costly in terms of labor, after a two year period of initial planting, the main costs are labor, maintenance, and opportunity (associated) costs. This option will also not be as effective as storm protection immediately upon implementation, as the mangroves will take time to grow to the size that will be an effective defense against storm surge.

As noted above, we should not assume that each of these solutions has the same level of effectiveness. For example, replanting mangroves and reducing coral extraction will have very different effects on wave attenuation in a storm event, as will replanting mangroves and building sea walls. The actual level of effectiveness of each of these measures is not a subject of this report (although comment is provided on the potential effectiveness of combines scenarios), and only the costs are determined and analyzed. The cost-effectiveness of each of these measures, carefully calculated with respect to the effectiveness of the proposed measure, or in an optimization approach, would then be a useful next step. This way the biophysical aspect of whether the measure is sufficiently protective in Lami Town could be combined with a least-cost approach, to suggest measures that are both proven to reduce storm surge at a minimum cost.

AVOIDED DAMAGES

The next part of the economic analysis was to integrate the least-cost study with estimates of the benefits of avoided damages—that included the projected losses that could potentially occur if no adaptation action is taken in Lami. While the least-cost analysis and associated sensitivity analysis presented above are useful in understanding how the costs of each action project over time, planners may benefit from considering the benefits of implementing actions to mitigate the effects of storms. This can be done by analysing the losses that may occur when no action is taken.

The economic losses estimated from flooding are quite high, with several past floods in the Fiji Islands contributing from FJD 3 to 40 million (US 1.7 to 22.6 million), with the household losses being underestimated in these calculations. The economic losses estimated in this report are losses that the households and businesses would be estimated to incur in the event of a flood or storm surge. This is the cost of a "status quo" scenario, where the existing storm protection measures are assumed to be in place during the storm and the damages are determined after the storm. When later determining the costs and benefits of implementing storm protection measures, it is assumed that these damages from storms are "avoided damages"; they are damages that were not incurred because storm protection measures were implemented. That is, the monetary values estimated as the costs of damages in the status quo scenario are assumed to be the benefits of actions taken for storm protection, and these avoided damages generally include the following costs:

- Lost income from business closures
- Losses to households
- Cost of repair to government structures
- Provision of flood relief supplies and services
- Health costs
- Education costs.

FLOODING PROBABILITIES AND ESTIMATING DAMAGES

There are many types of damages to households, businesses and the government structures that occur with floods, and these are often separated into categories called "tangible" and "intangible" damages. Figure 4 below shows the breakdown of the different types of damages.

In Figure 7 we can see some differences in tangible and intangible losses. Tangible losses are those for which monetary costs can be estimated, and intangible losses from flood damage are generally not easy to monetise, though they are important to note. Direct losses occur immediately after floods, and indirect losses occur as a consequence of the flood.

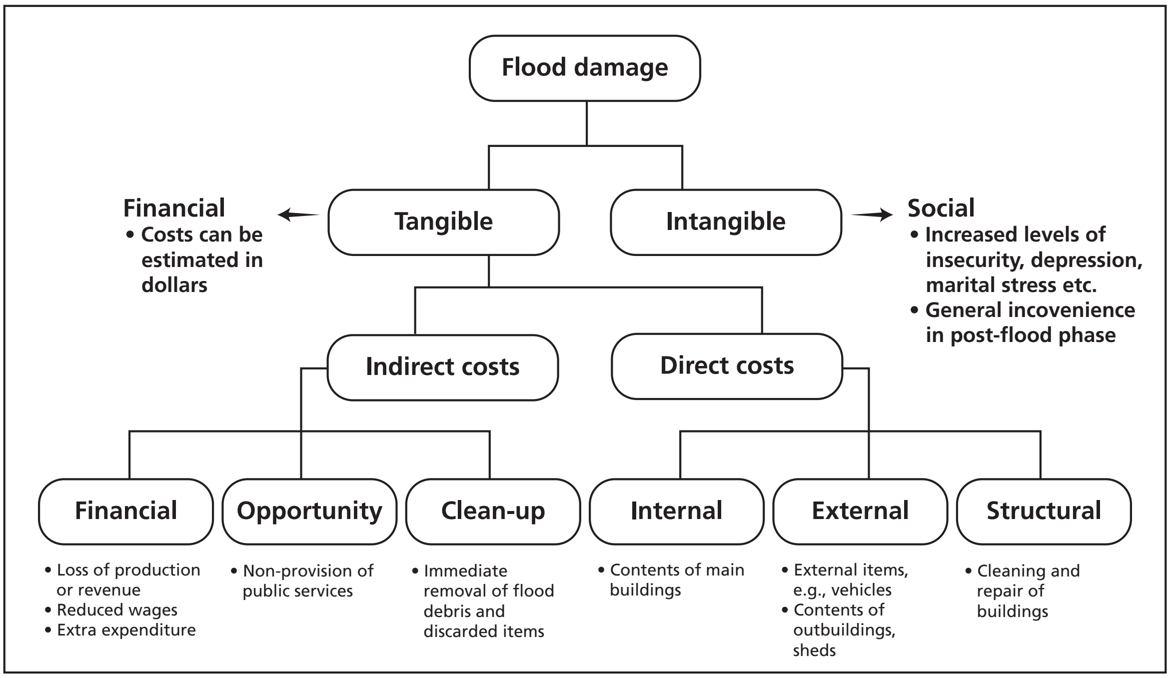


Figure 7. Flood damages broken down into types of costs.

In general, the information needed to determine the expected economic losses in a flood include the following:

- flood hazard map;
- detailed information regarding the height of the houses from the ground;
- detailed flood damage information from surveys or key informants;
- locally determined stage damage curve (used to determine the relationship between the flood height and percent damage to the home);
- probabilities of 1-in-5, 1-in-20, 1-in-50, and 1-in-100 floods.

In studies of different floods in Fiji and in Samoa, in which households and businesses were surveyed after floods to determine losses, the stage damage curves used were those developed and used by the United States Army Corps of Engineers (USACE).

In many studies which examine flood damages, flood risks, expected damages from floods for households and businesses are calculated. In order to determine the accurate flood damages, decision-makers can make use of detailed surveys taken after flood events. Such studies performed after the Ba and Nadi floods involved detailed sampling and surveying of households and businesses to determine the losses of both tangible and intangible assets. To accurately determine the flood hazard, this economic information should be informed by a detailed flood hazard map which describes the floodplain area and the associated probabilities for vulnerability to flooding events.

Estimates of losses for households and businesses in Lami Town

While the preferred method to estimate the costs of flooding to households and businesses in Lami Town would be to use direct surveys and interviews, for this report, existing estimations of flood damages in the Fiji towns of Ba and Nadi were substituted, recognising that some differences occur. The per-household and per business average damages were calculated from these studies, and the average cost per household was estimated at FJD 4,153 and the average cost per business was estimated at FJD 116,643. It is important to note that both the businesses sampled represented a large range, and the percent losses per household and businesses will vary greatly. Tables 4 and 5 show the average values of households and businesses used for this study, based on values estimated for the Ba and Nadi floods.

Since a detailed flood hazard map of Lami Town was not ready in time for this report, it was not possible to construct the stage damage curves to determine the losses per height of flood above the ground floor for the buildings in Lami Town. Hence, the following spatial analysis was performed. First, a building footprint layer was created, which shows all the buildings in Lami Town (Figure 8).

Table 4. Losses per household estimated for Lami Town in the event of a flood.

Household losses	Cost per household (FJD)
Lost possessions	$1,830
Structural damage	$1,925
Lost wages	$202
Clean-up	$142
Medical costs	$25
Evacuation costs	$24
TOTAL	**$4,153**

Table 5. Losses per business estimated for Lami Town in the event of a flood.

Business losses	Cost per business (FJD)
Structural Damage	$14,864
Lost Assests	$46,446
Clean up costs	$10,362
Disrupted business	$42,723
Evacuation costs	$73
Relocation/storage	$355
Extra salaries	$1,155
Other	$666
TOTAL	**$116,643**

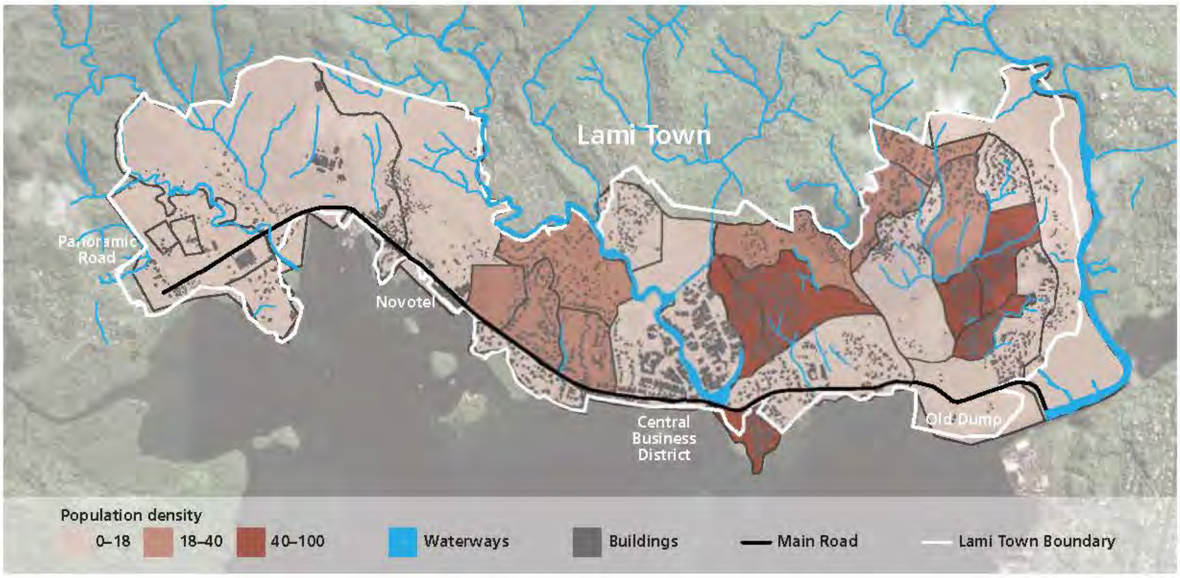


Figure 8. Building footprints and population density in Lami Town.

Next, using the above building footprint layer for Lami Town, the buildings at high risk of flooding were identified. For this study, it was assumed that buildings within 30 meters of the rivers and coasts were at high risk of flooding (Figure 9).

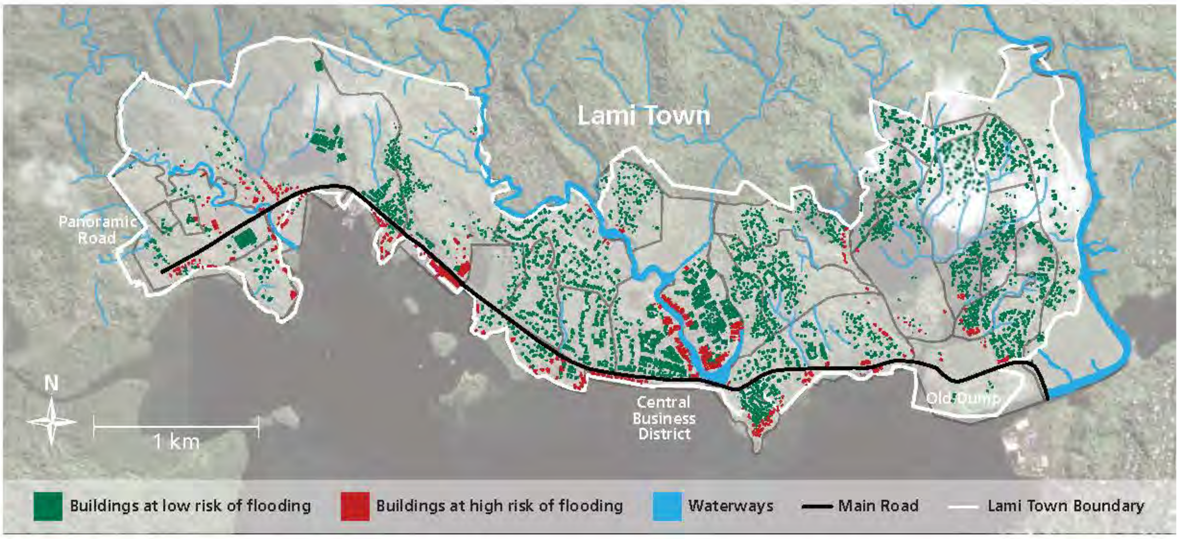


Figure 9. Buildings (both residential and industrial) within 30 meters of coastal and river areas in Lami Town (469 total).

Then, it was determined which of these buildings were industrial by analysing the map below (Figure 10), and determining that from a total of 469 buildings in the at-risk zone, there were 256 industrial buildings at risk of flooding. Hence there were 213 residential buildings estimated to be at risk.

