Coastal Management Adaptation to Climate Change using Ecosystem-based Adaptation Strategies (Samoa Component)

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by

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Chapter 1
Introduction to Ecosystem-based Adaptation Strategies for Coastal Management Plans

Introduction

Samoa consists of four main inhabited islands (Upolu, Savai'**i**, Manono and Apolima) and six smaller uninhabited islands (Figure 1). The islands lie between 13ºS–14ºS and 170ºW–173ºW and have a total land area of approximately 2934 km^2 (Samoa's First National Communication under the UNFCCC, 2000) and shoreline length of 573 km (MNREM 2005). Its population of over 195,000 (CIA 2013) lives primarily in coastal villages, and fishing and agriculture support subsistence living in addition to providing income through sales at open-air markets. The majority of the country's income comes from overseas remittances, international development aid, tourism, and agricultural exports; the latter two income sources are very vulnerable to the devastating impacts of cyclones and other strong storms (CIA 2013).

Figure 1. Map of Samoa (CIA 2013).

Samoa Coastal Environment

The Samoa coast and nearshore environment comprises multiple habitats and characteristic features: coastal forest, wetlands, beach, nearshore reef, and the biological and physical processes that connect these components. Changes to one process or habitat can change the whole system; for example, modification of coastal wetland habitat can have consequences on local sediment budgets and transport pathways (Richmond 1991).

In the nearshore, coral reefs provide habitat for hundreds of species. Coral reefs may be narrow (10 m) or wide (several km) and reduce the wave energy reaching the shoreline (Gillie 1997). Fringing coral reefs grow quickly, several millimetres per year (Gillie 1997).

Beachrock is often found on the beach or just seaward of the shoreline. Beachrock forms in both the intertidal zone and beneath the surface of the beach sand near the water table. It is created when calcium carbonate (lime) cements sand grains together. Exposure of beachrock occurs when the overlying sand is removed and indicates that the shoreline is eroding (Richmond 1991). As beaches erode and retreat landward, beachrock ledges may be left in the nearshore ocean, acting as breakwaters by reducing the incoming wave energy and sometimes forming sheltered swimming areas (Cambers 2002).

Beaches are constantly changing profile and alignment in response to changes in wave conditions, eroding during storms and accreting during fair-weather. Beach sediment comes from the adjacent reef flat, which in turn derives sediment from both the reef (breakdown of coral and beachrock) and riverine input (Richmond 1991). Carbonate sediment is also derived from foraminifera (marine plankton), *Halimeda* algae, and shells (Gillie 1997). Tropical carbonate beaches often have low volumes of sand because of limited natural supply rates (coral) and the rapid formation of underlying beachrock (Gillie 1997).

Rivers and streams affect the coast in several ways. They deliver large amounts of terrigenous sediment from dark volcanic rocks. At the mouth of the river, where the river enters the sea, freshwater flow and increased turbidity inhibit coral growth. The sudden deceleration of current at the river mouth results in sediment deposition which in Samoa usually forms a river mouth spit. A small submerged delta sometimes forms if a shallow offshore terrace exists, but high wave energy along the coast and narrow shelf prevents the formation of large deltas (Richmond 1991). Offshore of the larger rivers there are often gaps in the reef known as ‘ava’, allowing the river to discharge directly to the open sea. Common along the south coast of Upolu are ephemeral streams that are fronted by reef flats, so high-discharge events (such as during extreme rainfall events) deposit large amounts of mixed-sized sediment onto the reef flat, forming a flood delta that is reworked by waves and currents that remove the finer sand and leave a lag of coarse debris (Richmond 1991).

Tropical cyclones and associated high winds, large waves, storm surge, flooding, and heavy rainfall can have significant impacts on Samoa’s coastal environments (Gillie 1997). Although in the short-term they often erode beaches, cyclones contribute significantly to the long-term supply and replenishment of coastal sediment (Gillie 1997).

The coastal vulnerability of Samoa is exacerbated by climate change impacts, human modifications, and their interactions with natural processes. Gibb (2000) identifies multiple factors contributing to coastal erosion in Samoa including sea-level rise; short-term (2-10 year) sea level increases related to ENSO (El Niño-Southern Oscillation) cycles; regional tectonic subsidence at a rate of 0.05 to 1.4 mm/yr; coastal engineering structures that block alongshore sediment transport; destruction of protective coastal vegetation; and extraction of nearshore seabed, beach sand, and river alluvium that would otherwise nourish the coast. Mined sediments are often used for road construction and cement manufacture (Nunn 1994).

The impacts of climate change and coastal structures, and their contributions to coastal erosion, are discussed in more detail below.

Impacts of coastal engineering structures

Coastal engineering structures include seawalls, revetments, retaining walls, groynes, jetties, and breakwaters. Historically, these structures were regarded as providing tangible protection. Although several types of structures (e.g. seawall, retaining wall) do initially halt shoreline erosion by locking the coastline in one position, they do not prevent the ongoing physical process of erosion (Linham and Nicholls 2010). Instead, the sediment erosion problem is transferred to the nearshore area immediately in front of the structure (Pilarczyk 1990) or along adjacent shorelines (USACE 2008). Natural shorelines and beaches respond to factors such as sea level and waves, but shorelines with hard structures cannot maintain this balance as forcings change. Additionally, these hard stabilization structures can degrade the recreational value of beaches and can also be expensive to construct and maintain (USACE 2008).

Seawalls are built parallel to the shore, with a footing that extends into the ground, in order to prevent coastal flooding and to hold sediment behind it and to provide protection from wave action; they may be vertical or sloping (USACE 2008; Linham and Nicholls 2010). They prevent shoreline erosion behind the seawall. Waves hit the seawall with high force, moving sand offshore and alongshore, away from the structure and any beach that initially existed in front of the seawall, and causing scour at the foot of vertical seawalls; seawalls are also susceptible to overtopping (USACE 2008). Because sediment from updrift locations can no longer settle in front of the seawall, the beach is lost; because sediment is no longer moving from the stabilized beach to downdrift beaches, adjacent unarmored shorelines erode. The downdrift end of the seawall typically experiences increased erosion, including flanking, which erodes sediment behind the seawall (Figure 2A) (Linham and Nicholls 2010). Seawalls also prevent natural inland migration of habitats as sea level rises (Linham and Nicholls 2010). Pacific Island communities are increasingly interested in building seawalls from local materials (Mimura and Nunn 1998) due to their perceived protective function against coastal erosion, tsunamis, and flooding (Hills et al. 2013). Poorly designed seawalls also provide materials that in larger Pacific wave events, such as tsunamis, have become dangerous projectiles (Etienne et al. 2011). Well-designed coastal structures require skilled engineering design, appropriate materials, good quality long-term environmental data, and committed maintenance (Linham and Nicholls 2010), the costs of which are often out of reach for small Pacific Island states (Pratt and Govan 2010). The most appropriate use of seawalls is when high-value land, such as urban area infrastructure or emergency road, cannot be protected in other ways or relocated (Linham and Nicholls 2010).

Sandbags (Figure 2B) are sometimes used as a cheaper and faster alternative to building a seawall. Walls of sandbags are sometimes considered a ‘soft’ engineering structure because of their supposed temporary nature, but in reality they are usually left in place indefinitely and have similar impacts as seawalls do: loss of beach in front of and downdrift from the sandbags, and a flanking effect that erodes sand from behind the end of the sandbag wall.

Bulkheads, or retaining walls, are also built parallel to the shore in order to hold land in place, to prevent water side losses, and to protect the land from wave attack (Figure 2C) (USACE 2008). Like seawalls, they cause erosion in front of the structure and downdrift, prevent inland habitat migration and coastal adjustment to oceanographic conditions, and are vulnerable to overtopping and flanking. They do not have a buried base like seawalls do and so are more susceptible to undermining and failure (USACE 2008).

Revetments (Figure 2D) are built directly on top of an existing slope to protect the land from waves and strong currents (USACE 2008). They are particularly vulnerable to failure of the structure toe (which can cause failure of the entire revetment), overtopping, and groundwater pressure (USACE 2008). These structures also cause erosion in front of the structure and downdrift, and prevent inland habitat migration and coastal adjustment to oceanographic conditions.

Nearshore breakwaters are shore-parallel structures placed in the water, detached from shore, to reduce the amount of wave energy reaching the beach. This slows the alongshore drift of sediment, allowing some sand to settle along the beach and producing a shoreline bulge in the sheltered area behind each breakwater (Figure 2E). They reduce the volume of sediment reaching downdrift beaches, and so accelerate erosion in these adjacent areas (USACE 2008). In Samoa, fringing reefs and beachrock exposed within the nearshore area act as breakwaters in that they reduce the wave energy reaching the shoreline; the reef flat (the reef area extending across the lagoon) and reef crest (seaward edge of the reef flat) absorb up to 90% of a wave's force, with wider flats absorbing more wave energy (Wells et al. 2006). They also provide a sediment source to that shoreline as they degrade (Wells et al. 2006).

Groynes are built perpendicular to the shoreline in order to trap sediment being transported alongshore, causing beach accretion updrift of the groyne and beach erosion downdrift of the groyne (Figure 2F) (USACE 2008).

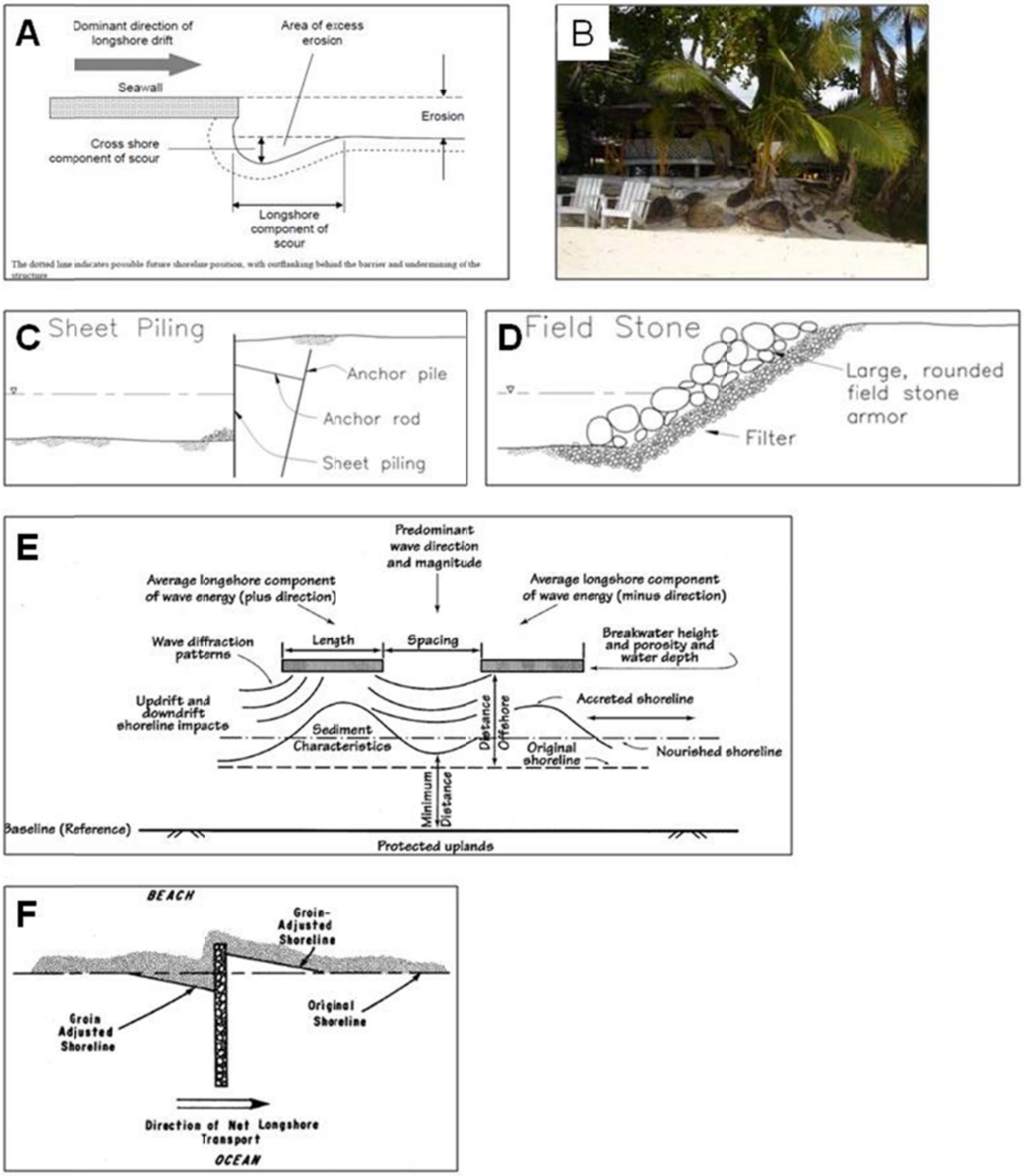

Figure 2. Types of coastal structures. A) Seawalls (Figure 4.9 from Linham and Nicholls (2010) as adapted from McDougal et al. (1987)); B) sandbags; C) bulkheads (Figure V-3-7 from USACE (2008)); D) revetments (Figure V-3-8 from USACE (2008)); E) breakwaters (Figure V-3-20 from USACE (2008)); and F) groynes (Figure V-3-23 from USACE (2008)).