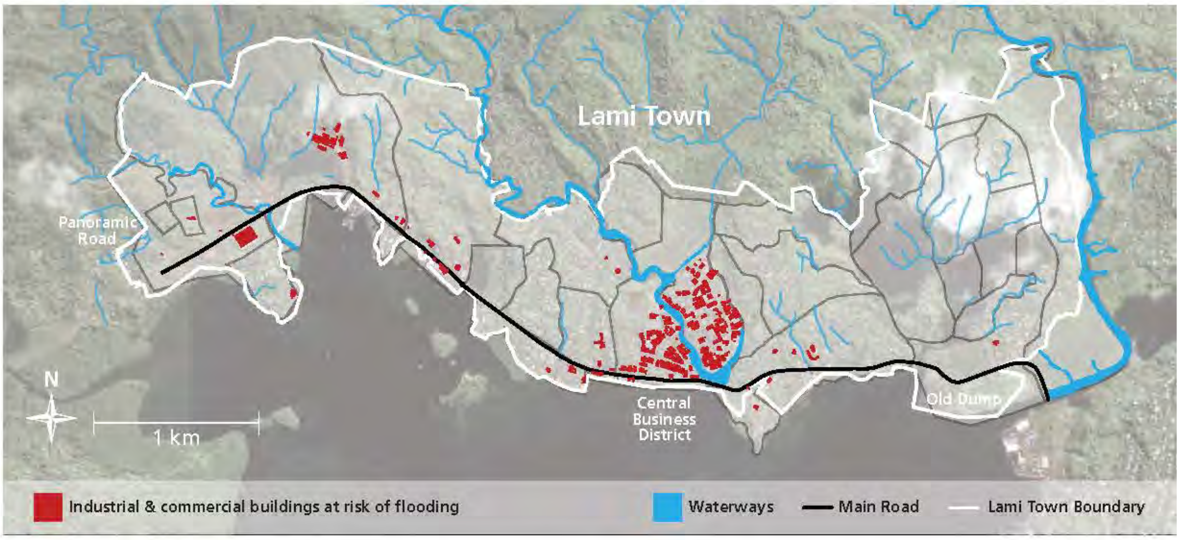
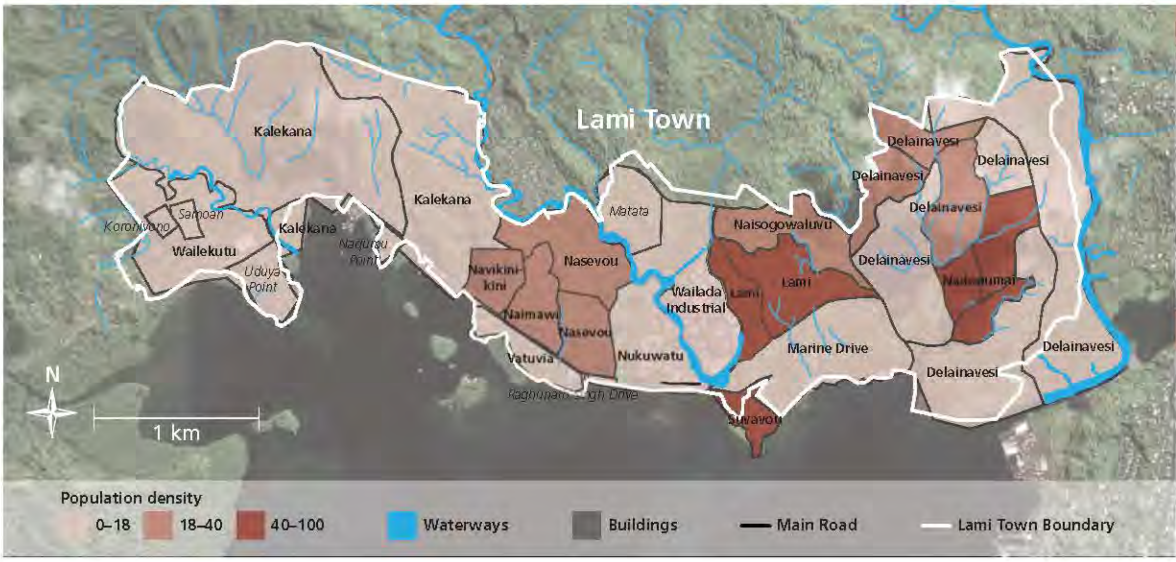


Figure 10. Industrial and commercial buildings at risk of flooding in Lami Town (256 total, comprising 139,500 square meters of total area).

Using the population density estimate map below (Figure 11), it can be seen that there are several areas with zero population estimates, which are informal settlements, for which accurate estimates for housing losses in the event of a flood were impossible to determine.

While this study of population density focused on the formal settlements, information on the informal settlements was provided by the Lami Town Vulnerability and Adaptation Assessment (LTVAA);. By using survey methods, the number of households in the informal settlements was estimated to be 88 households. Hence the potential total business losses estimated for Lami Town was FJD 29,860,608 and the total households, now numbering 301, was FJD 1,250,053.

Without including the high number of informal housing settlements along the coastline and river areas, it was assumed that the number of households likely to experience high flooding risk would be an underestimate. The average value for housing losses for formal houses for the 88 additional houses in the informal settlements identified by the Lami Town Vulnerability & Adaptation Assessment, was used. It can be assumed that while the housing damages might be less than the average household losses estimates used in this study, the losses might represent a



Settlement	Population density ha^{-2}
Delainavesi	137.88
Kalekana	7.88
Lami	97.05
Marine Dve	15.38
Nadonumai	94.20
Naimawi	25.51
Naisogowaluvu	20.21
Nasevou	26.45
Navikinikini	33.74
Nukuwatu	15.76
Suvavou	61.24
Vatuvia	10.75
Wailada Industrial	6.33
Wailekutu	7.55
Average	**28.69**

Figure 11. Population density per hectare in Lami Town, Fiji. Zero values indicate sub-settlements without additional population figures.

much higher percentage of household income. That is, a flood event might indeed represent a much higher loss to a household living in the at-risk informal coastal or riparian zones, but is not well estimated by economic measures. However, for this study, the average value is applied to all households—whether they are in formal or informal settlements.

Cost of repair to infrastructure

The infrastructure damages in a flood event include damages to bridges, sea walls, roads, parks, schools, government buildings and hospitals. These damages vary, and repairs can be costly, with funding potentially diverted from other services such as education or public programs. The cost of repairs to structures after floods has been estimated for the sugar cane industry by Lal et al. (2009). These estimates followed a survey in which growers were asked about repairs to the machinery, rails and infrastructure following floods.

Provision of flood relief supplies and services

Government provision of resources for flood relief supplies and services represent a large cost to the government. These costs include food, water and clothing rations for affected flood victims. While these values are not available for Lami Town specifically, it is expected that they would represent a high cost to the government.

Health costs

The health costs incurred as a result of flooding are difficult to determine for Lami Town. In general, these costs should include those associated with water quality safety and sanitation. Several studies have shown that improved water supply, improved sanitation, hygiene interventions and improved drinking water quality can reduce the incidence of health related effects (diarrhea and gastrointestinal issues) by 6 to 45 percent, depending on the improvements implemented. Research on the effects of water pollution on Palau and the Cook Islands have estimated that health costs due to solid waste pollution are approximately USD 697,000, and the benefits of implementing drinking water safety planning amount to USD 108,835. In Fiji, health costs after floods in Fiji were estimated in few studies, and these were used to estimate the costs for the Lami Town Area. In a 2009 survey of the economic implications of floods to sugar-industry areas, researchers found a range of disease costs for the towns of Labasa, Lautoka, Penang, and Rarawai of FJD 5,680 to 39,515, with an average of FJD 24,317. For this study the estimate for Rarawai (FJD 32,987) was used, as it is located in the low-lying Ba River area, and was thus assumed to have more similarities with Lami Town than the other towns listed above. Using a per person estimate for the Rarawai area, and the population of Lami Town, it is estimated that the health costs following a flood in Lami Town would be FJD 46,396.

Education costs

The education costs of flooding are associated with days of school missed by elementary to high school aged children. This is not practical to measure economically, but it represents a high cost in terms of the continuity of instruction.

SUMMARY OF TOTAL AVOIDED DAMAGES

In summary, the total losses for estimated for Lami Town, based on information from the Ba and Nadi floods, are presented in Table 6.

Table 6. Summary of estimated potential losses from flooding in Lami Town, estimated from reports on Ba and Nadi floods.

Losses with no adaptation action	Estimated cost (FJD)
Lost income from business closures	$29,860,608
Losses to households	$1,250,053
Cost to repair government structures	unavailable
Provision of flood relief supplies and services	unavailable
Health: costs avoided	$46,396
Education costs	unavailable
TOTAL	**$31,157,057**

Avoided damages and Status Quo

The Status Quo conditions—not preparing for storms by either ecosystem-based adaptation or engineering solutions—would incur all of the costs estimated in Table 6. However, preparing for storms reduces this amount. These avoided costs, commonly referred to as "avoided damages" can then used to estimate the benefits for any of the "action" scenarios proposed. One issue here is that the ecosystem-based adaptation options and the engineering options may result in different levels of avoided damages, depending on the protection that the natural versus engineered infrastructure provides. To address this issue, it would be best to use information from an existing study done in Fiji, in which the protection of different types of infrastructure was estimated.* For this study however, since no local study was available, certain assumptions regarding the uncertainty surrounding the effectiveness of the adaptation options for avoiding damages were used, as described below.

The estimation of an avoided damages figure for a range of alternative interventions (in terms of "percent effectiveness") is a key challenge for decision-makers involved in disaster risk reduction. There are a wide range of variables that will impact this effectiveness, including the exposure/scale of the hazard (e.g. height of the storm surge), the conditions of the site (such as near shore bathymetry) and the final design/configuration of the intervention. In environments with good quality data across these three areas, and where there is sufficient experience with structures of that design type, the effectiveness of the intervention can be quantified. In such cases it may be possible to create a "Stage damage curve", which is a picture of the vulnerability to specific levels of exposure.

For example, Figure 12 illustrates a hypothetical stage damage curve for building damage vs flood height that is rooted in building design characteristics and materials construction. In this case, the two adaptation options (raising the houses floor level or moving the house to a new location) will shift the curve to the right.

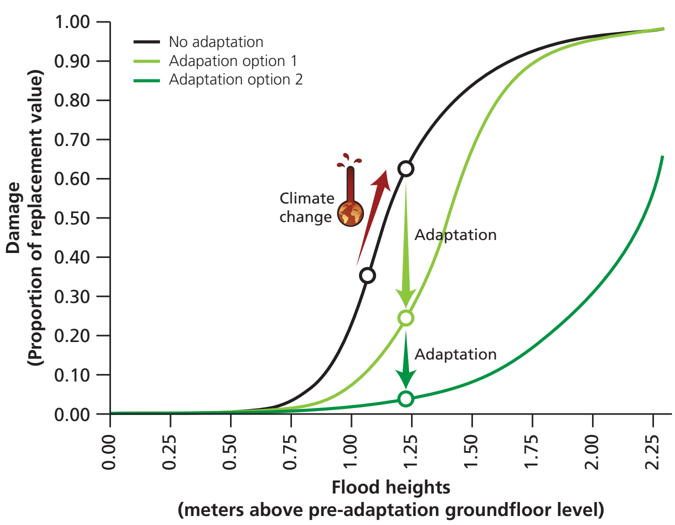


Figure 12. Hypothetical stage-damage curves. Source: CCAIRR findings IN: Asian Development Bank (2005). Climate Proofing: A risk-based approach to adaptation.

In low quality data environments (such as many rural and even urban contexts in the Pacific†) construction of such stage damage curves becomes particularly challenging. In such cases, it is suggested that the use of benchmarks from comparable contexts where disasters have occurred and results analysed is one of the better methods for pre-design decision-making.

* However, not having found such a study, one option is to use the results of a mangroves study performed in India, in which damages to villages were estimated for villages with only natural infrastructure, only concrete infrastructure and neither (Badola & Hussain 2005). Using the percent losses for mangroves and the engineering solution, compared to the no action solution, we calculate that the household losses for mangroves is 73% of the losses if there is no action, and household losses for houses protected by an engineering solution is 348% of the losses if there is no action.

† For example, in Woodruff's (2008) analysis of a project in the Lower Vaisigano catchment area of Samoa all costs associated with flooding event could not be quantified.

The use of vegetation in disaster risk reduction also presents additional challenges for decision-makers as there are even more variables to be considered, and a more limited (but rapidly increasing) set of case studies on effectiveness when compared to engineering solutions.

In this analysis, cost-benefits have been based on three different levels of effectiveness in terms of avoided damages: 10%, 25% and 50%. In their case studies, scientists are generally cautious about presenting % figures, even ranges for particular ecosystem types in a given context, given the range of variables and the potential implications of "rules of thumb." There are some minor exceptions in more detailed studies of larger events: Laso Bayas et al suggests between 2 to 30% reduction in structural damage for protection is observed from Indian Ocean Tsunami in Aceh, and wave reduction estimates of between 0.26–5.0 %/m of vegetation are suggested in a literature review by Anderson et al., 2011.

While there is no agreed method for quantifying a storm surge reductive capability for sea walls it should be acknowledged that appropriately designed hard infrastructure will provide a superior avoided damages result to ecosystem-based adaptation alternatives in most circumstances. As such, for coarse analyses it is suggested that such hard infrastructure interventions would be more likely to be in 25–50% end of the effectiveness spectrum, and that ecosystem-based adaptation options would generally be more likely to provide between 10–25%. Based on this assumption and in the absence of any design information, it is suggested that an appropriate initial conservative estimate of avoided damages for the four scenarios would be based on 10–25%% for the ecosystem-based adaptation scenario, 25% for the two hybrid scenarios and 25–50% for the engineering scenario. The avoided damages estimates should not be considered "additive," in that implementing five ecosystem-based adaptation options that estimate avoided damages at 10% each, is equal to implementing one engineering option that estimates avoided damages at 50%. The ranges given above are merely for estimating relative levels of avoided damages from data collected in other sites. Data from a study on avoided damages performed in Lami Town would be a more accurate estimate of site-specific avoided damages estimates from Lami Town. The actual effectiveness of these measures depends on the design and context of the site, as mentioned in an earlier section.

In future analyses, this assumption can be tested since there is a lag effect of, for example, mangrove effectiveness, or a co-benefit of jobs created for the engineering solution. The avoided damages will enter in as benefits, along with the ecosystem service benefits at a later stage, in each of the four following scenarios. Below is the description of each of four scenarios, and the specific methods of calculating the costs for each action of the scenario.

It is important to note that in the economic analysis to follow, it was assumed that some proportion of the damages from table 13 will be avoided. This is due to the fact that the Ba and Nadi floods were major events, which occurred in areas where the types of businesses and wealth (assets) of households might be higher than in Lami Town. In addition, with the probability of storms increasing with climate change, the incremental damages that successive storms might cause and the changing value of the infrastructure and livelihoods affected may all contribute to the estimate of avoided damages being an overestimate. Hence we take varying proportions of the total damages calculated above as the avoided damages (benefits) of storm protection in Lami, and will use these in the upcoming benefit-cost analysis. This will be instructive to planners in terms of how to integrate benefits and costs into decision-making, and local knowledge about storm damage in Lami would certainly refine these estimates. The total costs were projected over a time period of 20-years, at a discount rate of 3%, to get the total cost of the estimate for Lami, using the information from the Ba and Nadi floods as described above. Then different proportions of this larger amount were determined for use in Part Two of the economic analysis below. Table 7 below summarises the calculations for avoided damages from floods.

Table 7. Proportions of avoided damages for Lami Town over 20-years, at a 3% discount rate.

Avoided damages estimate for Lami, as a percentage of the total calculated (FJD)			
100%	50%	25%	10%
$463,538,332	$231,769,166	$115,884,583	$46,353,833

Economic analysis Part Two: benefit-cost analysis using avoided damages

The avoided damages calculated in Table 6 were adjusted on the assumption that a certain percentage of the avoided damages in Table 7 were applicable to Lami Town. Initial calculations were based on 50% of the total damage estimated, which were then decreased to 10% in the sensitivity analysis. The entire percentage of avoided damages was not used in the analysis, since local information suggests that costs of damage in Lami Town would be lower. The benefit-cost ratio formulation presented in Equation 4 was used, and 50%, 25% and 10% of the avoided damages as a potential benefit of implementing any of these eight adaptation options.

Table 8. Proportions of avoided damages for Lami Town over 20-years, at a 3% discount rate.

Cost of damage avoided per dollar spent (FJD)	Adaptation options	Assumed % damage avoided 50%	25%	10%
	Replant mangroves	$77	$38	$15
	Replant stream buffer	$146	$73	$29
	Monitoring & enforcement	$1,498	$749	$300
	Reduce upland logging	$2,035	$1,018	$407
	Reduce coral extraction	$2,988	$1,494	$598
	Build sea walls	$15	$8	$3
	Reinforce rivers	$96	$48	$19
	Increase drainage	$140	$70	$28

The higher the percentage of avoided damages used as a benefit in the benefit-cost calculation, the higher the benefit-cost ratio for the adaptation option (Table 8). This follows from the fact that when the benefits are higher for the same cost, the benefit-cost ratio will be higher. The higher benefit-cost ratios were identified for the least expensive adaptation options: reducing upland logging and coral extraction, and monitoring and enforcement. The lowest ratios are for the most expensive activities—building sea walls, reinforcing rivers, increasing drainage, and replanting mangroves. Although the unit cost of replanting mangroves per square metre is the most affordable adaptation option, the overall cost includes all potential sites for replanting mangroves, hence the high overall cost.

For a project to be desirable, the benefit-cost ratio should be positive and as high as possible, indicating the scale by which benefits exceed the costs. All of the ratios in Table 8 are above one, hence they are all desirable actions to pursue from the perspective of efficiency. The higher the benefit-cost ratio, the more desirable the project. From this perspective, the three highest benefit-cost ratios are for monitoring and enforcement, and reducing upland logging and coral extraction. However, as noted in the earlier sections, these three activities are not likely sufficient for storm surge protection. Of the remaining activities, increasing drainage and replanting stream buffers have similar benefit-cost ratios, and building sea walls has the lowest ratio, though it is still positive.

Over a longer planning period, the engineering solutions may offer a higher benefit-cost ratio, and thus be more desirable than if they were implemented over a shorter time period. This is a reflection of the larger up-front costs of building the engineered structures for storm protection. Replanting mangroves and stream buffers have similar ratios in both time horizons, but slightly higher for the 20-year time horizon. Again, this is because these two ecosystem-based adaptation solutions have installation costs, rather than just labor and maintenance costs over the time period, associated with them.

The above least-cost analysis was followed by the integration of costs and avoided damages (as benefits) to examine each of the interventions separately. In many cases, planning authorities would like to take strong measures in order to anticipate the possible negative effects of storm surges, given the uncertainties surrounding their effectiveness as well as the value of the avoided damages. The loss of property and livelihoods, disruption of social policies, and dislocation of citizenry are all damages that can be expected during a storm surge. Efforts to minimise these negative effects might require utilising more than one adaptation option. In many studies, ranging from site level analyses, to larger scale climate modelling, and from micro to macroeconomic research, both theoretical and applied, researchers use scenarios to characterise different categories of drivers or actions. For Lami Town, scenario analysis was used to examine whether only engineering or only ecosystem-based adaptation measures are desirable, or if some blended scenarios would be appropriate for implementation. The scenario analysis is described in the next section.

SCENARIOS

On some occasions, decisions on adaptation can be taken by implementing one adaptation solution only. This is the case described above, where each of the selected adaptation options are compared in a least-cost analysis. However, analyses of scenarios can estimate the economic implications of a suite of adaptation options, implemented to reduce vulnerability to storm surges. To examine how a framework for ecosystem-based adaptation decision-making can be applied in Lami, scenarios of possible adaptation options for mitigating the effects of storm surge were examined. The available spatial information was not sufficiently detailed to do an assessment on a site by site basis, so suites of adaptation options were compared. The advantage of examining scenarios, rather than each adaptation one by one, is that these decisions are usually not taken in isolation, so it can offer a more realistic assessment for recommending a course of action.

In environmental decision-making, there are several ways to examine how to measure the relative benefits of different sets of options. Different methods include the development-pressures-state-impact-response (DPSIR) methodology, which describes how to create scenarios based on drivers of change. This method of looking at the "critical uncertainties" is often used to analyze phenomena such as climate change, when the threshold for damages is unknown, or when information regarding the state of the environment or economy lacks completeness. In this study of storm protection and associated benefits in Lami Town, uncertainty exists regarding the effectiveness of the different types of options for storm protection.

Table 9. Four scenarios examined, ranging in emphasis on ecosystem-based adaptation and engineering options.

Ecosystem-based Adaptation options Focusing on maintaining the current natural protective effects of mangrove forest, coral reefs, mud flats and forest, working to preserve and re-establish these habitats to reduce vulnerability of the community.	**Hybrid 2: Emphasis on Engineering options** While including a wide range of adaptation options, the predominant choices are for engineering rather than ecosystem-based adaptation actions.
Hybrid 1: Emphasis on Ecosystem-based Adaptation options While including a wide range of adaptation options, the predominant choices are for ecosystem-based adaptation actions rather than engineering actions.	**Engineering options** Focusing on engineering actions targeted to improve current infrastructure, take actions to limit the effects of severe weather on that infrastructure and the building of protective barriers in streams and along the shoreline.

The scenarios are described below in Table 9:
To examine each of the scenarios in more detail, the specific actions for each of the scenarios are described briefly in Table 10.

DETAILED DESCRIPTION OF SCENARIOS

While some of the costs and benefits were relatively straightforward to estimate, others were more difficult due to lack of data. The information was taken from a variety of local Fijian sources, wherever possible. If the local costs and benefits were not available, costs from other Pacific Islands were substituted. While this is not a perfect solution, the results can be refined as more Fiji-specific

Table 10. Further description of scenarios and how the actions entered into the scenarios.

Adaptation option	No adaptation actions taken	Ecosystem-based adaptation scenario	Hybrid 1: emphasis on ecosyste-based adaptation	Hybrid 2: emphasis on engineering	Engineering solutions scenario
ECOSYSTEM-BASED ADAPTATION ACTIONS					
Replant mangroves	• Not implemented	• Full revegetation of coastline where mangroves are currently not present (64 ha).	• Revegetation of 75% of the coastline where mangroves are currently not present (48 ha).	• Revegetation of 25% of the coastline where mangroves are currently not present (16 ha).	• No revegetation of the coastline.
Replant stream buffer	• Not implemented	• Full revegetation of riverine areas (32.5 ha).	• Revegetation of 75% of riverine areas (24 ha).	• Revegetation of 25% of riverine areas (8 ha).	• No revegetation of riverine areas.
Monitoring and enforcement	• Not implemented	• Surveillance of replanted areas every day.	• Surveillance of replanted areas twice a week.	• Surveillance of replanted areas once a week.	• No surveillance.
Reduce upland logging	• Not implemented	• Upland logging reduced on 50% of area.	• Upland logging reduced on 25% of area.	• Upland logging reduced on 10% of area.	• No reduction of upland logging.
Reduce coral extraction	• Not implemented	• Coral extraction reduced by 100%.	• Coral extraction reduced by 50%.	• Coral extraction reduced by 25%.	• No reduction in coral extraction.
ENGINEERING ACTIONS					
Build sea walls	• Not implemented	• Not implemented	• Build sea walls along 25% of currently unprotected area (1,853 m).	• Build sea walls along 75% of currently unprotected area (5,557 m)	• Build sea walls along 100% of currently unprotected area (7,410 m).
Reinforce rivers	• Not implemented	• Not implemented	Complete 25% proposed engineering options: • Construct gabion baskets (30 m³); • River realignment (37.5 m); • Protect river with spall-filled reno mattress (250 m); • Dredge 25% of river recommended (7,500 m³).	Complete 75% proposed engineering options: • Construct gabion baskets (90 m³); • River realignment (112 m); • Protect river with spall-filled reno mattress (750 m); • Dredge 75% of river recommended (22,500 m³)	Complete 100% proposed engineering options: • Construct gabion baskets (120 m³); • River realigning (150 m); • Protect river with spall-filled reno mattress (1,000 m); • Dredge 100% of river recommended (30,000 m³).
Increase drainage	• Not implemented	• Not implemented	• Build drainage ditches along 25% of Lami Roads (20,688 m).	• Build drainage ditches along 75% Lami Roads (62,062 m).	• Build drainage ditches along 100% Lami Roads (82,750 m).

data becomes available. The costs and benefits were converted to Fiji Dollars (FJD), for the year 2010. The costs of the ecosystem-based adaptation options include all of the costs incurred with the conservation, replanting, surveillance of the mangroves, coral reefs, mudflats/seagrasses, stream buffers and upland forest. These costs each include installation, labor, maintenance, and opportunity costs. The information on each of the costs was determined on a per area basis, and the spatial analysis informed the areas used to determine the costs. If a daily cost was relevant, for example, for labor costs, then the daily rates were estimated using information from the Lami Town Council on the costs of labor. The costs of the engineering options were estimated by a variety of sources. One source was the Lami Town Council authorities, and another was from the "Investigation of Lami River Improvement" government document, from the Land and Water Resources Management Division of the Fiji Department of Agriculture.

Ecosystem-based adaptation scenario

In the ecosystem-based adaptation scenario, maintenance of the existing mangrove area and full revegetation of non-mangrove coastline and riverine areas would be implemented. Daily surveillance of the restored mangrove areas and the riverine locations by government officials was included. Logging would be curtailed in the upstream area completely, with this area under surveillance. Coral reef extraction would be curtailed, with daily surveillance. No engineering options were included in this scenario. The cost calculations follow:

Replant mangroves

The area of the existing mangroves as determined by our spatial analysis was 88 ha. For the replanting of mangroves along the entire coastline, the non-mangrove lined coastline was taken as determined by a site visit and subsequent spatial calculations, and determined this length was 6.4 km (Figure 13). Then using a figure of 100 m width, the total area of the mangroves to be replanted along the coastline was determined to be 64 ha. Using the information from the local OISCA project on mangrove replanting, the 'per ha' biannual planting costs were used (FJD 2,000 for seeding per year for two years; FJD 1,500 for labor; FJD 1,500 for equipment and maintenance) to determine the total cost for replanting mangroves along the non-mangrove coast. The cost of removing the non-mangrove infrastructure was not estimated, and note that this removal would have labor and transportation costs, as well as some sedimentation costs associated with it.

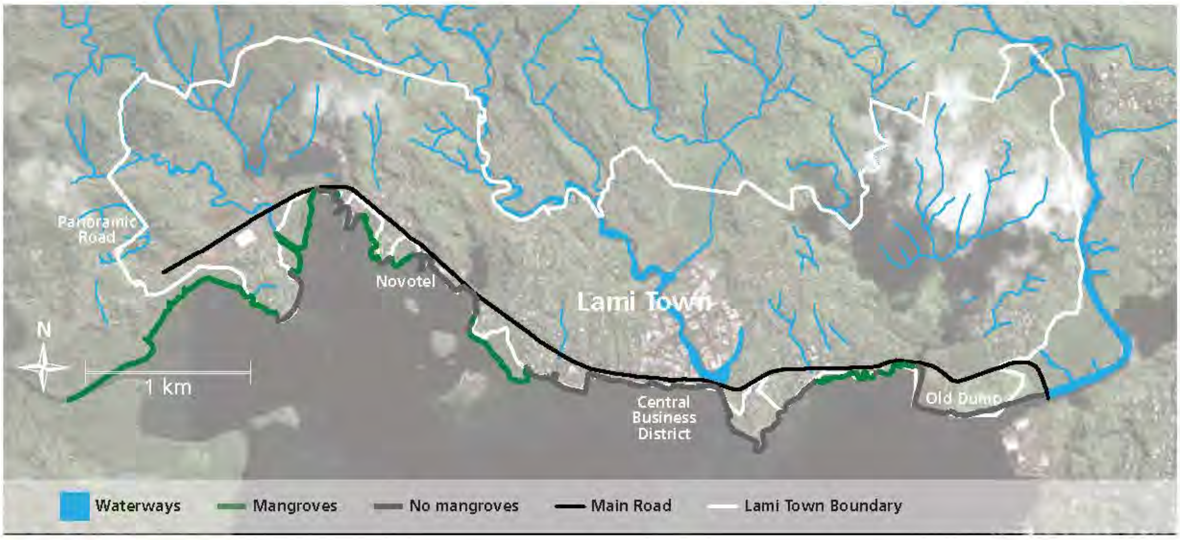


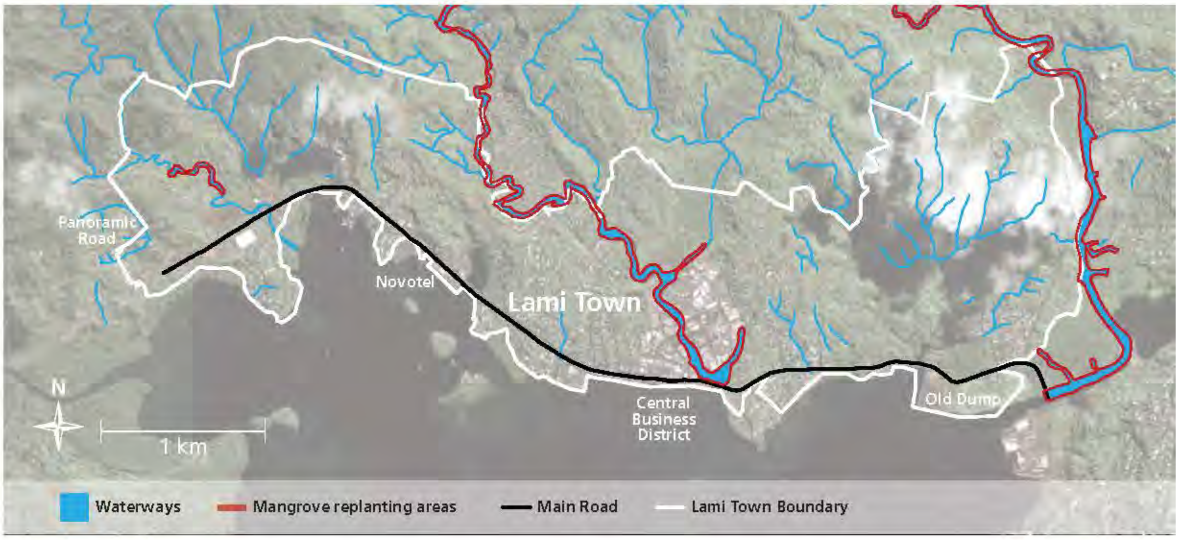
Figure 13. Mangrove and non-mangrove lined coast of Lami Town. Mangrove coastal length equals 5.5 km, while non-mangrove coastal length equals 6.4 km.