Anticipated Coastal Impacts of Climate Change in Samoa

Small island states such as Samoa will face significant climate change impacts, particularly sea-level rise, that will further exacerbate the impacts of human activity on coastal ecosystems; threats include coastal engineering structures such as seawalls, sediment erosion and runoff to oceans, destruction of habitat, urban expansion including in-filling of lagoons, invasive species, unsustainable fisheries practice and eutrophication (Hills et al. 2013). Projected magnitudes of climatic changes are listed in Table 1.

Currently, seasonal differences in temperature are minimal (1ºC) but ENSO is an important source of variability in the region's surface air temperature and sea-surface temperature (ABM 2011). In Samoa, maximum ambient surface temperatures may increase by 0.7ºC, and extreme heat events with maximum temperature of 34ºC, which currently occur less than once every 100 years (less than 1% chance of occurring in any one year), will likely have a return period of 40 years by 2050 (2.5% chance of occurring in any one year) (AECOM 2011). Globally, the average temperature is projected to increase by 1.4 ºC to 5.8 ºC between 1990 and 2100 (MNREM 2005). Increased temperature will stress coral reefs, leading to coral bleaching (which has a threshold starting at 29.5 ºC) and increased disease transmission (USP no date). It will also contribute to sea level rise through thermal expansion of ocean water. Changes in temperature may also affect vegetation communities.

Seasonal differences in rainfall are marked, with 75% of the total annual rainfall being received in the wet season from November to April (approximately 350 mm/month) (ABM 2011). Total annual rainfall will increase due to an increase in wet season rainfall by up to 5% by 2090, but dry season rainfall will not change much (ABM 2011). The frequency and intensity of extreme rainfall events will also increase over the course of the 21st century (ABM 2011). Increased rainfall will increase runoff during the wet season, leading to increased siltation of coral reefs, contributing to coral stress. Changes in precipitation may also affect vegetation communities.

The number of tropical cyclones is expected to decline over this century, but the tropical cyclones that do form will have stronger winds and will bring more rain (ABM 2011). This will likely increase damage to infrastructure, vegetation, and terrestrial and marine ecosystems including coral reefs.

Sea-level rise is caused by increasing ocean and atmospheric temperatures which in turn causes thermal expansion of the water and melting of glaciers and ice caps. It contributes to coastal erosion by encroaching on formerly exposed beach area, and by promoting offshore sediment transport (Linham and Nicholls 2013). Sea-level rise in Samoa, as measured between 1993-2010, has been about 4 mm/yr, which is higher than the global average of 3.2 mm/yr, but which also reflects the higher water level during the La Nina and ENSO-neutral years during the data period (ABM 2011). Interannual variability in sea level, which causes periods of lower and higher regional sea levels, is about 20 cm, after removal of the seasonal cycle (ABM 2011). Rate of sea-level rise is expected to increase to 14 mm/yr by 2050 (ABM 2011), with a total increase of 5-15 cm by 2030 and 20-60 cm by 2090 under higher emissions scenarios (Figure 3) (ABM 2011). Interannual variability in sea level will likely continue to be around 20 cm throughout the century; storm winds and waves will continue to force extreme sea level events. Sea-level rise will increase coastal inundation, coastal erosion, wetland loss, and salt-water intrusion into fresh groundwater (AECOM 2011). One assessment determined that global sea level rises 0.49 m above 1900 levels by 2100, beach erosion rates will increase by 3-22 m for sheltered lagoon beaches and by 10-23 m for open-exposed beaches (MNREM 2005).

Ocean acidification is driven primarily by increased oceanic uptake of carbon dioxide in response to increased concentrations of atmospheric carbon dioxide. Globally, ocean acidification has increased by 30% since the industrial revolution (Hills et al. 2011). Measurements of the seawater aragonite saturation state indicate that a value above 4 is optimal for coral growth and healthy reef ecosystems, while values between 3 and 3.5 provide marginal conditions for coral health. In the Samoa region, the aragonite saturate state has declined from 4.5 (optimal coral growth) in the late 18th century down to 4.1 by 2000 (ABM 2011). The ocean will grow increasingly acidic this century; the annual maximum aragonite saturation state is expected to decline to below 3.5 (marginal coral health) by 2060 and to continue its decline thereafter (ABM 2011). This will add stress to reef ecosystems that will already face cumulative threats of rising sea temperature (Hills et al. 2011), increased coral bleaching, storm damage, and fishing pressure (ABM 2011).

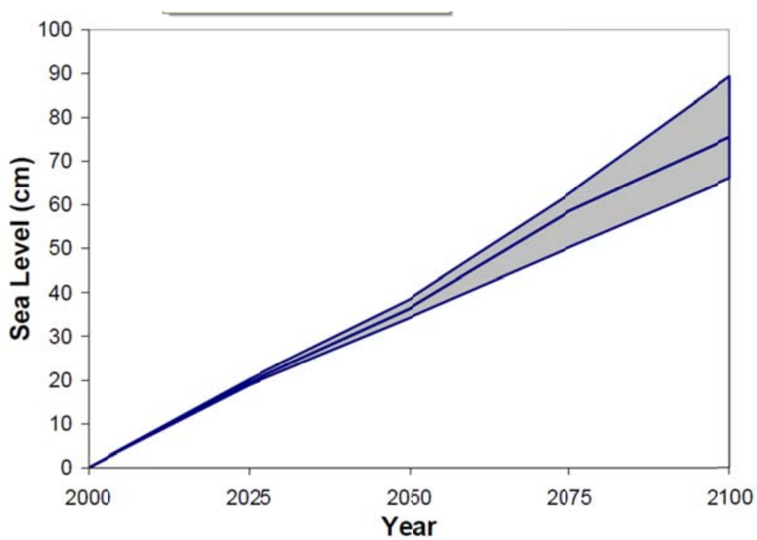

Figure 3. Mean sea level projection and uncertainty envelope for Apia, Samoa, based on the maximum and minimum values from all combinations of available global climate models and emission scenarios. Figure 5 from Hay (2006).

Variable	Season	2030	2055	2090	Confidence
Surface air temperature (°C)	Annual	+0.6 ± 0.4 +0.8 ± 0.4 +0.7 ± 0.3	+1.0 ± 0.4 +1.4 ± 0.5 +1.4 ± 0.4	+1.4 ± 0.6 +2.2 ± 0.7 +2.6 ± 0.7	Moderate
Maximum temperature (°C)	1-in-20-year event	N/A	+1.0 ± 0.5 +1.4 ± 0.6 +1.5 ± 0.4	+1.3 ± 0.5 +2.1 ± 1.0 +2.6 ± 1.3	Low
Minimum temperature (°C)	1-in-20-year event	N/A	+1.2 ± 1.8 +1.6 ± 1.6 +1.5 ± 1.9	+1.5 ± 1.6 +2.0 ± 2.2 +2.3 ± 1.9	Low
Total rainfall (%)*	Annual	+1 ± 6 +2 ± 9 +4 ± 11	+3 ± 9 +4 ± 15 +5 ± 14	+3 ± 13 +5 ± 17 +7 ± 24	Moderate
Wet season rainfall (%)*	November-April	+1 ± 8 +2 ± 10 +3 ± 11	+4 ± 11 +5 ± 15 +5 ± 11	+4 ± 14 +6 ± 16 +8 ± 22	Moderate
Dry season rainfall (%)*	May-October	+2 ± 9 +3 ± 15 +4 ± 14	+3 ± 11 +4 ± 23 +6 ± 23	+2 ± 14 +3 ± 26 +5 ± 36	Low
Sea-surface temperature (°C)	Annual	+0.6 ± 0.4 +0.7 ± 0.3 +0.7 ± 0.4	+0.9 ± 0.3 +1.2 ± 0.4 +1.3 ± 0.5	+1.3 ± 0.4 +2.0 ± 0.7 +2.4 ± 0.8	High
Aragonite saturation state (Ωar)	Annual maximum	+3.6 ± 0.1 +3.6 ± 0.2 +3.6 ± 0.2	+3.4 ± 0.1 +3.2 ± 0.2 +3.2 ± 0.2	+3.2 ± 0.2 +2.9 ± 0.2 +2.6 ± 0.2	High
Mean sea level (cm)	Annual	+10 (5–15) +10 (6–14) +10 (5–15)	+18 (10–26) +21 (11–30) +20 (10–29)	+31 (17–45) +38 (20–57) +40 (21–59)	Moderate

*The MIROC3.2(medres) and MIROC3.2(hires) models were eliminated in calculating the rainfall projections, due to their inability to accurately simulate present-day activity of the South Pacific Convergence Zone (Volume 1, Section 5.5.1).

Table 1. Table 12.3 from ABM (2011). Projected change in the annual and seasonal mean climate for Samoa, under the B1 (low; blue), A1B (medium; green) and A2 (high; purple) emissions scenarios from IPCC (2007). Projections are given for three 20-year periods centred on 2030 (2020–2039), 2055 (2046–2065) and 2090 (2080–2099), relative to 1990 (1980–1999). Values represent the multi-model mean change ± twice the inter-model standard deviation (representing approximately 95% of the range of model projections), except for sea level where the estimated mean change and the 5–95% range are given (as they are derived directly from the Intergovernmental Panel on Climate Change Fourth Assessment Report values). The confidence associated with the range and distribution of the projections is also given (indicated by the standard deviation and multi-model mean, respectively).

Ecosystem-Based Adaptation Project

Project Purpose

This project, "Coastal Management Adaptation to Climate Change (Samoa component)" is part of a larger regional initiative by the Secretariat of the Pacific Regional Environment Programme (SPREP) to initiate coastal and marine Ecosystem-based Adaptation (EbA) projects in vulnerable communities.

An Ecosystem-based Adaptation (EbA) approach integrates the sustainable use of biodiversity and ecosystem services into a comprehensive adaptation strategy (CBD 2009). EbA leverages the ability of healthy ecosystems to help buffer climate change impacts on humans, habitats, and resources on which both depend (Hills et al. 2011). By managing, conserving, and restoring ecosystems, human communities can increase their resilience and reduce their vulnerability to periods of acute climatic events, to long-term climate change impacts, and to other impacts resulting from degraded ecosystems (Hills et al. 2011).

This project selected two coastal sites experiencing erosion, and developed EbA strategies to reduce erosion while preserving and enhancing the local ecosystem. The project developed lessons learned, publications, and methodologies that are widely applicable across the region, particularly in areas where sea walls and infrastructure alterations are not a feasible option and also where mangroves are ill-suited. The selected site locations, characteristics, and EbA plans are described in detail in Chapters 2 and 3. Appendix A provides information on native Samoa vegetation appropriate for using in coastal EbA plans. Appendix B lists meetings and site visits related to the project. Appendices C and D outline the monitoring plans for each site.

Project Site Selection

This project focuses on two sites with the potential to accomplish the following objectives outlined by SPREP:

1) To identify strategic alternative coastal adaptation measures to climate change, focusing on geomorphic and vegetative methods that local communities can implement with limited outside support;
2) To prepare site-specific coastal management plans for communities;
3) To demonstrate the scale and timing of the erosion problem;
4) To conduct field surveys of beach geomorphology and identify causative factors of the coastal erosion;
5) To conduct training related to field geomorphology, identification of causative factors, and mitigation measures for coastal erosion;
6) To carry out a trial of beach-strengthening procedures; and
7) To test community educational/outreach materials.

These sites have the attributes outlined during the project's planning stage:

1) Erosional sand beach with length of 100 m – 500 m
2) Lack of significant human impact such as ongoing sand mining or harbour construction
3) Suitability for EbA demonstrations

4) Feasibility of locally-implemented solutions
5) Need for coastal protection
6) Potential high-visibility opportunities for educational outreach
7) Community or landowner support and interest
8) MNRE priorities

Site Research

Members of the project team visited the sites on several occasions for different purposes (Appendix B), including a reconnaissance visit to evaluate the suitability of the site and several meetings with each landowner to gather additional information about the site, to develop restoration plans, and to deliver and plant vegetation. Additional information about the sites was gathered via published literature, aerial photographs, and local expertise in botany, climate change, and disaster management.