Replant stream buffer

Replanting stream buffer was performed in a similar method as above. A buffer of 10 m was included along all of the river edges of Lami Town. Figure 14 shows the buffered area, and the total area, which totalled approximately 32.4 ha.

Note that for this calculation, the buffers include areas outside of the Lami Town boundary. These areas were included, despite the political boundary, because stream stabilization in the upland watersheds is important to avoid excessive sedimentation in the floodplain. While the sedimentation can benefit agriculture, it can also affect drainage

Figure 14. Buffered areas of rivers for replanting.



systems, water supply, as well as cause damages to housing and industrial settlements located in the affected regions. Similar costs of planting along the river edges were used as in the mangrove example above, as specific, river replanting information was not available, and similarity in effort and cost was assumed.

The opportunity cost is also included in this analysis. The opportunity cost is the value of the foregone alternative use of the area. For the river and mangrove replanting, the opportunity costs were estimated in the following ways. The areas where mangroves would be replanted could have a use for some subsistence fishing and crabbing, and hence values from the lower end of estimates for subsistence fishing in Fijian mangroves were used to estimate the opportunity cost, FJD 10 per household per week. It is possible that the area was used as a mudflat rather than as a mangrove area, and hence the value of mudflats could also be used, as described as within the range in TEEB (2010). Another option is that this area along the coastline had no alternative use, and hence the opportunity cost was zero. For this analysis, the subsistence fishing estimate was used, but the estimate could be refined through further consultation with key stakeholders and experts. For the coral reef protection, the foregone alternative is the halting of extractive coral activities, which yield FJD 73 per week. This activity is currently legal, however illegal harvesting of live corals comprises a large percentage of this extraction. Similarly, the ecosystem service value was taken from the range provided in published literature and described in the TEEB report.

Monitoring and enforcement

The surveillance for this area was estimated from the Tikina Wai monitoring project, where it was estimated at FJD 20/day. It was assumed to be one person for the mangroves and coral reef area and one person for the river buffer and upland forests, and work occurring 5 days a week for 52 weeks of the year. This estimate can be increased if it is a government official from the Department of Environment on a specific salary who would be in charge of the surveillance in the mangrove and coral reefs, and an official from the Department of Agriculture providing surveillance of the river buffers.

Build sea walls

None.

Reinforce rivers

None.

Increase drainage

None.

Hybrid 1: Emphasis on ecosystem-based adaptation scenario

In this hybrid scenario, mangroves would be restored along 75% of the coastline where there is currently no mangrove, and riparian buffers would be replanted along 75% of the streams. Surveillance of the restored mangrove areas and the riverine locations by government officials was calculated for twice weekly visits. Logging would be curtailed in 25% of the upstream area, and this area would be under surveillance twice a week. Coral reef extraction would be curtailed by 50%, with twice weekly surveillance. Gabion baskets, river realignment and river protection would be implemented along 25% of the streams. Dredging carried out in 25% of the areas, and drainage ditches built along 25% of Lami's roads. Sea wall construction along 25% of the coastline that is unprotected by built structures would be carried out. The cost calculations follow:

Replant mangroves

The non-mangrove lined coastline was determined by a site visit and subsequent spatial calculations to be 6.4 km, and for this scenario, 75% of this coastline was replanted with mangroves. Then using a figure of 100 m width, the total area of the mangroves to be replanted along the coastline was determined to be 48 ha. Using the information from the local OISCA project on mangrove replanting, the 'per ha' biannual planting cost was used (FJD 2,000 for seeding per year for two years; FJD 1,500 for labor; FJD 1,500 for equipment and maintenance) to determine the total cost for replanting mangroves along the non-mangrove coast. As for the ecosystem-based adaptation scenario, the cost of removing the non-mangrove infrastructure was not estimated.

Replant stream buffer

River replanting was done over an area of 24 ha.

Monitoring and enforcement

The surveillance for this area was estimated from the Tikina Wai monitoring project, where it was estimated at FJD 20/day. It was assumed to be one person for the mangroves and coral reef area and one person for the river buffer and upland forests, and work occurring 2 days a week for 52 weeks of the year.

Build sea walls

From the determination of built and natural coastline shown in Figure 9 above, it was determined that 7,410 m of coastline is natural (natural beach, mangrove, unclassified natural coastline, natural rock and unprotected reclaimant). A sea wall would be built along 25% of this coastline, and the existing sea walls retained. The newly built sea wall for this scenario would be 1,853 m long. The cost for this was estimated to be FJD 2,214,317.

Reinforce rivers

An existing report by the Ministry of Land and Water Resource Management Division (MLWRMD) of the Fiji Islands in December of 2010 detailed the engineering solutions which are available to Lami Town for flood and storm surge control. The figures in the report were used for this study. For this Hybrid 1 scenario, we will use 25% of the suggested amount of engineering solutions. This corresponds to constructing gabion baskets for stream stabilization along the rivers for a distance of 30 m^3. In addition, river realigning was done on 37.5 m of river and protecting the river with spall-filled reno mattress for 250 m. The costs for constructing gabion baskets, river realignment, and installing spall-filled reno mattresses was estimated at FJD 266,725, and were not divided into installation, maintenance, labor and opportunity costs. The MLWRMD's report also suggested dredging 30,000 m^3 along the rivers. For Hybrid Scenario 1, 25% of the most critical areas would be dredged, totalling 7500 m^3. The cost for dredging was an additional FJD 99,375, coming to a total cost of FJD 366,100 for all river reinforcement actions.

Increase drainage

Drainage ditches would be built along 25% of Lami Town's roads, which is a distance of 20,688 m. The cost for this was estimated to be FJD 241,216.

Hybrid 2: Emphasis on engineering scenario

In this hybrid scenario, mangroves would be restored along 25% of the coastline currently without mangrove forest, and riparian buffers would be replanted along 25% of the streams. Surveillance of the restored mangrove areas and the riverine locations by government officials was calculated for once weekly visits. Logging would be curtailed in 10% of the upstream area, and this area would also be under surveillance once a week. Coral reef extraction would also be curtailed by 25%, with once weekly surveillance. Gabion baskets, river realignment and river protection would be implemented along 75% of the streams. Dredging would be carried out in 75% of all identified areas, and drainage ditches built along 75% of Lami's roads. Sea walls would be constructed along 75% of the coastline that is unprotected by built structures. The cost calculations follow:

Replant mangroves

The non-mangrove lined coastline was determined by a site visit and subsequent spatial calculations to be 6.4 km, and for this scenario, 25% of this coastline would be replanted with mangroves. Then using a figure of 100 m width, the total area of the mangroves to be replanted along the coastline was determined to be 16 ha. Using the information from the local OISCA project on mangrove replanting, we used the "per ha" biannual planting costs (FJD 2,000 for seeding per year for two years; FJD 1,500 for labor; FJD 1,500 for equipment and maintenance) to determine the total cost for replanting mangroves along the non-mangrove coast. As for the ecosystem-based adaptation scenario, the cost of removing the non-mangrove infrastructure was not estimated.

Replant stream buffer

River replanting was done over an area of 8 ha.

Monitoring and enforcement

The surveillance for this area was estimated from the Tikina Wai monitoring project, where it was estimated at FJD 20/day. It was assumed to be one person for the mangroves and coral reef area and one person for the river buffer and upland forests, and work occurring 1 day a week for 52 weeks of the year.

Build sea walls

A sea wall would be built along 75% of this coastline, retaining the current sea walls. The newly built sea wall for this scenario would be a distance of 5,557 m. The cost for this was estimated to be FJD 6,642,951.

Reinforce rivers

Using the Ministry of Land and Water Resource Management's report for the Hybrid 2 scenario, 75% of the suggested amount of engineering solutions would be used. This corresponds to constructing gabion baskets for stream stabilization along the rivers for a distance of 90 m. In addition, river realigning would be carried out on 112 m of river and protecting the river with spall-filled reno mattress for 750 m. The costs for constructing gabion baskets, river realignment, and installing spall-filled reno mattresses was estimated at FJD 800,176, and were not divided into installation, maintenance, labor and opportunity costs. For Hybrid Scenario 2, 75% of the most critical areas would be dredged, which is 22,500 m^3. The cost for dredging was an additional FJD 298,125, coming to a total cost of FJD 1,098,301 for all river reinforcement actions.

Increase drainage

Drainage ditches would be built along 75% of Lami Town's roads, which is a distance of 62,062 m. The cost for this was estimated to be FJD 723,649.

Engineering scenario

In the Engineering scenario, no ecosystem activities would be undertaken. Gabion baskets, river realignment and river protection would be implemented along all the stream lengths. Dredging would occur in all suggested stream reaches, and drainage ditches would be built along all of Lami's roads. Sea wall construction would be carried out along the entire coastline that is currently unprotected by built structures. (The environmental benefits of this scenario were reduced to 10% of the status quo environmental benefits, because it is likely that some percentage of ecosystem benefits will exist despite the emphasis on building solutions which will negatively affect the natural ecosystems.) The cost calculations follow:

Replant mangroves

None.

Replant stream buffer

None.

Monitoring and enforcement

None.

Build sea walls

A sea wall will be built along 100% of the coastline which is unprotected by engineering structures, and the existing sea walls will remain as well. The newly built sea wall for this scenario will be a distance of 7,410 m. The cost for this was estimated to be FJD 8,857,269.

Reinforce rivers

Using the Ministry of Land and Water Resource Management's report for the Hybrid 2 scenario, all of the suggested engineering solutions would be fully implemented. This corresponds to constructing gabion baskets for stream stabilization along the rivers for a distance of 120 m. In addition, river realigning was done on 150 m of river and protecting the river with spall-filled reno mattress for 1,000 m. The costs for constructing gabion baskets, river realignment, and installing spall-filled reno mattresses was estimated at FJD 1,066,901, and were not divided into installation, maintenance, labor and opportunity costs. The MLWRMD's report also suggested dredging 30,000 m^3 along the rivers. For the engineering scenario this entire amount would be dredged. The cost for dredging was estimated to be an additional FJD 397,500, coming to a total cost of FJD 1,464,401 for all river reinforcement actions.

Increase drainage

Drainage ditches were built along all of Lami Town's roads, which is a distance of 82,750 m. The cost for this was estimated to be FJD 964,865.

	Percentage implementation of adaptation actions			
Adaptation action	**Ecosystem-based actions**	**Emphasis on ecosystem-based actions**	**Emphasis on engineering actions**	**Engineering actions**
Replant mangroves	100%	75%	25%	0%
Replant stream buffer	100%	75%	25%	0%
Monitoring & enforcement	100%	40%	20%	0%
Reduce upland logging	100%	50%	20%	0%
Reduce coral extraction	100%	50%	20%	0%
Build sea walls	0%	25%	75%	100%
Reinforce rivers	0%	25%	75%	100%
Increase drainage	0%	25%	75%	100%

Table 11. Summary of percentage implementation of adaptation options in Lami Town for each of the four scenarios.

Economic analysis Part Three: integrating scenarios into benefit-cost analysis and including avoided damages

The next step in the economic analysis was to perform a scenario analysis to determine what the benefit-cost implications of implementing a suite of adaptation measures, rather than one at a time. The environmental and engineering costs associated with all four of the scenarios were calculated as described above. The avoided damages were set at the 50% level, and a sensitivity analysis will follow to test discount rates, time horizons and percent of estimated damages avoided.

RESULTS AND DISCUSSION OF ECONOMIC ANALYSIS

Table 12 below shows the sums of the avoided damages, environmental costs and engineering costs. In general we can see here that the engineering costs increase from the ecosystem-based adaptation Scenario, where they are zero, to the engineering scenario, where they are highest. Similarly, the environmental costs decrease from the ecosystem-based adaptation scenario to the engineering scenario. The engineering and environmental costs were estimated from discussions with Lami Town, government agencies, technical reports and government information.

Table 12. Calculations of the discounted costs and benefits for each scenario, calculated over 20-years, at a 3% discount rate.

Scenario	Avoided Damages	Environmental Costs	Engineering Costs
Ecosystem	$231,769,166	$4,754,586	$0
Hybrid 1	$231,769,166	$3,521,062	$4,816,610
Hybrid 2	$231,769,166	$1,208,739	$14,449,830
Engineering	$231,769,166	$0	$19,266,440

Regarding avoided damages, the fact that estimates from the Ba and Nadi floods are used introduces a level of uncertainty, due to the differences in physical climate, socioeconomic status infrastructure, vulnerability and a host of other factors. Further research, including modeling on the flood heights and associated flood damages will allow for the estimates of avoided damages to vary with each scenario based on the type of storm event. In similar studies of natural resource management, restoration and climate adaptation, researchers have attempted to estimate the buffer factor of mangrove using combined physical and economic model inputs such as percent maintenance costs avoided, ratio of mangrove stand width and the wavelength of incident ocean waves . More recent research has combined technical analysis and participatory approaches in order to estimate the economic benefits of different ecosystem services when compared to each other.

Table 13. Results of economic analysis for four scenarios, over 20-years at a 3% discount rate using Avoided Damages benefits, shading shows conservatively estimated proportion of avoided damage for each scenario.

			Assumed percentage damage avoidance		
Scenario	NPV	ANPV	50%	25%	10%
Ecosystem	227014580	15258946	49	24	10
Hybrid 1	223431495	15018106	28	14	6
Hybrid 2	216110598	14526027	15	7	3
Engineering	212502726	14283521	12	6	2

The results of the economic analysis for each of the scenarios included the Net Present Value (NPV) and Annualized Net Present Value (ANPV), and the benefit-cost ratios.

Ecosystem-based adaptation scenario has the highest NPV and ANPV, while the engineering scenario has the lowest values (Table 13). The values do not vary by much between the four scenarios however, and they were calculated using the avoided damages set at 50% of the amount calculated for Lami for the engineering option, 25% for the hybrid options, and 10% for the ecosystem-based adaptation options in determining the effectiveness (amount of damages avoided). The NPV and ANPV are positive, which indicates that all four scenarios are desirable, and could be considered for implementation. The benefit-cost ratio of the ecosystem-based adaptation scenario is the highest when 50% of the avoided damages were used in the calculations, but when 10% of the avoided damages were used, the ratios did not differ by much. The interpretation is that a lower avoided damages value translates into a lower benefit value, and from Equation 4 we can conclude that the ratio would be reduced.