During site visits, the landowners were asked questions covering landowner interest in project participation; changes in beach erosion patterns (recently, over the last decade, and after storms); changes in land use along his property or adjacent properties (such as sand mining or seawall construction); prior or existing efforts to slow erosion; and other site dynamics such as irregular river openings. Possible methods to slow coastal erosion were then discussed with each landowner, and site plans were developed collaboratively with the consultant, landowner, and MNRE officers.

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Chapter 2
Coastal Management, Restoration, and Monitoring Plan for Vaiula Beach Fales (Tafatafa, Upolu, Samoa)

Site Location

The potential EbA site identified (Figure 1) is the coastline along Vaiula Beach Fales, which is located at Tafatafa, within the Faipule District of Falealili along the southern coast of the island of Upolu, Samoa.

Site Description

The 250-m long site (Figure 2) is located along the edge of a large lagoon and is centered within a concave stretch of shoreline bounded by a groyne approximately 500 m to the west and a natural headland approximately 650 m to the east (Google Earth 2013). The fringing reef is approximately 1.5 km offshore of the site. The Vaiula River runs through the eastern side of the site.

Geomorphology

The inshore geology of this area is known as the Salani Volcanics Formation, which is susceptible to erosion and weathering (Gibb 2000). The coast has a fringing reef and a narrow coastal strip consisting mostly of fine coral sand with lesser amounts of terrigenous material (Richmond 1991). Near the eastern edge of the property, the Vaiula River sometimes opens into the lagoon following high-precipitation events (e.g., July 2012) but at most times, the river mouth is sealed with sand moved onshore by wave action, and a small landlocked pond forms (Figure 4A). Richmond (1991) found that streams and rivers, by discharging sediments and freshwater, inhibit coral growth around river mouths, and that most of the sediment is transported offshore rather than being added to the beaches. Streams do add some sediment to the coast, causing accretion to the west of their deltas, and also create breaks ("ava") in the reef system (Government of Samoa 2002).

A continuous line of beachrock extends along this beach and adjacent beaches, and is particularly close to shore at this site (Figures 3, 4B), being exposed at low tide except immediately offshore of the river mouth. The seafloor within the lagoon is predominantly sand with scattered stands of coral (*Acropora* spp.); there are large sand deposits surrounding the river mouth.

A nationwide study of Samoa's Coastal Hazard Zones, comparing shorelines from 1959 and 1999, indicated that the Tafatafa coastline has a high coastal sensitivity index compared to other coastlines in Samoa (Gibb 2000). Such areas are characterised by low-level depositional coasts, medium to high erosion rates, and medium to high short-term shoreline fluctuations; they are also subject to overtopping by both storm wave and tsunami wave run-up (Gibb 2000). The Tafatafa coastline has a maximum storm wave run-up of 2.21 m above the mean high water shoreline, a gradient of -2^{o}, a long-term shoreline erosion trend of -0.22 to -0.44 m/yr, and a maximum short-term shoreline fluctuation of +/- -5 – 10 m (Gibb 2000). Erosion has accelerated in the past few years, undercutting 20-year-old coconut trees and washing beneath day-use fales on the beach (personal communication, Muliaga David Peterson, landowner, Vaiula Beach Fales, and others familiar with the site, 14 April 2013). During the interval between a site visit on 2 August 2012 and a second visit on 13 February 2013, erosion had undermined multiple coconut (*Cocos nucifera*) trees, causing them to fall over; additionally, some fale pilings and the roots of fetau (*Calophyllum inophyllum*) and talie (*Terminalia catappa*) trees had been exposed (Figures 4C, 4D, 4E).

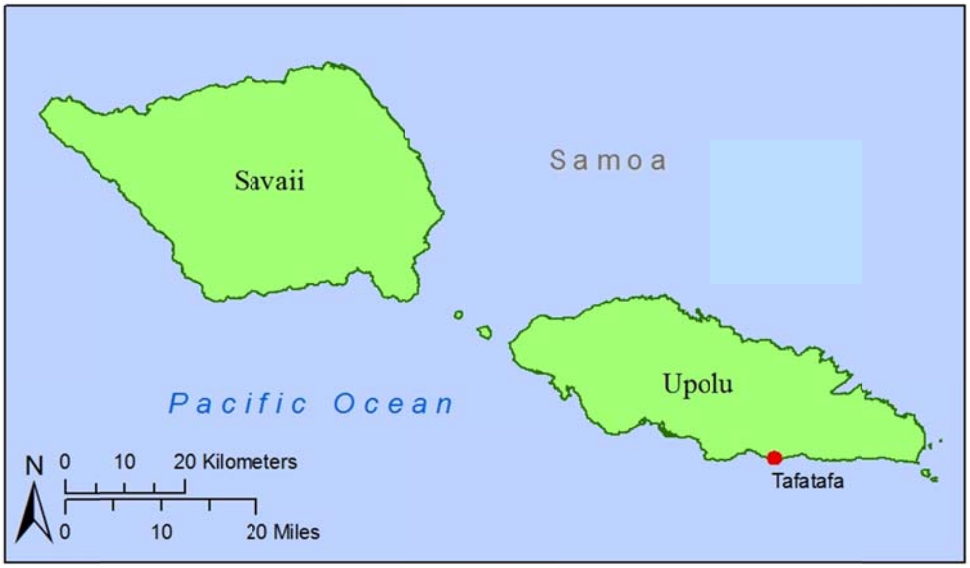

Figure 1. The Vaiula Beach Fales project site is in Tafatafa on the south coast of the island of Upolu, Samoa. Data courtesy of SPREP.

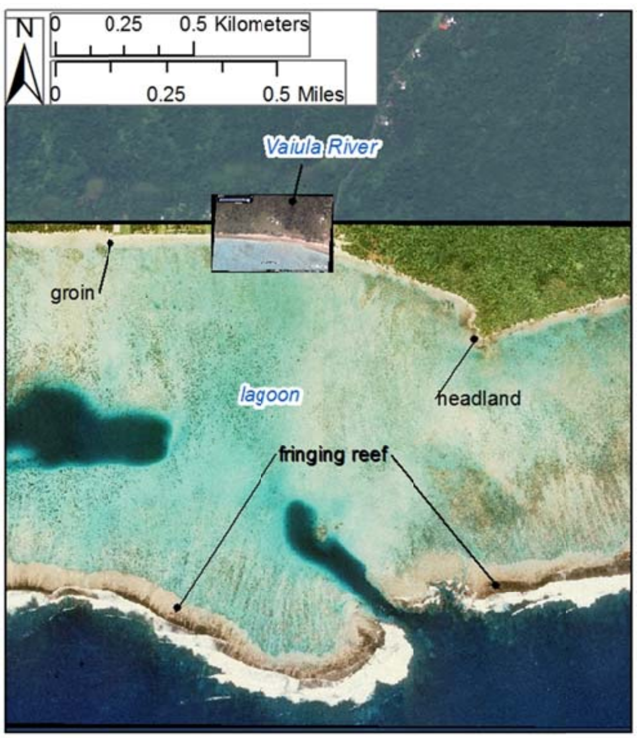

Figure 2. The project site is located along the edge of a large lagoon with a fringing reef approximately 1.5 km offshore. The concave stretch of shoreline is bounded by a groyne and a natural headland; the Vaiula River runs through the eastern side of the site. Photo of conditions in 1999 courtesy of SPREP.

Human use

Locals and tourists visit Vaiula Beach Fales for day trips and for overnight accommodation in the open fales. The establishment also offers motorboat trips to go outside the reef for fishing, surfing, and snorkeling.

The site (Figure 3) includes eighteen open fales for visitors' day use or overnight stay, a larger fale for guest dining, a large two-story fale with a small pub, two toilet and shower blocks, and the main fale in which the landowner and his family live (Figure 4A). Of these structures, eleven open fales and the two-story pub fale are positioned along the eroding shoreline. Some of these fales are on pilings that are washed by waves at high tide (Figure 4C), while others sit adjacent to an eroding and scarped sand bank that is approximately 1 – 1.5 m high and vegetated with approximately ten mature coconut, fetau, and talie trees, some lau talotalo (*Crinum asiaticum*) (an exotic shrub species), and sparse grass (Figures 4D, 4E). Foot traffic occurs along the entire bank as visitors move between the fales and the ocean. Vehicular access is from the site eastward along the beach and across the river mouth (when closed) to an adjacent set of beach fales connected to the main road (Figure 4A), and via a new unpaved road from the site through the forest to the main road.

After heavy rains in 2012 connected the Vaiula River to the ocean, the landowner filled the river mouth with boulders and sand to restore vehicle access. This action caused water to pond (Figure 4A) and reduced the sediment contribution to the nearshore. Future river openings will likely wash some of these boulders out into the ocean, where they could damage the reef.

Land management practices at adjacent properties are also changing the sediment dynamics of the coastline. Immediately west of the Vaiula Beach Fales site is a property with sparse grasses and open fales (Figure 4F). Local residents stated that most of the vegetation (trees, grasses) had been removed from the property. The beach is sloped and eroding, with little vegetation to stabilize the sediment. To the west of that property, a landowner has cut through the beachrock, presumably to improve access to the deeper water (Figure 4G). Onshore of this cut, large boulders have been placed along the eroding bank to slow the erosion that was likely accelerated by the absence of beachrock to break incoming wave energy (Figure 3G). Further west, a hotel has a 70 m groyne extending into the water, and limited sand trapping is evident in 2010 aerial photographs (Figure 2) (Google Earth 2013).

Natural Resources

The project site has a diversity of natural resources that are economically valuable in terms of tourism potential, particularly the beach and ocean and related recreational activities. The Vaiula River and the nearshore marine waters along this site support a diversity of fish, coral, and echinoderm species. The coconut and fetau trees along the eroding bank help to stabilize the sediment, provide food and habitat for multiple animal species, and have the potential to support small-scale production of(coconut cream, drinking coconuts, and fetau oil for use at the site or for market sale. A few fue moa (*Ipomoema pes-caprae*) and fue fue sina (*Vigna marina*) vines were noted in a small area of the site during the site visit on 8 May 2013; these species should be encouraged to grow in order to stabilize sediments on the beach.

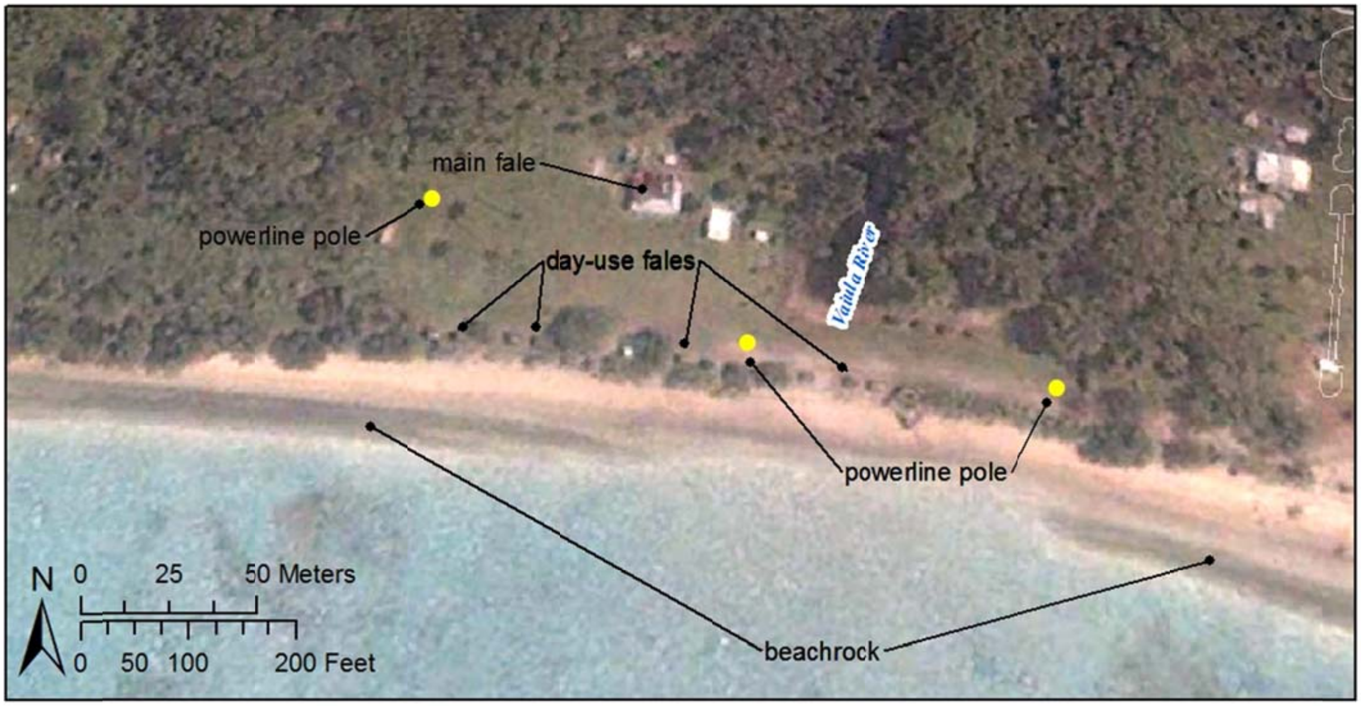

Figure 3. The site includes open fales for day use, the landowner's family home, a river, and additional infrastructure including power line poles. The line of beachrock is particularly close to the shoreline at this site, compared to other properties along the coast. Photo of conditions on 27 January 2010 from Google Earth (2013).

Figure 4. A) The site includes visitor-use open fales, larger enclosed fales including the landowner's home, and toilet and shower blocks, and the main fale in which the landowner and his family live. Vaiula River mouth (now closed by sand) is in the foreground, with ponding evident. B) The line of beachrock is particularly close to the beach at this site. C) Waves wash underneath some fales. D) Other fales sit along an eroding sand bank lined by coconut and E) fetau trees. F) The adjacent property is eroding following removal of trees and other vegetation. G) To mitigate erosion following removal of beachrock at a nearby property, rocks have been piled along the eroding bank.

Cultural Resources

The Vaiula River, which runs through the site, translates as "Red Water." According to Samoan legend, this water turned red when Malietoa's stepson killed two large creatures that were part demon and part "tuna," or freshwater eel. This stepson also saved his father's life when visiting the Manua Islands, where the king poisoned Malietoa's ava. Knowing of this poison, the stepson drank his father's ava and died. As his father and friends paddled the boat with his body back to Upolu, he was splashed with salt water, which brought him back to life. In recognition of this event, "Vaiula" is part of several titles in villages across Samoa (personal communication, Peterson, 14 April 2013).

Threats

Threats to this site occur at global, regional, and local scales. Relative sea level rise, a potential increase in the frequency and magnitude of tropical cyclones, and potential destruction of reef crest and lagoon corals through bleaching due to rising water temperatures, will all allow additional wave energy to reach the coast and to remove sediments. Because most of the beach sediment is derived from coral, a reduction in coral production will lead to a reduction in sediment available to the beach. Land-use practices such as deforestation, cattle farming and agriculture increase erosion and sediment runoff to the coast, impacting the health of the lagoon and reef system, which serves as a defense from cyclone hazards to coastal infrastructure damage (Government of Samoa 2002). Many villages have built artificial headlands into the lagoon, interrupting alongshore sediment transport (Government of Samoa 2002), and sand mining was also reducing the sediment supply until the practice was banned in 1990 (personal communication, local resident, 2 August 2013).

Local threats include constructed headlands along updrift coastlines, which reduce the sediment available to the beach; foot traffic across the eroding sand ridge, which accelerates erosion; removal of vegetation that would otherwise trap and stabilize sediment; and removal of beachrock, which would otherwise reduce wave energy reaching the beach. Soil stability is lessened in the absence of a varied coastal vegetative assemblage, typically a combination vines, shrubs, and trees. The absence of beachrock directly in front of the river mouth allows higher wave energy to impact the beach, but when the river is flowing or has recently flowed, a large sand delta at the river mouth provides additional protection and sediment supply. Invasive species are also a threat; the invasive vine fue saina (*Mikania micrantha*) was noted in one area during a site visit (8 May 2013).

An additional threat is the potential for future construction of hard coastal structures (e.g., seawalls, groynes, revetments) rather than ecosystem-based adaptation strategies to protect the coastline at this and adjacent sites. Recent coastal plans (e.g., Government of Samoa 2002) and landowner requests (personal communication, Titi Simi, MNRE-DMO, 23 April 2013) include hard structures such as seawalls. Furthermore, during the 13 February 2013 site visit, the landowner reported that a government agency had visited within the last three months and encouraged him to build a seawall to protect his land.

Desired Future Conditions

The landowner wants to maintain a beach, minimize land loss, and continue to provide an attractive destination for tourists, beachgoers, and others wanting to hire fales for the day and overnight. He also stated that he does not want a seawall on his property because it would cause the loss of his beach.

Alternatives Considered

The five potential strategies described below can be implemented individually or in combination. These strategies were discussed with the landowner on 13 February 2013 and revisited during a meeting on 14 March 2013. These strategies were also examined according to the Planning and Urban Management (Environmental Impact Assessment) Regulations (Government of Samoa 2007); and the preferred alternative is described according to those regulations.

No Action

This option, also known as a "do-nothing" approach, maintains the status quo. This would require no labor for implementation and no changes to current land use patterns. Erosion of the bank would continue, eventually undermining fales and existing trees. Action to preserve or rebuild the fales would very likely be required within the next five years or following a severe erosion event.

Protect existing vegetation

This short-term option involves building a support structure to protect the existing large fetau and talie trees that are currently stabilizing the bank despite the erosion-induced exposure of their roots. This would place engineering structures on the beach, although those structures would be relatively small and likely made of natural materials (wood). This strategy would extend the life of the trees and their stabilization functions for a short-term period, although erosion would continue along the adjacent portions of the bank and likely would flank the structures. This may be more appropriate as a strategy to use in combination with planting new vegetation, so that the bank erosion is reduced while new vegetation is established.

Plant vegetation to stabilize sediments

This strategy involves planting a mix of native coastal vegetation along the eroding bank and also behind the current line of beachfront fales. The root systems would stabilize sediment on a short-term and long-term scale, slowing erosion at the current bank edge and at the future coastline approximately 6-10 m inland. This option would require developing a site plan for appropriate native coastal species and number of seedlings needed, obtaining seedlings, and planting and monitoring the new vegetation. This strategy would likely slow ongoing erosion now and over the next few decades.

Plant vegetation to focus foot traffic

This option involves planting low, dense vegetation in a line along the existing bank, leaving narrow unvegetated sections for beachgoers to use when moving between fales and the beach. This strategy would reduce sediment loss by focusing erosion on a few small areas rather than the current situation in which the entire bank edge is eroded by people accessing the beach.

Build stairways or boardwalks to focus foot traffic

This option would install multiple stairways or flexible boardwalks (planks connected by rope) along the existing bank for use when moving between fales and the beach. These structures could require ongoing maintenance or replacement when impacted by waves and storms. Like the previous option, it would reduce sediment loss by focusing erosion on a few small areas rather than the current situation in which the entire bank edge is eroded by people accessing the beach. Stairways would allow sand to accumulate beneath the structures. Flexible boardwalks would allow sand compaction but would minimize additional vertical loss of sediment.

Relocate fales landward

This option would remove fales from the eroding bank edge, and would place them further landward, away from the immediate threat of being undermined by bank erosion and wave action. Of all options presented, this one would require the highest level of labor and materials, and might reduce desirability to beachgoers. It would conserve the materials from the existing structures and reduce the risk of their damage or loss due to a storm or other erosion event.

Preferred Alternative

The preferred alternative was refined through several consultations between the landowner, MNRE Forestry officers, MNRE Department of Environment and Conservation, and SPREP. It meets the criteria to be ecosystem-based and to support enhanced biodiversity values; to increase coastal resilience by slowing the coastal erosion rate of erosion; to be feasible for local implementation, and to be acceptable to the landowner. The final plan, to plant vegetation to stabilize sediments and to focus foot traffic, combined two of the potential strategies described.

Selection of Plant Species

Species selection for this project was limited to native coastal (littoral zone) vegetation that would grow along sandy shorelines, help to stabilize sediments within two years, limit erosive foot traffic into narrow pathways, and be satisfactory to the landowner. Suitable species were identified through the literature, field observations, and expert opinions from officers of the Ministry of Natural Resources and Environment and the Ministry of Agriculture and Fisheries. These species are described in Appendix A.

MNRE Forestry officers provided advice on species suitable for the site, and which of those were available through the MNRE Forestry Division's Togitogiga nursery, the Ministry of Agriculture & Fisheries nursery at Nu'u, or elsewhere on the island.

The selection was narrowed further by landowner preferences, including immediate availability of seedlings to implement the project; demonstrated success of existing fetau (*Calophyllum inophyllum*) and coconut (*Cocos nucifera*) in retaining sediment along his beach and riverbank; and the shade provided by mature fetau trees. Traditional knowledge indicates that the local variety of coconut is better able to withstand coastal erosion and undermining compared to the hybrids and other varieties planted in Samoa. To diversify the vegetation, evaluate the success of an additional species, and perhaps thereby increase the resilience of the future coastline, he also agreed to plant milo (*Thespesia populnea*). To minimize bank erosion, the fast-growing vine fue moa or beach morning glory (*Ipomoema pes-caprae*) and the dense shrub to'ito'i (*Scaevola taccada)* were selected. The to'ito'i will be planted with gaps by each fale to focus foot traffic and its erosive impacts into several narrow pathways, thereby minimizing foot-traffic erosion along the majority of the bank.

Initially, the landowner and forester were concerned that the fue moa would become invasive, but this species has not been classified as invasive in the literature (GISD 2013, Meyer 2000, PIER 2013), and it has been documented as a native species used in traditional Samoan medicine (ADAP 2001). The Pacific Invasives Partnership was also contacted and their botanists' consensus is that this species is not invasive (personal communication, Posa Skelton, SPREP and Art Whistler, University of Hawaii-Manoa, 9 May 2013). As a result of this confirmation, the landowner agreed to transplant the vine from another area on his land to the eroding bank.

Talie (*Terminalia catappa* and *Terminalia samoensis*) was rejected for this site due to the high maintenance requirements of collecting the rubbish (fallen leaves) beneath the existing trees on the land. Leva (*Cerbera manghas)* was rejected for this site due to landowner concern that children would eat the poisonous fruit.

Selection of Planting Locations

MNRE Forestry officers provided advice on appropriate locations for plantings, spacing between seedlings, and the number of seedlings required.

Fast-growing vegetation will be planted near the edge of the bank both to stabilize the bank and to define foot pathways from the bank to the beach. Additional lines of tree seedlings will be planted at a setback of approximately 6 m, where the trees will mature to stabilize a future shoreline while adding present-day value in terms of human use (shade, traditional medicine) and habitat (food and shelter) for various species.

To retain existing sediment and reduce the erosion rate of the bank, the fast-growing local coconut, to'ito'i, and fue fue sina will be planted along the edge of the bank, where space between the fales and beach allows. This will require approximately 20 coconut seedlings (planted 10 m apart) and 40 to'ito'i seedlings. The to'ito'i will also be placed so as to discourage foot traffic except through narrow pathways connecting the fales to the beach.

Two rows of fetau, leva, and milo trees will be planted approximately 6 m landward of the fales, where they will grow to stabilize the future coastline. This setback is a feasible distance from the seaward line of fales and the landward line of power poles and wires. Seedlings will be planted approximately 8 m apart and in a triangle formation, that is, two rows offset by 4 m (Figure 5). Some trees will also be planted along the seaward edges of the riverbanks to stabilize sediment and minimize river widening. This plan will require approximately 45 tree seedlings.

Additional Actions

The landowner acknowledged that additional coastal erosion will likely undermine the existing fale structures. He is prepared to relocate the fales inland, landward of the proposed new line of tree seedlings. There may be a need for additional follow-up actions, as described in the monitoring and evaluation section below.

Invasive species should be removed when observed. The invasive vine fue saina (*Mikania micrantha*) was noted in one area along the riverbank during a site visit (8 May 2013).

Potential Benefits of the Preferred Alternative

The project will strengthen the site's resilience to climate change impacts and to ongoing impacts of coastal erosion, storms, and waves. It will greatly increase native vegetation cover and sediment stability. The plantings will increase the agricultural (coconut) and traditional medicinal resources at the site. It will improve the scenic value, aesthetic appeal, and amenities of this recreational site by preserving land area and beach quality, and increasing shade cover. It will enhance opportunities for tourism, environmental education, and coastal stewardship. It will also increase opportunities to share traditional knowledge and practices such as traditional medicines and historic and cultural resources including Samoan legends related to the Vaiula River.