Sensitivity analysis

In addition to the sensitivity analysis presented above with the proportion of avoided damages, an extensive sensitivity analysis was performed across the time periods and discount rates, and the tables are presented in the Appendix. General trends show that for the 20-year time horizon, the ANPV decreases from the ecosystem management scenario to the engineering scenarios. If the extreme scenarios are compared—engineering and ecosystem-based adaptation only—the results show that over both the 20-year and 10-year time horizon, the benefit-cost ratios increase for the ecosystem-based adaptation scenario as the discount rate increases, and benefit-cost ratios decrease or remain the same for the engineering scenario as the discount rate increases. For the blended scenarios, the results are more mixed in terms of the increasing and decreasing trends with respect to discount rate. In general, since the benefit-cost ratios are positive in all cases, all of the scenarios under the time horizons and discount rates are possible for implementation from a benefit-cost framework.

In the next section, we build upon the analysis and add the estimated value of ecosystem services as a benefit to the scenario analysis. First the ecosystem service valuation methods are described, and then estimated for Lami Town. Then these values will enter into the final economic section of the report.

DESCRIPTION OF ECOSYSTEM SERVICES IN LAMI TOWN

Ecosystem services can be systematically described in a framework that categorises the services in the following way :

- Provisioning services: the materials that ecosystems provide
  Examples: food, water, building materials
- Regulating services: the services that ecosystems provide
  Examples: storm protection, clean drinking water
- Supporting services: the services which underlie the ecosystem
  Examples: nutrient cycling, biodiversity
- Cultural services: generally services that are non-material
  Examples: recreation, spiritual activities.

Each of these services are crucial to both ecosystem functioning and human well-being. However, in order to value them in monetary terms, it will be important to examine how each of these services are used, and categorise them in the following way.

Some ecosystem service values are “Use Values,” and others are “Non-Use Values.” Together, the use and non-use values contribute to the Total Economic Value (TEV) of an ecosystem. There are several ecosystem service values that are provided by tropical coastal and marine ecosystems, and are shown here in Table 14.

Use values can be categorised as either direct or indirect—and hence have different methods by which they are generally estimated. Non-use values are much more difficult to estimate from an economic standpoint, since they refer to such intangibles as cultural heritage and existence

Table 14. *Values and services provided by the natural ecosystems surrounding Lami Town.*

Use values	Use values	Non-use values
Direct values	**Indirect values**	**Existence & bequest values**
Fishing	Nutrient retention	Cultural heritage
Aquaculture	Nutrient recycling	Resources for future generations
Transport	Flood control	Existence of specific, important species
Water supply	Storm protection	Existence of wild places
Recreation	Habitat for species	
Genetic material	Nursery ground for fisheries	
Scientific opportunities	Shoreline stabilization	
Wild resources		

values. Hence it is clear that the estimates for the TEV will usually underestimate the exact values, since much of the value of the ecosystem cannot be estimated accurately by economic methods. Using this general framework, we construct an estimate of the value of ecosystem services in Lami below.

METHODS OF BASELINE ECOSYSTEM SERVICE VALUATION FOR LAMI TOWN

In order to determine the baseline value of ecosystem services of the Lami Town area, a combination of spatial and economic analysis was used. Using satellite imagery and existing spatial datasets of the various ecosystems, the spatial extent of each of the four important ecosystems of Lami Town was determined: mangroves, coral reefs, mudflats and forest. When possible, data directly obtained from ecosystem service valuation studies from Fiji were used, however, the primary literature on ecosystem service valuation for Fiji was scarce. Hence, the ecosystem service valuations were used for which many studies informed the values for ecosystem services, such as meta-analytic* studies, when necessary. The implication is that the ecosystem service benefit estimates might not reflect the "exact" ecosystem service value for Lami Town, but it is an estimate informed by the economic valuation literature.

For the mangrove and coral reef estimates for storm protection, a range of values found in a recently performed meta-analysis of storm protection studies, focusing on coastal ecosystems worldwide was used. These values were indirect benefits of the ecosystems, and associated with their storm protection function. For mudflats, information from a study which included an estimation of the range of ecosystem services of mudflats in Thailand was used. The studies on mudflats included both direct and indirect uses. In addition, values from the range of values collected by the 'The Economics of Ecosystems and Biodiversity' (TEEB) consortium were consulted. The 'direct use' values for the mangroves are estimated from research performed in Fijian mangroves systems, where the rural and urban values for mangrove forestry and fisheries products were estimated. A study on biodiversity and ecosystem service values of global forests was used to inform the ecosystem service values for the upland forests. Information regarding the ecosystem service benefit of harvesting coral was determined from local knowledge. Data on the decreased value of the agricultural land—in both formal and informal areas—being leached of nutrients via erosion stemming from storm surge is something that could have been included were the necessary data available.

BENEFIT TRANSFER

To estimate the ecosystem values for mangroves and coral reefs, a benefit transfer function was used. This is a method in which values are extrapolated from one site, where good data are

* A meta-analytic regression function is performed as follows. The researcher examined the literature on economic valuation of storm protection, and regressed the vector of estimated benefits from ecosystem services on a large set of potential drivers of ecosystem service value to determine the function and magnitude with which the drivers affect the ecosystem service value. The function was used to estimate values for several areas.

available, to another site, using an adjustment function where necessary. This site where data is sourced is referred to as the "study site," and the site where the value of the ecosystem service will be estimated is called the "policy site". To estimate the value for the same ecosystem service, a method for transferring the estimated environmental benefit from the study site to the policy site, is required. One method is called "point transfer," where the economic value, per unit area, is directly transferred from one site to the other. The second method of benefit transfer is a "value function transfer," where the value transfer functions can capture the heterogeneity across the sites by changing the independent variables such as the size of ecosystem, the valuation methods, and other socio-economic characteristics found to be relevant in the estimate of the value. This method allows for systematic adjustments resulting from some environmental characteristics in the sites, as well as socio-economic characteristics.

Benefit transfer has the advantage of being inexpensive and allowing for rapid estimation of ecosystem service values in sites where a primary study has not been performed. However, there are several questions regarding the accuracy and validity of transferring the results from one site to another. Transfer errors are defined as the difference between the benefit transferred from the study to the policy site, and the "true value" of the ecosystem service at the policy site. Transfer errors are expected to be lower when the two sites are similar, and are minimised with intra-region rather than inter-region transfers. Matching of site, contextual, institutional and quantity and quality characteristics between the policy and study sites will all decrease the benefit transfer error. For the analysis performed below, the results of an ecosystem service valuation performed in Fiji and benefit transfer estimates from studies in the Pacific Islands and around the world were used.

In this study, a combination of point and value transfers were used to determine the direct and indirect use values for mangroves, coral reefs, mudflats and forests. Firstly, the full extent of each of the four areas was determined using spatial analysis, in all cases, the calculations were performed for a one-year period.

Mangroves

The existing mangrove area in Lami Town covers 88 ha (Figure 15). For the mangrove areas of Lami Town, the ecosystem service value for coastal shoreline protection was estimated using a meta-analytic regression function developed from study sites where the values for storm protection had been determined and applied to policy sites with unknown values, such as in Lami Town. The equation incorporates the key drivers affecting the value of the ecosystem service, and was applied to Lami, to determine the ecosystem service of storm protection. The indirect benefits of mangroves in Fiji was determined to be FJD 471 ha^{-1}, which was then multiplied by the area of mangroves in Lami Town, 88 ha, to give a total of FJD 41,448. The direct, extractive benefits for people from mangroves were determined by using values from a study of the use of Fijian mangroves by Thaman (1998). The value of the mangroves to households was FJD 40.6 in 2010. It was estimated from spatial analysis and population information that 974 people live in the unofficial settlements, specifically in Wailekutu and Navikinikini. However, this may be an underestimate as people making direct use of mangroves might be larger, and include those in other informal settlements not adjacent to the mangroves. Additionally, other inhabitants of Lami Town may depend on some mangrove benefits. The vulnerability assessment estimates that 88 households are located in the unofficial settlements of Lami Town. Based on these numbers, an assumption was made that a total of 200 households (including those living in more official settlements) use the mangroves for their direct ecosystem service value, was determined to be FJD 8,110. Hence, the total estimated ecosystem service value for mangroves in Fiji is FJD 49,558.

Coral reefs

The existing coral reef area in Lami town covers 1387 ha (Figure 15), and this was determined by using spatial analysis. Similar to the method described above regarding the benefit transfer, the indirect, storm protection benefits of coral reefs were determined to be FJD 471 ha^{-1}, and over an area of 1,387 ha yield an ecosystem service value of FJD 653,277 in 2010. In terms of the direct benefits of coral reefs, one of these benefits was identified as coral extraction for use in septic treatment in Lami Town. From local information, the figure of FJD 73 per week was used, which yields a FJD 10.4 per day, and assuming 10 people are selling the reef products, for 50 days a year, then the value Is FJD 5,214. Hence, the total ecosystem service value for the coral reefs was calculated as FJD 658,491.

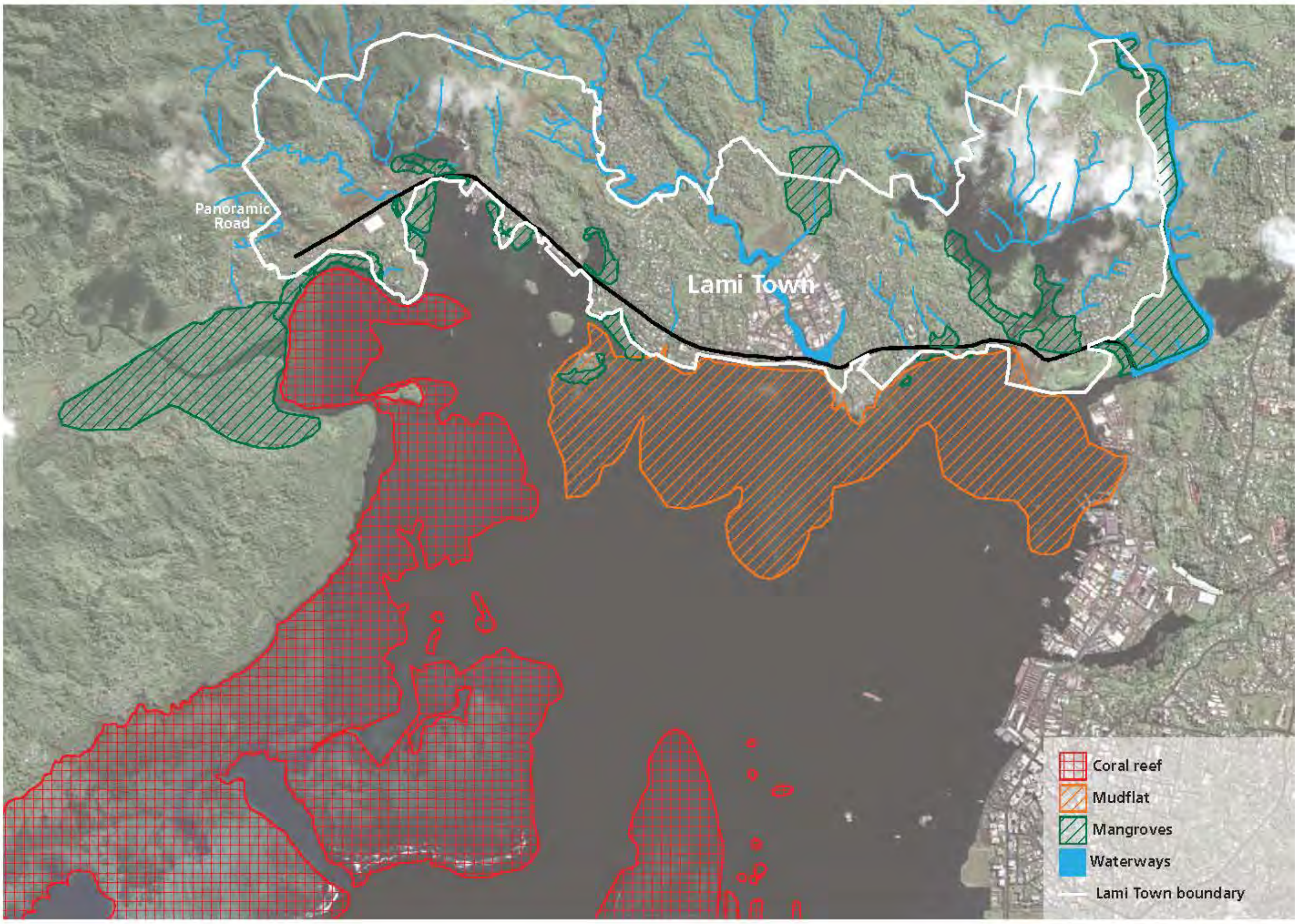


Figure 15. Location of mangrove, seagrass, and coral areas surrounding in Lami Town.

Mudflats/seagrasses

The mudflats and seagrasses surrounding Lami Town cover 330 ha (Figure 15). From a study on seagrasses, the point transfer of data from a value given in the TEEB report was used, which, when converted to FJD 2,010, yielded FJD 139 ha^{-1}. In total, for 330 ha of seagrasses, we calculated FJD 40,590. For the direct benefits of mudflats, using results from Chuenpagdee (1998), it was revealed that the direct benefits of crabbing from mudflats yields FJD 123 per household. Using an estimate of 200 households, it is estimated that the direct benefits of the mudflats to be FJD 24,600. The total for this ecosystem is FJD 65,190.

Forested area

The forested area covers 5,755 ha as determined by spatial analysis (Figure 16). Estimating that approximately 20% of the area is forested, the total forested area is 1,151 ha. A global study on forests by Ojea (2010) shows the value of forests to have an indirect value of FJD 6.65 per ha, yielding a total of FJD 7,654.

Summary of direct and indirect ecosystem service values

Table 15 presents a summary of the direct and indirect ecosystem services provided by the natural habitat of Lami Town as described above.

RESULTS OF ECOSYSTEM SERVICE VALUATION

While ecosystem service valuation involves careful study of a site to determine all the environmental benefits, often there are benefits which are not included—either due to lack of data or to the services being monetarily unquantifiable. However, using the methods and assumptions described above, the results of the calculations for the ecosystem services chosen in Lami Town are given below in Table 15.