Potential Impacts of the Preferred Alternative

The preferred alternative does not have any anticipated significant environmental impacts. This plan is unlikely to have any adverse environmental consequences related to environmental pollutants, changes in the social or cultural characteristics of the site, or changes in possible future use of the site. No irreversible or irretrievable commitments of resources are required.

The project incorporates the assumption that natural coastal processes, including erosion, will continue. This project also acknowledges the likelihood that adjacent or nearby coastal landowners may take actions to protect their coastlines, and that some actions (e.g., seawalls) may adversely impact the project site. Although the strategies should slow the rate of erosion by stabilizing sediment, they will not completely prevent erosion in the short-term or in the long-term. The landowner accepts that the risk of continued erosion is preferable to construction of a seawall or other strategies that would lead to a loss in sandy beach area and associated recreational values of his site.

Continued erosion may require the relocation of day-use fales and, if severe erosion should occur, of the power line poles behind the day-use fales. Severe flooding, as occurred in 2012, may again re-open the Vaiula River mouth as water drains to the ocean, blocking access to the coastal road that extends eastward from the site; however, an unpaved road created in 2012 now provides access from the site to the main road through the village.

Figure 5. The site restoration plan calls for shrubs, vines, and coconut trees to be planted along the eroding bank, and for tree seedlings to be planted behind the existing fale locations. Photo of conditions on 27 January 2010 from Google Earth (2013).

The shoreline and vegetation monitoring protocol described below will be useful not only to evaluate the success of the short-term actions but also to establish baseline conditions and future conditions and trends in shoreline position and behaviour. The lack of such datasets was a confounding situation in the development of this coastal management plan; a set of shoreline monitoring data will improve development of future management and assessment of coastal conditions.

Monitoring Strategy

Monitoring methods to evaluate success of the project will include baseline and follow-up surveys of location of shoreline features, seedling survival, and landowner satisfaction. The monitoring protocol is described in more detail in Appendix C.

Location of the high tide line, the edge of vegetation (top of eroding bank), and the bottom of the eroding bank will be measured as a distance from fixed reference points along established transect lines (Figure 6). Transects are set approximately 20 m apart, but exact distances vary to allow lines to extend from fixed reference points (fales and power line poles) where possible. All lines are parallel and have a bearing of 187° from true North (175.5° from magnetic North).

The distance between the reference point (usually a power line pole or fale foundation) and the bank edge, bank base, and high tide line, in addition to the change in height between each shoreline feature, will be recorded (Figure 7). These measurements should be documented at least once per year (preferably once every 6 months for the first 3 years) during the same season, for example, in May and November of each year. To capture a representative high-tide line, measurements should occur on normal tides, that is, not during a full or new moon and not under strong onshore or offshore wind conditions. Additional measurements should be recorded following major erosion events to capture storm impacts and typical storm recovery time period. This information will improve evaluation of the project's effectiveness under both calm and stormy conditions.

Shoreline features can be identified by several characteristics (Figure 8). The top edge of the eroding bank may be marked by the boundary between vegetation and sand or a sudden change in slope to near-vertical. The base of this bank is marked by another sudden change in slope from near-vertical to near-horizontal. The high tide line can be discerned as the boundary between the wet and dry sand just after high tide. Wave run-up may extend beyond the high tide line because some waves splash or move higher on the beach. The wrack line, a line of debris (leaves and shells) carried by the water and stranded on the beach, also helps to delineate the high tide line. If tides are high and/or the beach is narrow, the high tide line may be at the base of the eroding bank or the edge of vegetation.

Monitoring should also include inspection of seedlings to confirm survival, and replacement of dying plants where necessary. Landowner satisfaction, including willingness to maintain vegetation, should also be evaluated at least annually.

These monitoring plans can be undertaken by the landowner, the designated MNRE officer, or other volunteer with a minimum of effort. The simplest materials needed to accomplish the monitoring are a map (or knowledge) of profile monitoring transect and seedling locations; a measuring tape to measure distances from the reference points; a compass to measure bearing; Emery rods (Emery 1961) to measure change in height; the vegetation appendix or other botanical reference or knowledge; and paper and pen for noting distances and species rates of survival. The designated MNRE officer should maintain a record of these measurements; it is recommended that a duplicate copy be kept with the landowner.

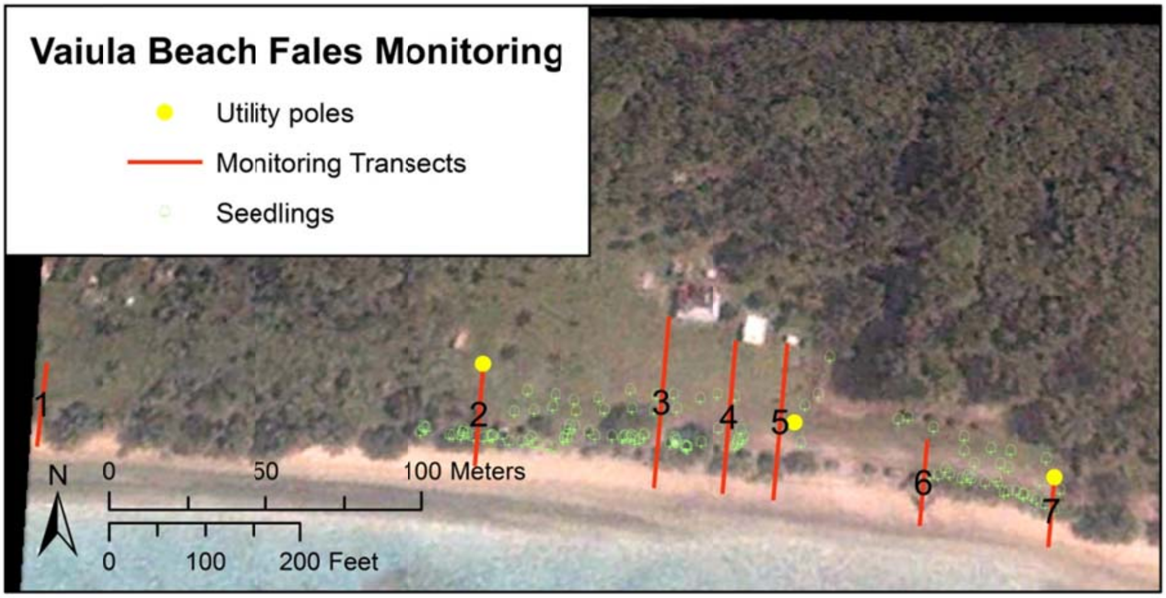

Figure 6. The monitoring plan includes measuring changes in the positions of shoreline features along ten transect lines. Photo of conditions on 27 January 2010 from Google Earth (2013).

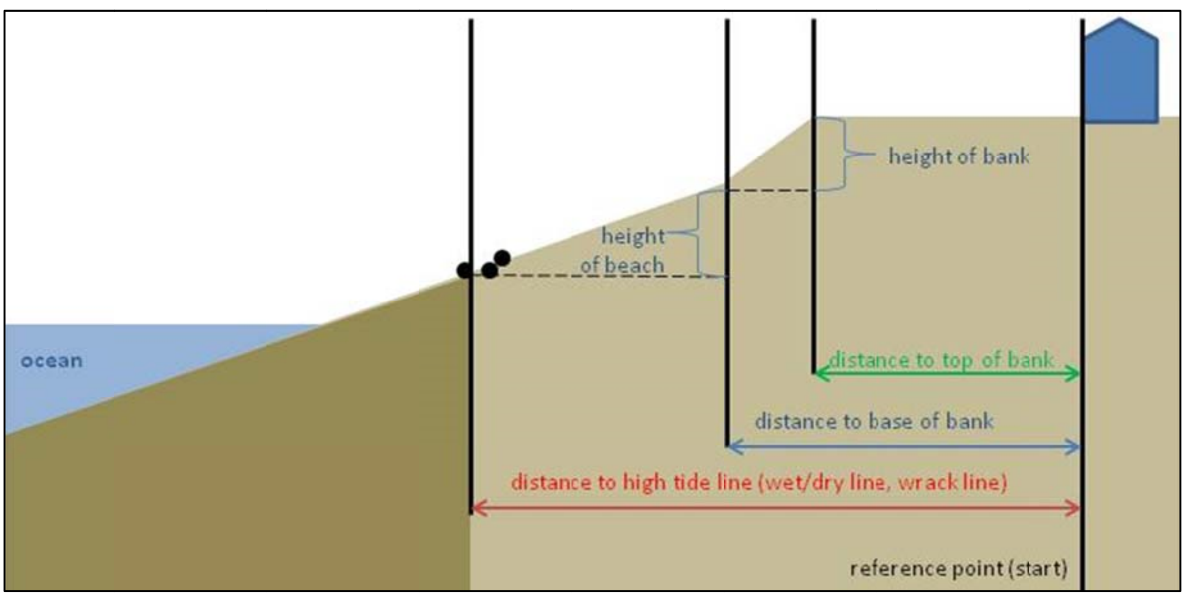

Figure 7. Distances between the reference point and each shoreline feature, in addition to the height of the scarped bank where applicable, should be measured at least once per year.

Figure 8. Several characteristics assist in the identification of shoreline features including the top, base, and height of the eroding bank, and the normal high tide line as a proxy for shoreline position.

Evaluation Strategy

Metrics to evaluate performance over short term (1 year)

Planting according to the finalized site plan should be complete. When seedlings are planted appropriately, an 80% survival rate is expected (personal communication, Suemalo Talie Foliga, MNRE-Forestry, 19 April 2013). Signage and other outreach strategies describing project goals should be created within one year of plantings.

If the project is unsuccessful in meeting any of these goals, follow-up actions described below should be undertaken by the designated MNRE officer.

Metrics to evaluate performance over longer term (10-50 years)

Natural coastal processes, cyclones, and climate-related changes are expected to impact this site over the next few decades. The site will experience erosion during this time period. It is also likely to be impacted by the coastal modifications of adjacent and regional landowners responding to the same coastal changes. This project intends to enhance site resilience to these events by slowing the erosion rate while still allowing for the presence of an aesthetically pleasing beach and recreational access to the site.

Success over the long term will include healthy, mature native coastal vegetation (growth of the seedlings planted behind the day-use fales), an absence of infrastructure in the areas most vulnerable to erosion (landward relocation of day-use fales), continued landowner resistance to seawall construction, and community recognition of the value of EbA strategies to enhance coastal resilience (as demonstrated at this site). Based on Gibb's (2000) calculations of erosion rates along this beach, once the beachfront vegetation is established, the erosion rate should return to a mean of -0.44 m/year or slower, excluding major erosional events (e.g., a cyclone) or human modifications to adjacent beaches (e.g., sand mining). It should not exceed a short-term fluctuation of -5 m/yr in any one year.

Thresholds indicating the need for follow-up actions or mitigation

Individual seedlings should be replaced in-kind if dead. Species vary in their tolerance for light and exposure to salt spray. If seedlings of any one species have less than 80% survival rate, the type of species planted in those locations should be reconsidered. MNRE Division of Forestry at Togitogiga should be contacted for advice on replacement.

Bank (vegetation) retreat of more than 2.2 m during the 5 year period following implementation would indicate that the mitigation measures are inadequate for stabilizing the sediments. Higher erosion rates should first be considered in light of any major events that may have accelerated erosion, such as meteorological events (e.g., a cyclone) or an anthropogenic change to regional coastal processes (e.g., seawall construction along an nearby beach). If vegetation is destroyed and significant erosion (more than 5 m) is caused by meteorological events, new seedlings should be planted following the guidance in this plan, landowner preferences, and the advice of MNRE Division of Forestry at Togitogiga. If impacts are caused by manipulation of adjacent coastlines or sediment supply (such as sand mining), these impacts should be addressed directly where possible. If adjacent coastal manipulations cannot be prevented or undone, or if the strategies in this plan have proved inadequate under expected conditions, then additional strategies along the site beach may be required. Strategies may include sand replenishment or relocation of fales.

If the landowner is dissatisfied by unexpected outcomes (e.g., tourist response to vegetation growth), the MNRE Division of Forestry staff at Togitogiga can offer suggestions on pruning or replacing vegetation, and other steps such as enhanced communication efforts could be implemented.

Some of the day use fales are already being undermined by erosion, with waves washing beneath the structures at high tide. Fales should be evaluated on an individual basis and, when determined to be structurally unsound for use, should be relocated landward of the newly-planted line of vegetation.

Proposed Outreach Materials

Outreach efforts will demonstrate to communities the benefits of intact coastal biodiversity and community implementation of coastal adaptation measures using EbA principles. Outreach materials will be developed by a communication specialist in collaboration with the consultant. These materials will likely include signage at the property, printed materials for distribution, and interactive events.

The best way to reach villagers will likely be to host a special event at the village primary school, in collaboration with the teachers and the village's Women's Committee, in which children having speaking roles and other involvement, because this type of event engages village leaders and other parents (personal communication, Tapu Tuailemafua, University of the South Pacific-Alafua, 7 May 2013). To describe the project actions and goals to tourists and other site visitors, and to enhance the ecotourism value of the site, it is recommended that an interpretive sign be developed and erected at the site. To build capacity at MNRE, it is recommended that a presentation or field site visit with appropriate MNRE staff (Department of Environment and Conservation, Planning and Urban Management Agency, and Disaster Management Office) detail implementation methods, monitoring protocols, and lessons learned. To enhance the ability to identify plant species as native, introduced, and invasive, and to recognize the implications of planting choices, it is recommended that a short brochure with images is produced in both Samoan and English languages.

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Chapter 3
Coastal Management and Restoration Plan for Stevensons Resort (Manase, Savai'i)

Site Location

The selected EbA site is the coastline in front of Stevensons Resort, which is located at Manase, within the Faipule District of Gagaifomauga I along the northeastern coast of the island of Savai'i, Samoa (Figure 1).

Site Description

The 530-m long site is located at the western end of the Manase beach (Figure 2), which is 1.2 km long and fronts a series of beach fales and resorts. The Manase beach is slightly convex on the western side, changing to concave on the eastern side. The western end of the beach ends at a seawall that curves around a small headland; this seawall protects the coastal road and is not fronted by a beach. East of the Manase beach, the coastline turns sharply to the north, creating a headland that has two groynes projecting more than 150 m into the lagoon.

Geomorphology

The inshore geology of the Manase area (3.5 km alongshore length) is the Fagaloa Volcanics Formation, which is susceptible to weathering and erosion (Gibb 2000). It is bounded on each side by areas with very few rivers and consisting of the Lefaga Volcanics Formation, which is resistant to weathering and erosion (Gibb 2000). The coastal strip is narrow, consisting of a fine-sandy coral beach backed by wetlands and resorts before rising steeply to plantations above the cliffs (Government of Samoa, 2002). The fringing reef is up to 430 m offshore of Stevensons Resort; the lagoon narrows to 280 m offshore of the eastern end of the Manase beach. Beachrock is exposed very near the shoreline or beneath the sandy beach. The seafloor within the lagoon has dense coral stands.

Sediment transport direction is reported to vary seasonally, with a westward current from January through May and an eastward current from June through December (personal communication, Trevor Stevenson, Stevenson's Resort, 23 April 2013). Aerial photographs (Google Earth 2013) of Manase over the last decade indicate a continuously wide beach along Jane's Fales, approximately 600 m east of Stevensons Resort (Figure 2). This beach sits directly onshore of an opening ("ava") along the fringing reef, where water funnels offshore and there is a persistent fast-moving rip current (Figure 2). The hydrodynamics in this area, where lagoon water drains on a falling tide more quickly than other areas, affect the patterns of alongshore currents that in turn shape the beach.

A nationwide study of Samoa's Coastal Hazard Zones (Gibb 2000) examined shorelines from 1959 and 1999, just before the seawalls along Manase been constructed, so the shoreline characteristics detailed in that report may not be representative of the processes that have occurred following this major change along the coast. Unfortunately, more recent orthophotographs are not of sufficient quality to update the measurements. The study found that this area had a maximum storm wave run-up of 4.5 – 5.5 m above the mean high water shoreline, a gradient of 0^{o}, a long-term shoreline erosion trend of -0.11 m/yr, and a maximum short-term shoreline fluctuation of +/- -5 – 10 m. Shoreline position fluctuates (erodes and accretes) depending on the wave climate. These conditions, in addition to other coastal characteristics, resulted in a very high coastal sensitivity index compared to other coastlines in Samoa. Such areas are distinguished from coasts with high coastal sensitivity indices (e.g., Lalomanu, Tafatafa, Saanapu) by having higher erosion rates and short-term shoreline fluctuations and relatively high negative gradients behind the barrier ridge. They are subject to overtopping and flooding for extended periods by both storm wave and tsunami wave run-up (Gibb 2000).

Cyclone Evan, which hit Samoa in December 2012, is widely blamed as the cause of recent severe erosion along the Samoa coast (Figure 3), although some sand appears to have returned to the beach during early 2013 (personal communication, Trevor Stevenson, Stevensons Resort, 17 April 2013). The resort manager's personal observations are that the beach has narrowed over the last ten years, and that the erosion rate has accelerated within the last few years (personal communication, Tuipoloa Elizabeth Betham, Stevensons Resort, 23 April 2013). Previous cyclones have impacted this beach; in 1991, Cyclone Val destroyed a honeymoon suite and the small spit of land on which it had been built at the eastern end of the property (personal communication, Paul Anderson, SPREP, 2 May 2013, recounting his personal communication with Trevor Stevenson, 25 April 2013). An informal reconnaissance survey (i.e., mask and snorkel observation on 28 September 2013) revealed a subaqueous remnant of this land; it is composed of gravel and coral rubble, elongated in a cross-shore direction and separated from the beach by deeper water (personal communication, Paul Anderson, SPREP, 1 October 2013). This feature likely affects the local hydrodynamics by attenuating incident waves and perhaps by channelizing alongshore flow with the effect of accelerating the flow of water through the narrow channel; nearshore current measurements would need to be collected to verify this hypothesis. Another hypothesis is that the wave protection offered by this feature over the last decade has been diminishing as the feature degrades (personal communication, Dr. Doug Ramsay, NIWA, 4 October 2013).

Figure 1. The Stevensons Resort project site is in Manase on the south coast of the island of Savai'i, Samoa. Data courtesy of SPREP.

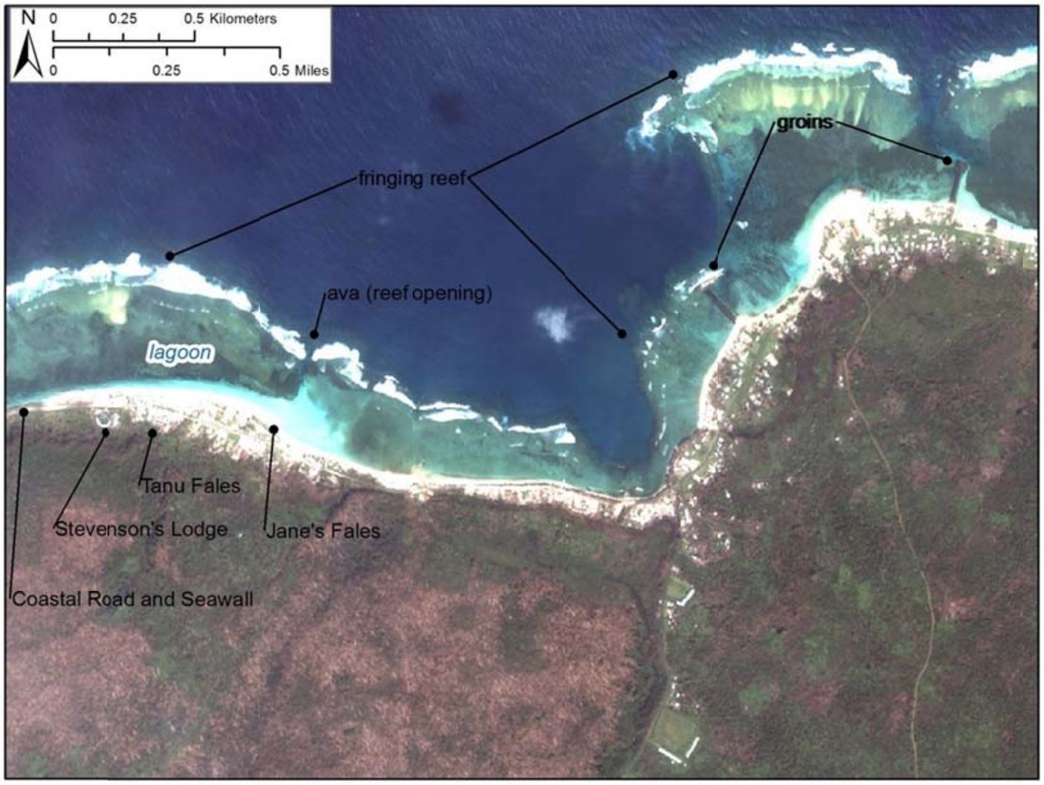

Figure 2. The project site is located along the edge of a narrow lagoon with a fringing reef approximately 430 m offshore. The beach is bounded by a seawall to its west. Photograph of conditions in 1999 courtesy of SPREP.

Figure 3. Erosion along the Manase shoreline is attributed to the December 2012 cyclone, as evidenced by these photos taken before (August 2012) and after (April 2013) the impacts at Tanu Fales (A, B, looking eastward) and Stevensons Resort (C looking westward, D looking eastward).

Human use

Stevensons Resort (Figure 4) offers a restaurant, beach and ocean access, and overnight beachfront accommodation in the open Eurofales and enclosed beach villas and suites. In front of the villas (Figure 5A) along the eastern half of this site, a short (1 m) retaining wall is perched high (5 m) above the beach, and large (up to 30 cm diameter) rocks have been placed at the base and at the easternmost end to prevent scouring around and behind the end of the wall. There are a few access points provided by a short set of concrete steps (Figure 5A) that end approximately halfway down the beach ridge. Foot traffic accelerates erosion of the beach ridge at the bottom of these stairways. Erosion has exposed the roots of the coconut, fau, fetau, and leva trees that grown in front of the retaining wall. The beach villas are set back from the retaining wall by about 4 m and some limited vegetation, including coconut trees and ornamental shrubs, is present in front of and around these villas.

Along the middle of the Stevensons Resort beach is an uncemented rock revetment built to protect new suites (Figure 5B). During the site visit on 26 April 2013, at low tide, freshwater was seen flowing in several places from beneath the revetment and across the beach into the ocean; at high tide, the ocean water covered the base of the revetment. Rocks often come loose from the mound and are replaced by staff when found. Some of these large rocks (up to 30 cm diameter) have migrated into the shallow ocean water, where they can damage live coral when strong waves move them; each of the loose submerged rocks was observed to be surrounded by broken coral debris.

West of the revetment, an open grass-covered lawn slopes gently to the beach, with no erosional scarp along the upper beach (Figure 5C). Stevensons Resort intends to build a swimming pool or restaurant in this location (personal communication, Trevor Stevenson, Stevensons Resort, 23 April 2013).

The Eurofales along the western half of the property are fronted by coconut and fau trees and fue moa (beach morning glory) along the open beach (Figure 5D). Some of the young coconut trees along the edge of the beach have been undermined by erosion. Just west of the Eurofales, at the end of the property, a narrow beach tapers to meet the seawall that protects the coastal road; the backbeach area is covered by fue moa (beach morning glory) (Figure 5E).

Stevensons Resort removes beachrock from the intertidal zone (Figure 5F); staff break exposed portions of rock into manageable sizes and then dispose of the pieces to improve the aesthetic appeal of the beachfront (personal communication, Paul Anderson, SPREP, 2 May 2013, recounting his personal communication with Trevor Stevenson, Stevensons Resort, 25 April 2013). This practice likely has detrimental impacts, as it removes sediment from the current beach and also removes the ability for the beachrock ledge to protect the future shoreline; offshore beachrock ledges act as breakwaters, reducing the incoming wave energy (Chambers 1998). This practice will not get rid of beachrock permanently, because it continues to form both in the intertidal zone and at depth within the body of the beach, beneath the sand surface and near the water table. Beachrock is created when calcium carbonate (lime) cements sand grains together. Exposure of beachrock, which occurs when the overlying sand is removed, indicates that the shoreline is eroding (Richmond 1991).