The next addition to the analysis is that the methods used to determine the discounted environmental benefits combined the direct and indirect uses of the ecosystems in Lami Town,

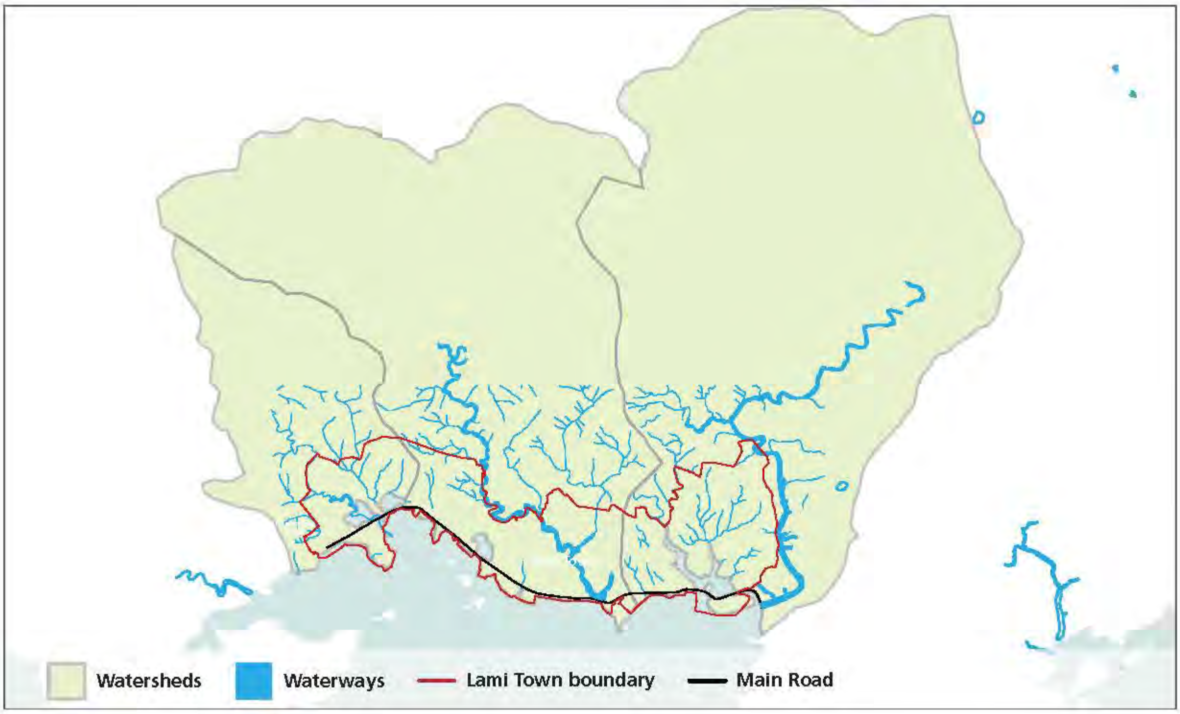


Figure 16. Upland forest area of Lami Town.

and used a combination of Fiji-specific studies and meta-analytic studies, to estimate the values. The environmental benefits of indirect ecosystem services are estimated from a range of values available in the literature, and used Fiji-specific values when these were available. The environmental and engineering costs—that is, the costs that were estimated for implementation of the various ecosystem-based adaptation and engineering options—were taken strictly from local sources or reports. Future efforts to perform some primary studies on Lami Town on indirect benefits, and to combine this information with the local costs, might give insight into the distribution of costs and benefits in the different scenarios. If no local primary studies are available or can be commissioned, then perhaps a concerted effort to locate economic valuation studies in the Pacific Islands and develop a transfer function to estimate the Lami Town values might be possible.

Table 15. Value of ecosystem services (per household or per hectare, and overall) for Lami Town over a one-year time frame.

Ecosystem	Type of value	Value (FJD)	Unit/year		Benefits (FJD year^{-1})
			Hectare	Household	
Mangroves	Direct[1]	$41	-	200	$8,200
	Indirect[2]	$471	320	-	$150,720
			Ecosystem benefits of mangroves		$158,920
Coral reefs	Direct[3]	$521	-	10	$5,210
	Indirect[2]	$471	1,387	-	$653,277
			Ecosystem benefits of coral reefs		$658,487
Mudflats/seagrasses	Direct[4,5]	$123	-	200	$24,600
	Indirect	$139	330	-	$45,870
			Ecosystem benefits of mudflats/seagrasses		$70,470
Upland forests	Indirect[6]	7	1,151	-	$8,057
			Ecosystem benefits of upland forests		$8,057
Streams	Direct[4]	60	32.5		$1,950
			Ecosystem benefits of streams		$1,950
			Total ecosystem benefits for Lami Town		**$897,884**

1. Thaman 1998; 2. Rao 2013; 3. CI-Fiji staff (personal communication); 4. TEEB 2010; 5. Chuengpadee 1998; 6. Ojea 2010.

Economic analysis Part Four: benefit-cost analysis including avoided damages and estimates of ecosystem service valuation

RESULTS AND DISCUSSION OF ECONOMIC ANALYSIS

The economic analysis presented in this benefit-cost analysis is not a general solution, but is partial in nature. It compares the restoration and monitoring costs with the indirect benefits of storm protection as well as a subset of the direct benefits available from the selected ecosystems. In addition, the analysis assumes a standard amount of damages avoided for each of the scenarios, which is discounted over the course of the 20-year period, but which is invariant to both the scenario and to the magnitude or frequency of the storms expected.

Including estimates of ecosystem service value into the benefit-cost analysis

Performing benefit-cost analyses in developing countries would be more accurate if it could account, to the extent possible, for the different conditions of the countries. In developing countries, a higher proportion of people are dependent on natural resources for their daily survival, whereas this proportion is much lower in the more developed world. Across developing countries, on average, nearly 80 percent of the labor force works in an agricultural or resource-based activity. When poorer, more vulnerable people rely on ecosystem services, these services are critical to survival. Hence, the environment in developing countries is related to the health and well-being of the nearby households. The well-being that the households in Lami Town derive from their natural capital includes the indirect storm protection, erosion prevention and water quality benefits, as well as direct benefits from fishing and crabbing. In addition there are a host of other benefits which this economic analysis does not address. The aggregation of multiple economic benefits is a methodological question, which researchers have been examining in different ecosystems and using various methods. For this analysis the benefits and costs as they were available were incorporated, and it is certain that some beneficial aspects of these ecosystems were not included. The benefits were aggregated by simple addition, whereas a different functional form might be appropriate.*

Table 16 shows the results for the final economic analysis, where costs were integrated with ecosystem service benefits and avoided damages. The benefit-cost ratios decrease for all scenario between the 20 and 10-year time horizons, but all are at least equal to or greater than 1. The benefit of spending one dollar on any of the scenarios is positive, but there appear to be higher returns for the scenarios which emphasise ecosystem-based adaptation.

The NPV and ANPV are all positive for each of the four scenarios. This indicates that from the information available, the present value of the benefits of each scenario is greater than the present value of the costs. Any project for which the NPV is positive is

Table 16. Results of economic analysis for 20-year time horizon, and 3% discount rate, including costs of implementation and benefits—avoided damages and ecosystem service benefits, shading shows conservatively estimated proportion of avoided damage for each scenario.

			Assumed percentage damage avoidance		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	238571628	16035761	51	27	12
Hybrid 1	232079947	15599418	29	15	7
Hybrid 2	218988248	14719450	15	8	3
Engineering	213653882	14360897	12	6	2

* Addition may be inappropriate if some of the benefits of ecosystem services are found to be described by nonlinear functions.

considered to be a project which will improve social welfare, and so the implication is that each of the four scenarios would increase the general welfare of Lami Town. The benefit-cost ratio compares the set of benefits to the set of costs and helps the decision-maker to make a choice between a set of alternatives. In this study of Lami Town, different scenarios of adaptation options were examined, and for each scenario, the present value of benefits and costs for each of the options which made up the scenario were calculated. If the ratio of benefits to costs is equal to or less than one, then the scenario is not worth pursuing. The higher the benefit-cost ratio, the greater the welfare provided by that option. For example, assuming 50% damage avoidance by all implemented scenarios, in the ecosystem-based adaptation scenario, the benefit-cost ratio was calculated to be 51 (Table 16). This indicates that for every one dollar invested into this scenario, the benefit is estimated at 51 dollars. In the engineering scenario, for every dollar invested into this scenario, the benefits were estimated to be 12 dollars. Both of these scenarios are greater than one, indicating that they are both desirable. However, the higher the benefit-cost ratio, the higher the return from the action, and hence the greater the welfare provided. The decision-maker will determine from local knowledge and understand the risks in choosing what proportion of avoided damages the adaptation option is likely to have.

SENSITIVITY ANALYSIS RESULTS

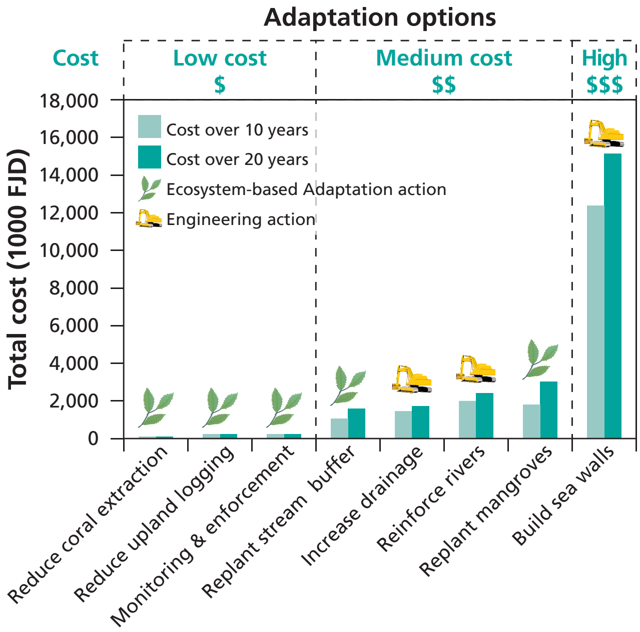
Two types of sensitivity analysis were performed in this study, the results of which are in Appendix. The discount rate and time were varied, separately, as in the previous section. The same general trends for the four scenarios resulted for using the different discount rates, with the ecosystem-based adaptation scenario having the highest NPV, ANPV and BC ratio, and the engineering option scenario having the lowest. However, once again the NPV and ANPV are all positive and all the benefit-cost ratios are greater than one, which suggests that all the scenarios are desirable. The changes in discount rate do not appear to be a key parameter that changes the NPV outcomes in this analysis. The generally low relative changes in the hybrid 1, hybrid 2 and engineering scenarios show that most of the costs occur within a relatively short time frame; the relatively higher installation costs in the first few years followed by the relatively lower maintenance costs in later years are shown in the result.

For this study, the sensitivity analyses did not reveal that any of the economic outcomes calculated are sensitive to either discount rate or time, in any of the four scenarios of shoreline protection. For the time horizon, the results showed that lengthening the time horizon tends to increase the benefit-cost ratio for each of the scenarios, implying that per dollar spent for the scenario, the benefits to society increase a small amount if the time horizon is increased to 20-years. The sensitivity analyses indicate that the sign of the NPV and ANPV, and the fact that the benefit-cost ratio is greater than one in all cases suggests that the analysis is robust to changes in time and discount rate. Further sensitivity analyses should include varying the physical inputs, such as sizes of areas to be replanted, as well as important costs, such as installation or labor costs.

Summary and discussion

This study examined the adaptation options in Lami Town and performed an economic analysis of those options. The results of this study, along with the Vulnerability Assessment which preceded it, illustrate some important issues with respect to the needs and possibilities for protection against storm surge in the municipality. In this report, the environment, the socio-economic and governance context in Lami Town was described. The report described the participatory exercise in which a set of adaptation options was determined, and categorised them in terms of their emphasis. A least-cost analysis was performed, and then the avoided damages were calculated to integrate into a benefit-cost analysis. Four scenarios were created to examine whether a suite of adaptation options would be desirable, and the economic analysis was performed using avoided damage estimates. Finally, the ecosystem service benefits of Lami Town were estimated, and then these benefits were integrated into the economic analysis. For each of the sections of the study, a sensitivity analysis was included, based on time, discount rate and estimated percent of damage avoidance.

Figure 17. Total cost to implement adaptation actions for all identified sites throughout Lami Town.



LEAST-COST ANALYSIS

Least-cost analysis calculated the overall costs for implementing actions separately, for two time horizons, 10 and 20-years (Figure 17). Both the ecosystem-based adaptation measures and the engineering measures included options with a range of costs; several have the potential of long effective lifespans with appropriate maintenance.

These actions range in effectiveness of damage avoidance as well as the expected time for initiation of provision of damage protection, hence the simple relative costs cannot be used, in isolation, for comparative decision making. Both the ecosystem-based adaptation options and the engineering options have quite a range of costs with the different solutions.

Table 17. Summary of estimated potential losses from flooding in Lami Town, estimated from reports on Ba and Nadi floods.

Losses with Status Quo solution	Estimated cost (FJD)
Lost income from business closures	29,860,608
Losses to households	1,250,053
Cost to repair government structures	unavailable
Provision of flood relief supplies and services	unavailable
Health: costs avoided	46,396
Education costs	unavailable
TOTAL	**$31,157,057**

AVOIDED DAMAGES

Avoided damages are calculated by estimating the damages that are incurred when no action is taken. This "do-nothing" scenario shows the damages that will be incurred if no action is taken (status quo). Hence they are also estimate of the benefits of taking action. The avoided damages analysis began with estimating the damages in Lami Town based on studies done in Ba and Nadi, Fiji (Table 17).

Since Ba and Nadi are different socioeconomically from each other and from Lami Town, proportions of the total avoided damages were determined for

Table 18. Proportions of avoided damages for Lami Town over 20-years, at a 3% discount rate.

Avoided damages estimate for Lami, as a percentage of the total calculated (FJD)			
100%	**50%**	**25%**	**10%**
463,538,332	231,769,166	115,884,583	46,353,833

the calculations: In Table 18 we present different proportions of the calculated avoided damages for Lami, using information from the Ba and Nadi floods. For the calculations from the benefit-cost analysis, we assume that engineering solutions provide 50% of the avoided damages; the hybrid solutions provide 25% of the avoided damages; and ecosystem-based adaptation provides 10% of the avoided damages.

The results of this analysis show that action is preferable to no action, with suggested actions to reduce the potentially expensive damages to Lami Town. It was assumed that the least-cost analysis included the lowest uncertainty with respect to the accuracy of the values used, since the information was obtained from government agencies, consultants and conservationists in Lami Town itself. The results showed that the low cost options for adaptation are the ones which do not involve high installation costs. Both the sea wall and the mangrove replanting options had very high costs compared to the other adaptation options. However, the relative effectiveness of options was not available in detail, and it is also recognised that both costs and effectiveness of these different options vary over time.

ECOSYSTEM SERVICE CALCULATION

In order to determine the baseline value of ecosystem services of the Lami Town area, a combination of spatial and economic analysis was used. Using satellite imagery and existing spatial datasets of the various ecosystems, the spatial extent of each of the four important ecosystems of Lami Town was determined: mangroves, coral reefs, mudflats and forest. Then, estimates of the economic value of ecosystem services were found in the literature. When possible, data directly obtained from ecosystem service valuation studies from Fiji were used, however, the primary literature on ecosystem service valuation for Fiji was scarce, and values from non-local or global studies supplemented. From the spatial and economic estimate, we estimated the ecosystem service benefits to Lami and the results are shown below in Table 19.