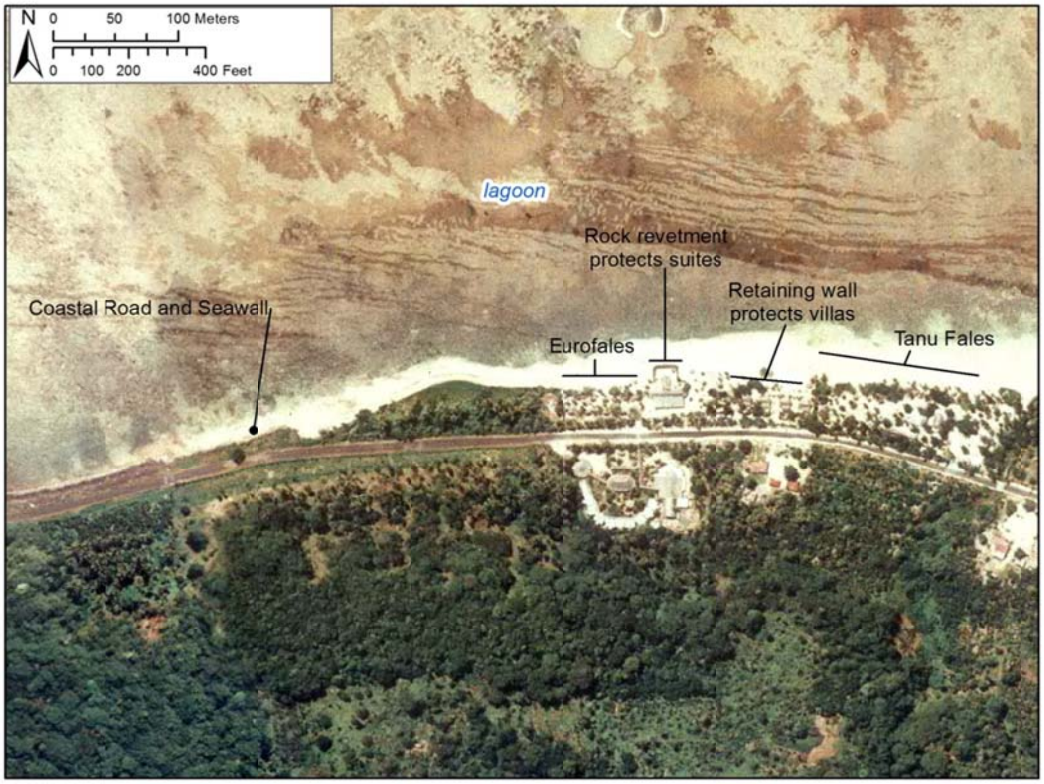

Figure 4. Structures at Stevensons Resort include Eurofales, new suites protected by an uncemented rock revetment, and older villas protected by a retaining wall and tree roots. The site is bounded to the west by a seawall that protects the coastal road, and to the east by another beach accommodation. Photo of ground conditions in 2004 courtesy of SPREP.

Figure 5. Site features as of April 2013. A) The villas are protected by a retaining wall and tree roots, which stabilize sediment but are being exposed by erosion. Concrete steps allow foot traffic to erode the upper beach. B) The rock revetment protecting new suites is uncemented, allowing large rocks to escape and damage coral. Freshwater flows from beneath the revetment. C) Eurofales are fronted by trees and open beach. D) On the western edge, the beach tapers to meet the seawall protecting the coastal road. The upper beach is covered by fue. E) West of the rock revetment, an open grass-covered lawn slopes gently to the beach, with no erosional scarp along the upper beach. F) Beachrock provides coastal protection, but is removed for aesthetic purposes.

Natural Resources

The project site has a diversity of natural resources that are economically valuable in terms of tourism potential, particularly the beach and ocean and related recreational activities such as swimming, kayaking, and snorkelling. The lagoon supports a diversity of turtle, fish, coral, and echinoderm species. The coconut, fetau, and fau trees along the eroding bank help to stabilize the sediment and provide food and habitat for multiple animal species. Along the western end, fue moa vines cover and help to stabilize the upper beach (Figure 5D).

The roots of fau trees that were planted along the Stevensons Resort coastline in 1996 have been exposed by beach erosion, but the root systems clearly play an important role in stabilizing the bank (Figure 5A). A line of coconut trees planted in front of the fau trees have also been impacted by erosion; most of the trees that have not yet fallen have exposed roots. The villas along the eastern side of the property have experienced settling and erosion, which has resulted in cracking of the foundation and some tiles (personal communication, Tuipoloa Elizabeth Betham, Stevensons Resort, 23 April 2013).

Cultural Resources

Stevensons Resort has incorporated Samoan culture and architecture into its design, serves traditional Samoan dishes in its restaurant, and presents live cultural shows several times each week with local village entertainers. Additionally, several types vegetation used in traditional Samoan medicine grow at the site, including fau (*Hibiscus tiliaceus*), fetau (*Calophyllum inophyllum*), leva (*Cerbera manghas*), moegalo or lemongrass (*Cymbopogon citratus*), and nonu (*Morinda citrifolia*).

Threats

Threats to this site occur at global, regional, and local scales. Relative sea level rise, a potential increase in the frequency and magnitude of tropical cyclones, and potential destruction of reef crest and lagoon corals through bleaching due to rising water temperatures, will all allow additional wave energy to reach the coast and to remove sediments. Because most of the beach sediment is derived from coral, a reduction in coral production will lead to a reduction in sediment available to the beach.

Major village construction projects may also be impacting the coastal ecosystem. Several residents have noted that the freshwater wetland landward of the coastal road through Manase has been partially filled for construction of new fales, including in the area landward of Stevensons Resort and the adjacent Tanu Fales. This action is believed to have blocked freshwater outflow to the ocean, caused the wetland to spread alongshore, and encouraged the seaward encroachment of development. This wetland used to be known as a good eel fishing area, but this food resource is no longer available in the wetland (personal communication, Tapulolou Tuailemafua, University of the South Pacific—Alafua, 7 May 2013).

The Manase coastal road immediately west of Stevensons Resort may also be impacting the coastal system. Its frequent repairs are likely due to undermining by freshwater flow, because construction of the coastal road blocked a seasonal river and no culverts were installed to allow water to flow into the ocean (personal communication, Tuipoloa Elizabeth Betham, Stevensons Resort, 23 April 2013, and Tapulolou Tuailemafua, University of the South Pacific—Alafua, 7 May 2013). Obstruction of riverine flow also would have reduced the amount of river sediment contributed to the nearshore environment, although the volume of this sediment is not a significant portion of beach sand, which is light-colored coralline sand and does not contain much dark terrigenous sediment.

Land management practices at other properties along the Manase beach are also changing the sediment budget and dynamics of the coastline. Two long groynes (Figure 2) east of Manase trap sand that otherwise would likely be available to the Manase beach, although this suspicion cannot be confirmed due to a lack of studies on the sediment transport system along this coast. Sand mining, which threatens sand availability along the beach, is not permitted in Manase Village but is reported to occur in small-scale events regardless of this prohibition. Individual landowners are believed to regularly remove sand from the Manase beach, including areas immediately adjacent to the east and west sides of the project site; this sand is reportedly moved inland to surround fales along the coast and farther landward, across the Manase road, for aesthetic purposes (personal communication, Trevor Stevenson, Stevensons Resort, 17 April 2013).

Some Manase resorts have individually emplaced hard stabilization structures such as seawalls, revetments, or sandbags (Figure 6). Because the Manase beach properties are part of the same coastal system, treating only one portion of the beachfront has had adverse impacts on adjacent landowners with natural shorelines. As described in the Introduction, hard stabilization structures disrupt sand transport, changing the natural patterns of sand movement along this shoreline by changing the beach's response to wave energy and by withholding sand that would otherwise nourish neighboring properties. As a result, erosion is accelerated along properties with natural shorelines, which continue to lose sand in the downdrift direction but have a reduced input of sand from the updrift direction.

Continuing threats originating from within Stevensons Resort include removal of beachrock, which is resistant to erosion and helps protect the coastline if left in place, and the release of large rocks from the revetment into the nearshore, where they destroy live coral.

Additional threats are posed by potential future construction of hard coastal structures (e.g., seawalls) and beach sand mining rather than implementation of ecosystem-based adaptation strategies to protect the coastline at this and adjacent sites. The shoreline along this beach will continue to fluctuate, and structures (resort buildings and seawalls) must allow space for the shoreline to move according to the wave climate. As of April 2013, the MNRE Disaster Management Office was responding to requests by individual resort owners for seawalls along the Manase coastline, beginning with site surveys and seawall design (personal communication, Titi Simi, MNRE-Disaster Management Office, 23 April 2013). Unfortunately, a seawall will cause erosion both in front of the seawall and downdrift (alongshore), and will likely increase the incentive for development (e.g., new resort facilities). A seawall will not protect the land and infrastructure behind it from a cyclone.

Stevensons Resort plans to build additional facilities along the coastline such as a pool or a restaurant (personal communication, Trevor Stevenson, Stevensons Resort, 23 April 2013). Building new infrastructure along this eroding coastline would threaten the investment and would also increase the incentive to build additional engineering and hard stabilization structures in the beach environment. Future storms and cyclones, with the associated storm surge and higher wave energy, also pose threats to the vulnerable shoreline and coastal structures.

Figure 6. The Manase beach is impacted by hard-stabilization structures built to protect specific properties, including A) sandbags at Vacations Resort, towards the eastern end of Manase beach, and B) rock revetment at Tanu Fales, adjacent to the eastern edge of Stevensons Resort.

Desired Future Conditions

The landowner wants to maintain a recreational beach, minimize land loss, protect and expand infrastructure along the beachfront, and continue to provide an attractive destination for guests. He stated that he is willing to try a variety of strategies to protect his coastline Trevor Stevenson, Stevensons Resort, 17 April 2013).

Alternatives Considered

The ten potential ecosystem-based adaptation strategies described below can be implemented individually or in combination. These strategies were examined according to the Planning and Urban Management (Environmental Impact Assessment) Regulations (Government of Samoa 2007), and the preferred alternative is described according to those regulations. A lack of information about the current sediment budget and sediment transport mechanisms along the Manase coastline inhibits development of a comprehensive solution.

No Action

This option, also known as a “do-nothing” approach, maintains the status quo. This would require no labor for implementation and no changes to current land use patterns. Beach erosion would continue to undermine existing trees and eventually the retaining wall in front of the villas. The protective revetment would continue to deteriorate due to wave action, and loose rocks would continue to enter the nearshore and damage live coral.

Gather additional information to develop regional coastal management plan

A lack of information on the Manase coastal system, including the hydrodynamics within the lagoon and the regional sediment transport pathways and volumes, challenges the ability for government and landowners to make informed land-management decisions. The scarcity of information is particularly troublesome considering recent infrastructure changes to roads and drainage along this coastline, increased government and landowner interest in building coastal stabilization structures in the area, and the initiatives of Manase landowners to protect individual properties despite or regardless of the interconnected nature of coastal processes, whereby changes along one section of the beach cause unintended changes in other areas within the coastal system.

A study of the regional hydrodynamic and sediment transport processes would identify sediment availability to the Manase shoreline and would clarify whether recent land-use changes to the coastal system (road construction, wetland infilling, seawalls, groynes) have accelerated beach erosion, informing development of a plan to mitigate or modify the impacts. This option would require development of a nearshore survey plan, identification of an appropriate geophysical research team, and additional funding for the field work and data interpretation.

Leave beachrock in place

This option would reduce current labour requirements at the resort by ceasing the practice of beachrock removal. Allowing exposed beachrock to remain in place on the beach would preserve both the protective nature of beachrock and the sediment source as the beachrock degrades. The landowner is concerned that guests using the recreational beach will find the presence of beachrock aesthetically displeasing.

Protect existing native vegetation

This short-term option involves protecting the diversity of native vegetation that is currently stabilizing sediments along the property shoreline. Actions could include building small box-like structures around the base of the existing large fetau and fau trees that are currently stabilizing the bank but are being undermined by erosion that has exposed their roots tree and exposed roots. Such structures could be made of natural materials (wood) and would reduce the impact of erosive waves, when meteorological conditions produced waves high enough to reach those trees on the back beach. If selected, this alternative should be combined with planting new vegetation, which will serve as the primary stabilizing vegetation when the now-mature trees are eventually undermined and felled. This strategy might extend the life of the trees and their stabilization functions for a short-term period. However, it would place new artificial structures on the beach, and erosion would continue along the adjacent portions of the beach and bank and likely would flank the edges of the structures.

Because the mature fetau and fau trees are still upright, not leaning, and are high enough on the bank to be out of the active wave zone under normal conditions, they will likely withstand another 5-10 years of erosion, during which time new vegetation could become established landward of the current tree line. A simpler protection method would be to monitor the health of those mature trees while the new vegetation is getting established; if a tree begins to lean, it can be anchored to a landward point by wrapping strong and wide nylon straps or similar device around the trunk (ensuring that the rope or strap does not cut into the trunk).