The scenarios ranged from ecosystem-based adaptation options to engineering options. These results were presented in order to suggest a way to combine different types of actions, should it not be feasible to implement one action at a time. The results of the studies show that the

Table 19. Value of ecosystem services (per household or per hectare, and overall) for Lami Town over a one-year time frame.

Ecosystem	Type of value	Value (FJD)	Unit/year		Benefits (FJD year^{-1})
			Hectare	Household	
Mangroves	Direct[1]	$41	-	200	$8,200
	Indirect[2]	$471	320	-	$150,720
			Ecosystem benefits of mangroves		**$158,920**
Coral reefs	Direct[3]	$521	-	10	$5,210
	Indirect[2]	$471	1,387	-	$653,277
			Ecosystem benefits of coral reefs		**$658,487**
Mudflats/seagrasses	Direct[4,5]	$123	-	200	$24,600
	Indirect	$139	330	-	$45,870
			Ecosystem benefits of mudflats/seagrasses		**$70,470**
Upland forests	Indirect[6]	7	1,151	-	$8,057
			Ecosystem benefits of upland forests		**$8,057**
Streams	Direct[4]	60	32.5		$1,950
			Ecosystem benefits of streams		**$1,950**
			Total ecosystem benefits for Lami Town		**$897,884**

time horizon over which the projects are implemented is an important aspect, and longer time horizons will yield a larger value per dollar spent, especially with activities with high installation costs. The discount rate was varied in this study, and this showed differences in returns over the time horizons.

Given all possible adaptation options, a relevant subset that could be fully costed were analysed to provide guidance on the best overall adaptation approaches. To assess the suite of potential adaptation options for Lami Town, the benefits and costs of four different combinations were compared with taking no action. The scenarios had a different balance of ecosystem-based adaptation and engineering options, with Scenario 1 comprised of all ecosystem-based options, Scenario 4 all engineering options, and the other two scenarios a combination of these (Figure 18).

Figure 18. Percentage implementation of adaptation options for each scenario.

Scenario 1

ECOSYSTEM-BASED OPTIONS

Focuses on maintaining the current natural protection from coral reefs, mangrove forest, mud flats and seagrass meadows, and upland forest, as well as working to preserve and re-establish these habitats to reduce vulnerability of the community. Specific adaptation options include replanting mangroves and stream buffer, reducing upland logging and coral extraction, and monitoring and enforcement.

Scenario 2

EMPHASIS ON ECOSYSTEM-BASED OPTIONS

Includes a wide range of adaptation options, however the predominant choices are for ecosystem-based rather than engineering options.

Scenario 3

EMPHASIS ON ENGINEERING OPTIONS

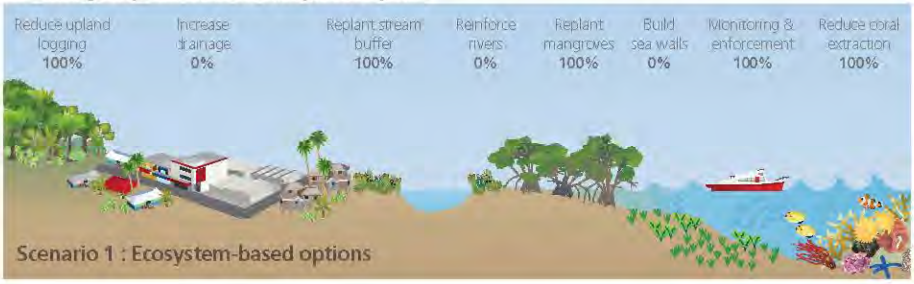
Includes a wide range of adaptation options, however the predominant choices are for engineering rather than ecosystem-based options.

Scenario 4

ENGINEERING OPTIONS

Focuses on engineering options targeted to improve current infrastructure, taking actions to limit the effects of severe weather on that infrastructure and the building of protective barriers in streams and along the shoreline. Specific adaptation options include building sea walls, reinforcing rivers (dredging, river realignment, and protecting river banks with gabion baskets or spall-filled reno mattresses), and increasing drainage.

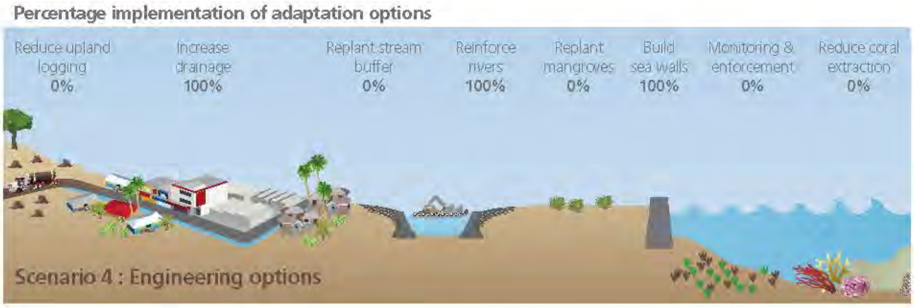
Percentage implementation of adaptation options



Percentage implementation of adaptation actions

Adaptation option	Ecosytem-based actions	Emphasis on ecosystem-based actions	Emphasis on engineering actions	Engineering actions
Replant mangroves	100%	75%	25%	0%
Replant stream buffer	100%	75%	25%	0%
Monitoring & enforcement	100%	40%	20%	0%
Reduce upland logging	100%	50%	20%	0%
Reduce coral extraction	100%	50%	20%	0%
Build sea walls	0%	25%	75%	100%
Reinforce rivers	0%	25%	75%	100%
Increase drainage	0%	25%	75%	100%

Percentage implementation of adaptation options



BENEFIT-COST ANALYSIS

When using the full suite of estimated costs, avoided damages, and estimates of ecosystem service benefits (see text above) applied to four scenarios, the results are detailed in Table 20.

Scenario	Benefit-to-cost ratio (FJD)	Assumed damage avoidance
Ecosystem-based options	$19.50	10–25%
Emphasis on ecosystem-based options	$15.00	25%
Emphasis on engineering options	$8.00	25%
Engineering options	$9.00	25–50%

Table 20. Benefit-to-cost ratio for each scenario of adaptaton options, with assumed percentage of damage avoidance.

The benefit-cost scenarios are highlighted and can be compared here. Here we can see that when integrating the avoided damages estimates, adjusted for category of intervention, that the benefit-to-cost ratios of the engineering solutions differ from the ecosystem-based adaptation solutions. This example highlights the important role that uncertainty plays in determining how much of the avoided damages can be associated with each of the categories of adaptation responses. The approach of this study was to use a 50% estimate for the engineering category, 25% for the hybrid categories and 10% for the ecosystem-based adaptation scenarios estimate of avoided damages. From this study, we can see that the Engineering option with a benefit-to-cost ratio of 12 and the Hybrid 1 scenario with a benefit-to-cost ratio of 10 have similar outcomes in terms of the benefits per dollar spent on the option. Hence, from this outcome we can see that the one possible plan for Lami Town would be to implement targeted engineering options but a general ecosystem-based adaptation approach, such that a high benefit-to-cost ratio can be preserved using a mix of solutions. Ultimately if the LTC or UN-HABITAT create an ecosystem-based adaptation design that they believe offers the same level of protection as sea walls, then the ecosystem-based adaptation scenario offers the highest benefit-to-cost ratio (above).

Using the least-cost approach, the costs were calculated and ranked. Benefit-cost ratios were calculated for each option, for specific scenarios and integrating different types of benefits in order to present whether or not the project should go forward—that is, whether the benefit-cost ratios were above 1 and the ANPV was positive. In all cases, this was true, hence any action to prevent storm surge would be economically efficient. However, the results in which the ANPV or the benefit-cost ratios were higher are actions or scenarios for which Lami would receive more benefit for each dollar spent. The information from the benefit-cost analysis should be used to compare the relative ratios and determine what other information would be important to know before making a decision. Such information includes: examining assumptions about uncertainty; examining assumptions about ecosystem-based adaptation vs. engineering options; examining social issues not included because they could not be monetised; examining how coastal geomorphology and watershed issues would affect values; distribution of benefits between different settlements in Lami, to name a few. This report is an aid to guide decision-making but the above questions need to be addressed by the decision-maker before planning any policy implementation.

Socio-political implications of adaptation options

Option	Details of the option	Social
ENGINEERING OPTIONS		
Bridge improvements	Raise and upgrade bridges.	• Public consultation and awareness, particularly for those residing near bridges and high-users.
Reinforce river bank	Reinforce river bank using gabion baskets.	• Public consultation and awareness, particularly for those residing near bridges and high-users.
Dredge river	Remove extra sediments.	• Public consultation and awareness, particularly for those residing near the river.
Increase drainage	Clear out any blocked drains.	• Public awareness on littering and securing loose soil.
Build sea walls	Build sea walls with concrete, rock, or tyres.	• Community awareness and engagement of private sector and schools.
ECOSYSTEM-BASED ADAPTATION OPTIONS		
Coastal revegetation	Replant mangroves, forests.	• Needs community support in order to be successful. Lami Town residents are largely dependent on mangroves for subsistence so should be supportive of any replanting schemes. Some settlements have piggeries located in mangroves—these may need to be relocated.
Conservation of mangroves, seagrasses/ mudflats, coral reef, forests, river buffer areas	Protect natural systems through monitoring and surveillance to limit extractive activities.	• Needs strong communication to engage community in recognising the benefits (e.g., shoreline protection, maintenance of inshore fisheries, erosion control) and the benefits of keeping these habitats intact and healthy.
POLICY AND SOCIAL OPTIONS		
Rezoning areas	Rezone areas such that building industrial or residential areas in vulnerable zones would not occur.	• Needs strong engagement from land trustees and descendants.
Regulating land tenure of informal settlements	Implement Fiji national housing policy that addresses the need to formalise the informal settlements in order to provide assistance.	• Community consultations to integrate settlements into disaster response plan.
Coastal relocation	Relocate people from vulnerable, coastal settlements to higher, drier areas.	• Initiate discussions with vulnerable communities and leaders to increase awareness of risk and improve understanding of the need to relocate.
River relocation	Relocate people from vulnerable riverine settlements to drier areas.	• Initiate discussions with vulnerable communities and leaders to increase awareness of risk and improve understanding of the need to relocate.
Disaster response planning	Develop a disaster response plan involving the community and the private sector.	• Public consultation and awareness.

Institutional	Governance
• The Fiji Roads Authority is responsible for maintenance of all roads and bridges.	• National – Fiji Roads Authority.
• Department of Environment is responsible for replanting and erosion control. National Disaster Management Office also has funding to assist with controlling river bank erosion.	• National – Department of Environment and National Disaster Management Office.
• The Ministry of Agriculture is responsible for all dredging works in Fiji.	• National – Land and Water Resource Management Department, Ministry of Agriculture.
• Lami Town council is responsible for inlets and Fiji Roads Authority is responsible for outlets.	• National – Fiji Roads Authority in consultation with Lami Town Council, and private sector on industrial sites.
• Multiple options including revegetation, tyres through to concrete sea walls.	• National – Department of Lands, Department of Environment, Lami Town Council with the private sector.
• The mangrove sub-committee under the National Integrated Coastal Management Committee is responsible for sustainable mangrove management at the national level.	• National – working with Department of Environment, Lami Town Council and the public/community.
• The Departments of Fisheries, Forests, and Lands have been working together to stregthen conditions for licenses to cut mangroves.	• National – working with Department of Environment on community and public awareness and with the Department of Fisheries, Forests, and Lands with mangrove licenses.
• Department of Town and Country Planning and Lami Town Council to review Lami Town's Planning Scheme to incorporate climate impacts and climate projections.	• National – Department of Town and Country Planning, Ministry of iTaukei Affairs, and Lami Town Council.
• Department of Housing is engaged in upgrading and regulating land tenure for informal settlements.	• National – Department of Housing and the national housing policy implementation action plan.
• Department of Housing has settlement upgrading and relocation funds to provide basic services to relocated households.	• National and local – Department of Environment with awareness raising; Lami Town Council and National Disaster Management Office developing local disaster preparedness and response time; Department of Lands and Department of Housing for relocation.
• National Disaster Management Office (NDMO) cannot offer assistance for informal settlements during flooding events; the national Climate Change policy recognises need to address impacts in regards to the urban development and housing sector.	• National and local – Department of Environment with awareness raising; Lami Town Council and National Disaster Management Office developing local disaster preparedness and response time; Lands and Housing for relocation.
• Lami Town Council has taken the initiative to work directly with NDMO in developing a disaster response plan that involves the community and private sector, has liaised with SPC–SOPAC Community Risk programme for tsunami mapping and secured through them signage and early warning system (AusAID).	• National and local – Lami Town Council in conjunction with NDMO, SPC–SOPAC, and AusAID.

Conclusions and recommendations

Conclusions	Recommendations
• Intact mangroves, forests, seagrass, mud flats, and coral reefs provide natural capital, by reducing flood and erosion potential while providing secondary ecosystem services, such as supporting inshore artisanal fisheries.	• **Protect and maintain** intact mangroves, forests, seagrass, mud flats, and coral reefs as a priority action, representing the cheapest options with greatest benefit-to-cost ratios.
• Lami Town has high vulnerability to flooding and erosion of industrial, commercial and residential buildings.	• **Target engineering options** to protect priority areas of built capital.
• An adaptation plan focused on ecosystem-based options, including targeted engineering options, will provide a high benefit-to-cost return in terms of avoided damages as well as provision of secondary ecosystem services.	• **Include social and policy initiatives** into an integrated adaptation plan, to complement ecosystem-based and targeted engineering options.
• Potential damages in Lami Town were estimated to be up to FJD 232 million, while implementation of all costed adaptation options was estimated to cost approximately FJD 24 million over 20-years.	• **Support planning** and prioritising of adaptation action strategies by determining the recipients of benefits from the different options, as well as identifying potential co-benefits (such as local employment).
• Built capital in Lami Town is very high in the most vulnerable areas, in close proximity to the coast and rivers.	• **Develop** a high resolution elevation map of Lami Town (including bathymetry) as a basis to further identification of priority sites for adaptation action, enable storm surge and flood modelling, and development of a specific flood height-Damage curves to inform a site-specific adaptation action plan.
• There are some large data gaps regarding both costs and effectiveness of different adaptation options, limiting support of informed decision making.	• **Examine assumptions** on the relative effectiveness of ecosystem-based and engineering adaptation options in order to determine which benefit-to-cost ratios to use as a part of decision-making, alongside other non-economic analyses of vulnerability, risk, social and political issues.
• The current analysis, focused on coastal and river areas, could be enhanced with expanded consideration and costings of watershed, policy and social options.	• **Refine economic analysis** using flood height-damage curves, elevation maps, watershed analysis, and costs for policy and social options as estimated by local economists.

Process for decision making

This cost-benefit analysis aimed to guide adaptation planning and implementation decisions within Lami Town Council. The following decision-making process illustrates the role of this report in the context of the broader adaptation planning process. The process for decision-making in other sites could follow the planning process used for Lami with modifications as necessary.

1

Identify key areas of vulnerability and possible adaptation options through a vulnerability assessment process.

Involves: Assessment of climate exposure.

2

Conduct a cost-benefit assessment of adaptation options identified in step one.

Involves: Least-cost analysis; benefit-cost assessment using avoided damage assessment; sensitivity analysis.

3

Detailed assessment and design of preferred adaptation options.

May involve: Visual inspection by experts, spatial analysis, storm surge modelling, flood modelling. Requires coastal engineering and restoration expertise.

4

Implementation of preferred adaptation options.

May involve: Partnerships between communities, government officials, and/or local and international contractors.

5

Monitoring and evaluation.

May involve: Assessment of community awareness, community participation, and effectiveness of adaptation options.

Further research

TAKING ACTION IS BETTER THAN TAKING NO ACTION

From this analysis it can be concluded that taking any action to protect the coastal community from storms—either ecosystem-based adaptation or engineering—is preferable to not taking action. Additional research can explore the effectiveness of the different types of adaptation options, processes to target where actions should be implemented, and novel or new options combining engineering and ecosystem-based adaptation options.

EFFECTIVENESS OF ADAPTATION OPTIONS IS UNCERTAIN

As discussed, the uncertainty in terms of the effectiveness of the different options is a major determinant in whether a certain category or scenario is desirable.

a. If the avoided damages are set at 50% for all scenarios, the ecosystem-based adaptation scenario yields the highest benefit per dollar spent on implementation, while the engineering scenario yields the lowest benefit per dollar spent on implementation. The higher level of expected benefits from an ecosystem-based adaptation scenario implementation is an important consideration, given that the natural areas of Lami Town provide additional benefits that were not captured by the economic values used in this analysis.

b. More realistically, if the avoided damages for the scenarios are set at 25–50% for engineering, 25% for the hybrid and 10–25% for the ecosystem-based adaptation, the results become more similar, with a smaller range.

Further research on the uncertainty and ranges of values regarding the expected avoided damages is a key avenue of research, and one which may be very illuminating for planners in Lami, and around the Pacific Island nations.

FURTHER SPATIAL ANALYSIS WILL HELP IMPROVE THIS PRELIMINARY RESEARCH

a. Spatial analysis will inform where, within Lami Town, a specific scenario might be feasible. Spatial analysis could suggest that hybrid actions might represent a more realistic suite of activities for Lami Town to implement, to target specific areas. For example, while engineering actions may be the most feasible options to implement within the industrial area itself, ecosystem or mixed adaptation options implemented upstream could significantly mitigate extreme weather impacts within the industrial area.

b. Spatial analysis combined with site-based economic data-gathering in specific parts of Lami Town would help to highlight the distribution of costs and benefits around Lami Town. Accurate measurements of the population size, income levels, and use of natural resources by informal settlements are important to include in this analysis.

c. Physical modelling combined with careful flood damage analysis specific to Lami Town could better inform the avoided damages component of this analysis, and improve the accuracy of the results.

d. The forested watershed above Lami Town provides protection against erosion, improves water quality and mitigates landslides in storm events. However, this area is outside the Lami Town boundary, and hence estimating the proportion of economic benefit from this upstream area to Lami Town residents should be carefully refined based on spatial analysis.

e. Important social/policy actions outlined earlier were not included in this analysis. Unfortunately, cost and benefit information regarding these options were not available at the time of the site visit. Further studies could use values from other Pacific Islands, or a participatory process of determining the costs of some of the social/policy could be held with relevant governmental officials.

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Appendix: Sensitivity analyses

SENSITIVITY ANALYSIS OF LEAST-COST ANALYSIS

A sensitivity analysis shows how the results of least-cost analysis respond to changes in time horizon and discount rate. In general the trends in the least cost alternatives are consistent over different time periods and discount rates. Tables A1, A2 and A3 show a sensitivity analysis holding the time horizon constant at 20 years and varying the discount rate from 10% to 1%. Tables A4, A5 and A6 show a sensitivity analysis holding the time horizon constant at 10 years and varying the discount rate from 10% to 1%.

Table A1. Calculation of costs for each action, calculated over 20 years at a 10% discount rate.

Actions	Cost
Reduce coral extraction	44392
Reduce upland logging	65164
Monitoring & enforcement	88541
Replant stream buffer	927151
Increase drainage	1287872
Replant mangroves	1766911
Reinforce rivers	1886824
Build sea walls	11822408

Table A2. Calculation of costs for each action, calculated over 20 years at a 7% discount rate.

Actions	Cost
Reduce coral extraction	55240
Reduce upland logging	81088
Monitoring & enforcement	110178
Replant stream buffer	1142290
Increase drainage	1412833
Reinforce rivers	2069901
Replant mangroves	2176185
Build sea walls	12969523

Table A3. Calculation of costs for each action, calculated over 20 years at a 1% discount rate.

Actions	Cost
Reduce coral extraction	94095
Reduce upland logging	138123
Monitoring & enforcement	187674
Increase drainage	1825888
Replant stream buffer	1909692
Reinforce rivers	2827192
Replant mangroves	3635857
Build sea walls	16761288

Table A4. Calculation of costs for each action, calculated over 10 years at a 10% discount rate.

Actions	Cost
Reduce coral extraction	32040
Reduce upland logging	47031
Monitoring & enforcement	63904
Replant stream buffer	684856
Increase drainage	1173584
Replant mangroves	1306156
Reinforce rivers	1719384
Build sea walls	10773266

Table A5. Calculation of costs for each action, calculated over 10 years at a 7% discount rate.

Actions	Cost
Reduce coral extraction	36623
Reduce upland logging	53760
Monitoring & enforcement	73045
Replant stream buffer	777115
Increase drainage	1240583
Replant mangroves	1481758
Reinforce rivers	1817543
Build sea walls	11388309

Table A6. Calculation of costs for each action, calculated over 10 years at a 1% discount rate.

Actions	Cost
Reduce coral extraction	49386
Reduce upland logging	72495
Monitoring & enforcement	98502
Replant stream buffer	1032739
Increase drainage	1412238
Replant mangroves	1968217
Reinforce rivers	2120394
Build sea walls	12964067

AVOIDED DAMAGES

Table A7. Proportions of avoided damages for Lami Town over 20 years, at a range of discount rates.

	Avoided Damages		
Discount rate	**50%**	**25%**	**10%**
3%	231 769 166	115 884 583	46 353 833
7%	165 039 153	82 519 576	33 007 831
10%	132 628 795	66 314 398	26 525 759

Table A8. Proportions of avoided damages for Lami Town over 10 years, at a range of discount rates.

	Avoided Damages		
Discount rate	**50%**	**25%**	**10%**
3%	132 888 008	66 444 004	26 577 602
7%	109 417 065	54 708 533	21 883 413
10%	95 723 314	47 861 657	19 144 663

LEAST-COST ANALYSIS USING AVOIDED DAMAGES

Table A9. Benefit cost ratios using a proportion of the avoided damages for Lami Town over 10 years at a 3% discount rate.

	Proportion of avoided damages as benefit			
Adaptation action	**100%**	**50%**	**25%**	**10%**
Replant mangroves	149	75	37	15
Replant stream buffer	284	142	71	28
Monitoring & enforcement	2996	1498	749	300
Reduce upland logging	4071	2035	1018	407
Reduce coral extraction	5975	2988	1494	598
Build sea walls	21	11	5	2
Reinforce rivers	135	67	34	13
Increase drainage	197	99	49	20

Table A10. Benefit-cost analysis (costs and avoided damages) using a 20-year time horizon and a 7% discount rate.

	Proportion of avoided damages as benefit			
Adaptation action	**100%**	**50%**	**25%**	**10%**
Replant mangroves	152	107	53	21
Replant stream buffer	289	203	101	41
Monitoring & enforcement	2996	2104	1052	421
Reduce upland logging	4071	2858	1429	572
Reduce coral extraction	5975	4196	2098	839
Build sea walls	25	18	9	4
Reinforce rivers	159	112	56	22
Increase drainage	234	164	82	33

Table A11. Benefit Cost Analysis (costs and avoided damages) using a 20 year time horizon and a 10% discount rate.

Adaptation action	Proportion of avoided damages as benefit			
	100%	50%	25%	10%
Replant mangroves	213	75	38	15
Replant stream buffer	406	143	72	29
Monitoring & enforcement	4207	1498	749	300
Reduce upland logging	5716	2035	1018	407
Reduce coral extraction	8391	2988	1494	598
Build sea walls	36	11	6	2
Reinforce rivers	224	70	35	14
Increase drainage	328	103	51	21

Table A12. Benefit Cost Analysis (costs and avoided damages) using a 10 year time horizon and a 7% discount rate.

Adaptation action	Proportion of avoided damages as benefit			
	100%	50%	25%	10%
Replant mangroves	148	74	37	15
Replant stream buffer	282	141	70	28
Monitoring & enforcement	2996	1498	749	300
Reduce upland logging	4071	2035	1018	407
Reduce coral extraction	5975	2988	1494	598
Build sea walls	19	10	5	2
Reinforce rivers	120	60	30	12
Increase drainage	176	88	44	18

Table A13. Benefit Cost Analysis (costs and avoided damages) using a 10 year time horizon and a 10% discount rate.

Adaptation action	Proportion of avoided damages as benefit			
	100%	50%	25%	10%
Replant mangroves	147	73	37	15
Replant stream buffer	280	140	70	28
Monitoring & enforcement	2996	1498	749	300
Reduce upland logging	4071	2035	1018	407
Reduce coral extraction	5975	2988	1494	598
Build sea walls	18	9	4	2
Reinforce rivers	111	56	28	11
Increase drainage	163	82	41	16

SCENARIOS: SENSITIVITY ANALYSIS RESULTS OF BENEFIT-COST ANALYSIS (USING COSTS AND AVOIDED DAMAGES)

Table A14. Results of economic analysis for four scenarios, over 20 years at a 7% discount rate using Avoided Damages as benefits.

			Benefit-cost ratio for different proportion of avoided damages		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	161610500	15254888	48	24	10
Hybrid 1	158386556	14950570	25	12	5
Hybrid 2	154062723	14542431	15	8	3
Engineering	148586897	14025552	10	5	2

Table A15. Results of economic analysis for four scenarios, over 20 years at a 10% discount rate using Avoided Damages as benefits.

			Benefit-cost ratio for different proportion of avoided damages		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	129846192	15251685	48	24	10
Hybrid 1	126818247	14896024	23	11	5
Hybrid 2	120673818	14174301	11	6	2
Engineering	117631690	13816974	9	4	2

Table A16. Results of economic analysis for four scenarios, over 10 years at a 3% discount rate using Avoided Damages as benefits.

			Assumed percentage damage avoidance		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	262971131	30828239	95	47	19
Hybrid 1	259772927	30453312	44	22	9
Hybrid 2	253287804	29693058	21	11	4
Engineering	246509576	28898443	14	7	3

Table A17. Results of economic analysis for four scenarios, over 10 years at a 7% discount rate using Avoided Damages as benefits.

			Benefit-cost ratio for different proportion of avoided damages		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	216502213	30825044	94	47	19
Hybrid 1	213494770	30396852	41	20	8
Hybrid 2	208733130	29718902	22	11	4
Engineering	202381875	28814626	13	7	3

Table A18. Results of economic analysis for four scenarios, over 10 years at a 10% discount rate using Avoided Damages as benefits.

			Benefit-cost ratio for different proportion of avoided damages		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	189391712	30822629	93	47	19
Hybrid 1	186507418	30353223	39	19	8
Hybrid 2	180674925	29404012	18	9	4
Engineering	176449523	28716347	13	6	3

SENSITIVITY ANALYSIS RESULTS OF BENEFIT-COST ANALYSIS (USING COSTS, AVOIDED DAMAGES, AND ECOSYSTEM SERVICE BENEFIT ESTIMATES)

Table A19. Results of economic analysis for four scenarios, over 20 years at a 7% discount rate using Avoided Damages and Ecosystem Services as benefits.

			Benefit-cost ratio for different proportion of avoided damages		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	171095439	16150199	51	27	12
Hybrid 1	165502782	15622292	26	13	6
Hybrid 2	156456068	14768346	15	8	3
Engineering	149535391	14115083	10	5	2

Table A20. Results of economic analysis for four scenarios, over 20 years at a 10% discount rate using Avoided Damages and Ecosystem Services as benefits.

			Benefit-cost ratio for different proportion of avoided damages		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	137468480	16146996	50	27	12
Hybrid 1	132536990	15567745	24	12	6
Hybrid 2	122597158	14400216	11	6	2
Engineering	118393919	13906505	9	4	2

Table A21. Results of economic analysis for four scenarios, over 10 years at a 3% discount rate using Avoided Damages and Ecosystem Services as benefits.

			Assumed percentage damage avoidance		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	137720309	16145022	97	50	22
Hybrid 1	132614838	15546505	45	23	10
Hybrid 2	122326895	14340444	21	11	4
Engineering	114385287	13409445	14	7	3

Table A22. Results of economic analysis for four scenarios, over 10 years at a 7% discount rate using Avoided Damages and Ecosystem Services as benefits.

			Benefit-cost ratio for different proportion of avoided damages		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	113373438	16141827	97	50	21
Hybrid 1	108795594	15490045	42	21	9
Hybrid 2	100902795	14366288	22	11	4
Engineering	93593638	13325629	13	7	3

Table A23. Results of economic analysis for four scenarios, over 10 years at a 10% discount rate using Avoided Damages and Ecosystem Services as benefits.

			Benefit-cost ratio for different proportion of avoided damages		
Scenario	**NPV**	**ANPV**	**50%**	**25%**	**10%**
Ecosystem	99169698	16139412	96	49	21
Hybrid 1	94911541	15446416	40	20	9
Hybrid 2	86339759	14051398	18	9	4
Engineering	81276339	13227350	13	6	3

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More information

For more information, please see the synthesis report:

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Both of these publications are available electronically at: **www.sprep.org** and **ian.umces.edu**

Exchange rates

Currency conversions of $1 FJD to USD, AUD, and NZD as of January 2013.

Currency	$1 FJD
US Dollar (USD)	$0.56
Australian Dollar (AUD)	$0.54
New Zealand Dollar (NZD)	$0.68

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