Plant vegetation to stabilize sediments

This strategy involves planting a mix of native coastal vegetation in front of the villas, both along the eroding bank and behind the retaining wall, and also supplementing the existing vegetation in front of the Eurofales. The root systems would stabilize sediment and slow the rate of erosion on a short-term and long-term scale. This option would require developing a site plan for appropriate native coastal species and number of seedlings needed, obtaining seedlings, and planting and monitoring the new vegetation. .

Ideally, a buffer zone of vegetation could be maintained between the beach and the infrastructure. This strategy would likely slow ongoing erosion now and over the next few decades.

Build stairways or boardwalks to reduce erosion of upper beach

This option would install multiple stairways (Figure 7C) along the existing bank for use when moving between villas and the beach. These structures would reduce foot traffic on the upper beach closest to the retaining wall, thereby reducing sediment loss along the backbeach; they would also allow sand to accumulate beneath the structures. These structures would require a small investment of labor and materials to build, and would need to be repaired or replaced when impacted by storms or weathering.

Stabilize rock revetment to reduce coral impacts and strengthen protective function

Securing or replacing the rocks in the uncemented rock revetment would minimize the chances of loose rocks entering the nearshore and destroying coral, which provides protection to the beach by dampening incoming wave energy. It would also strengthen the vulnerable structure and its ability to protect the suites and the land upon which they were built, but it would not slow erosion in front of the revetment. It would also likely accelerate erosion along adjacent portions of the beach, and therefore cyclical beach nourishment should be paired with this action. Sand placed in front of the seawall would be carried away, so renourishment would need to continue at regular intervals. This alternative would require identifying a coastal engineer to design the structure, developing a reconstruction plan, obtaining supplies and necessary permits, and monitoring the stability following implementation.

Build offshore structures to reduce wave energy

Offshore structures such as artificial reef balls or submerged breakwaters (Figures 7A, B) would reduce incoming wave energy and associated shoreline erosion, while providing marine habitat and enhancing sand deposition on the lee side of the structure. However, submerged breakwaters become ineffective during severe storm surge during cyclones, and can cause erosion and scouring on their lee side (Harris 2001). This alternative would require identifying a suitable coastal engineer to design the structure, developing an implementation plan, performing and documenting an Environmental Impact Assessment, obtaining supplies, and monitoring the stability following implementation.

Relocate structures landward to reduce vulnerability

This option would remove villas and suites, from the eroding bank edge, and would place them further landward, away from the threat of being undermined and eroded. It would also remove the rock revetment and retaining wall, leading to changes in back beach topography as the beach returned to a natural equilibrium profile. Of all options presented, this one would require the highest level of labor and materials, and might reduce desirability to beachgoers due to the increased distance between lodging and beach, and the potential for a change in the view from the lodgings. The alternative would conserve materials from the existing structures and reduce the risk of their damage or loss due to a storm or other erosion event. Following implementation of this alternative, the resort should avoid building new infrastructure close to the eroding shoreline, and new building designs should incorporate the ability for structures to be moved inland at a later date.

Coordinate actions with other Manase beach landowners to consider impacts on neighbors

Beach engineering actions taken by one landowner have the potential to affect multiple landowners along the same beach. In recognition of this interconnectedness, and of the shared goal of beach preservation, coastal landowners and village stakeholders should create a committee to coordinate beach management and engineering actions along the Manase beach. This would require a high degree of commitment and patience on the part of landowners, but would benefit the shared goal of beach preservation, and also has the potential to strengthen community relationships.

Figure 7. Alternatives considered included nearshore and beach structures including A) underwater reef balls that would provide marine habitat and B) as a group, would reduce incoming wave energy and associated shoreline erosion, and C) stairways that would reduce foot traffic and associated sediment loss on the upper beach. Photos of reef balls from Harris (2009).

Preferred Alternative

The preferred alternative was refined through several consultations between the landowner, MNRE Department of Environment and Conservation, and SPREP. It meets the project's criteria to be ecosystem-based and to support enhanced biodiversity values; to increase coastal resilience by slowing the coastal erosion rate; to be feasible for local implementation; and to be acceptable to the landowner. The preferred alternative combines several of the alternatives considered. In the short-term (one-year) period, three actions can be implemented immediately: leaving beachrock in place, leaving existing native vegetation in place, and planting new vegetation. Over a longer (four-year) period, an additional three actions are recommended: gathering additional information, stabilizing the revetment, and coordinating actions with other Manase beachfront landowners.

Several alternatives were considered and dismissed. The No Action alternative was dismissed due to concerns about ongoing erosion. Building structures to protect mature trees was dismissed due to the current health of existing trees and the doubtful benefits of construction while new vegetation is being established. Construction of offshore structures was dismissed because the cost effectiveness at this particular site is doubtful, considering the expanse of live coral present and the lack of protection that the structures offer under heavy storm conditions. Construction of freestanding stairways and boardwalks was dismissed by the landowner due to aesthetic considerations. Relocation of the permanent structures would be prohibitively expensive and so was also dismissed.

Short-term Actions (1 year)

Exposed beachrock will be left in place to continue protecting the beach from additional erosion, and to avoid removing additional sediment from the beach. The fue moa growing at the western end of the property (Figure 8) will be left in place and allowed to continue spreading in order to stabilize beach sediments. The native trees and shrubs growing along the back beach should be allowed to remain in place, but invasive species should be removed when observed to reduce competition with native species and associated habitat values. Although some of the largest trees with extensive root systems are being undermined by erosion, they continue to grow vertically (not leaning) and appear to be in good health. It is important to protect their role in sediment stabilization while new vegetation is getting established. If they begin leaning due to undermining, those trees can be stabilized by looping wide belts around the trees and anchoring them to the upper beach (ensuring that the support system does not cut into the trunk of the tree) or, in extreme cases, by building a protective box around the base.

Vegetation will be planted to help stabilize sediment and reduce erosion. Species selection for this project was limited to native coastal (littoral zone) vegetation that would grow along sandy shorelines, help to stabilize sediments within two years, and be satisfactory to the landowner. Suitable species were identified through the literature, field observations, and expert opinions from officers of the Ministry of Natural Resources and Environment. These species are described in Appendix A. MNRE Forestry officers provided advice on species suitable for the site, and which of those were available through the MNRE Forestry Division's Asau nursery in Savai'i. The selection was narrowed further by landowner preferences, including immediate availability of seedlings to implement the project; demonstrated success of existing fetau (*Calophyllum inophyllum*), and leva (*Cerbera manghas*) in retaining sediment along the beach and bank; and the shade provided by the mature trees present at the resort. Fau (*Hibiscus tiliaceus*) is also an appropriate choice with proven success at the site, but seedlings are not currently available from a known source, and so were not selected as part of this alternative; if seedlings do become available or can be transplanted from within the site, they should be included in the mix of new plantings. To supplement planted trees, and to provide additional shallow stabilization while the tree root systems are developing, the fast-growing vine fue moa (*Ipomoea pes-caprae*) and the dense shrub to'ito'i (*Scaevola taccada)* were selected. Fau, fetau, leva, and to'ito'i are used in traditional Samoan medicines.

Coconut trees (*Cocos nucifera*) may also be interspersed with other seedlings. They are not the best option for coastal stabilization due to their shallow root system in combination with their height, as demonstrated by the seaward line of fallen coconuts along the western edge of the property, although they do grow quickly, provide some stability to sediments until being undermined, and are aesthetically pleasing. Talie (*Terminalia catappa* and *Terminalia samoensis*) was rejected for this site due to the high maintenance requirements of collecting the rubbish (fallen leaves).

No vegetation will be planted in front of the rock revetment, because seedlings would not survive the wave action at the toe of this revetment, and none will be planted west of the Eurofales, because this area is well vegetated and has no vulnerable infrastructure. Vegetation will be planted along the back beach, landward of the storm tide line, along the 80 m stretch of beach immediately in front of and behind the retaining wall protecting the villas, the 20 m of grassy lawn west of the rock revetment, and the 50 m in front of the Eurofales. As illustrated in Figure 9, a row of fetau and leva will be planted with spacing of approximately 8 m between seedlings. Seaward of these trees, to'ito'i will be planted with spacing of approximately 4 m between seedlings, fronted and interspersed with fue moa transplanted from the western end of the property. This will require approximately 12 fetau seedlings, 12 leva seedlings, 40 to'ito'i seedlings, and 70 fue moa rooted cuttings.

Longer-term Actions (4 years)

The rock revetment protecting the suites should be redesigned and reconstructed by a coastal engineer in order to reduce impacts on the nearshore coral reef and to strengthen the protective function of the wall. The new design should reduce the ongoing loss of rocks and the structure's vulnerability to undermining by freshwater flow and wave-induced erosion and scour. However, a tighter revetment would likely accelerate erosion on adjacent portions of the shoreline and in front of the wall, necessitating periodic sand placement to protect the wall and mitigate adjacent erosion. Potential sources for sediment are unknown but might include the area outside of the reef offshore of the ava near Jane's Fales, or a land-based sand mine; sources should be investigated as part of the proposed nearshore study. Reconstruction would likely require government permits and compatibility with government design guidelines, which as of April 2013 were under revision (personal communication, Titi Simi, MNRE Disaster Management Office, 23 April 2013). Funding may be available through new government initiatives being implemented by Samoa's MNRE Disaster Management Office to build seawalls as part of a coastal protection and climate adaptation effort. Although it is likely not cost-effective to move existing facilities landward, it is recommended that future beachfront construction activities, such as replacing existing facilities or constructing new facilities such as a swimming pool or restaurant, consider the likelihood of continued shoreline erosion and the possibility of building in areas with lower coastal vulnerability.

In order to make informed coastal management decisions now and in the future, it is imperative to gain a greater understanding of the coastal and nearshore processes along Manase beach. This research effort would complement other ongoing and planned efforts in the region, including the Samoa MNRE Disaster Management Office coastal protection measures, a University of the South Pacific and European Union Global Climate Change project to help Samoan coastal villages adapt to future challenges (including drinking water and agriculture), and a research effort by the US National Oceanic and Atmospheric Administration known as "Two Samoas". It also has the potential to develop new partnerships with regional universities and SOPAC (SPC Applied Geosciences and Technology Division) to gather new data and obtain existing data (e.g., orthophotographs in SOPAC archives). Limited funding may be available as a component of funded SPREP projects.

The nearshore study should collect field data (nearshore bathymetry, wave and current measurements), integrate long-term historical data (waves, currents, sediment transport), develop conceptual and numerical models that represent the site, and use those results to identify appropriate beach protection methods. This work would likely cost around NZD$35,000 - $40,000 not including travel and lodging (personal communication, Dr. Shaw Mead, eCoast Consulting, 23 September 2013).

Specific research questions should include the following:

- What is the volume of nearshore sediment available to the beach through natural transport systems?
- What are the sediment inputs and removals from the Manase beach system (e.g. riverine input, nearshore-offshore exchange via avas, updrift headlands, coral rubble degradation, sand mining and nourishment)? What are the magnitudes of the major inputs and removals?
- What is the net annual alongshore sediment transport rate and direction? What, if any, are the seasonal differences and associated seasonal changes in expected beach profile?
- How has the current net sediment transport rate compare to the rate 10-15 years ago?
- What changes over the last 10-15 years have affected the sediment transport rate (e.g. wetland filling, seawalls, construction of road and drainage infrastructure, blocked river mouths, sediment mining from beach or nearshore)? What are the magnitudes of the changes in sediment input related to each of those projects?
- Has the beach has reached its new equilibrium state following changes to the sediment budget (e.g. road construction, wetland infilling) since 1999 (date of the last studied shoreline position)?
- What is the mean shoreline erosion rate (if a new equilibrium state has been reached), or what is the expected mean shoreline erosion rate following establishment of a new beach equilibrium?
- What is the average magnitude of cyclone-induced shoreline erosion? What is the average post-cyclone recovery period of the beach?
- What is the effect of natural fluctuations (ENSO, cyclones)?
- Are there potential nearshore sources of sediment to be used for beach nourishment (and if so, where and with what volume and what rate of recharge)?

To minimize and mitigate future threats to the Manase coastline, communication and cooperation efforts among Manase landowners are encouraged. According to the landowner, past attempts to organize cooperative meetings among Manase landowners were poorly attended and ultimately unsuccessful (personal communication, Trevor Stevenson, Stevensons Resort, 23 April 2013). It is worth pursuing a coordinated approach to coastal protection, however, particularly in consideration of the increasing landowner interest in and government support for coastal stabilization structures (e.g., seawalls) that will affect adjacent landowners, and the potential for significant associated impacts and costs.

Potential Benefits of the Preferred Alternative

Implementation of the short-term strategies described will reduce the site vulnerability to climate change impacts and to ongoing impacts of coastal erosion, storms, and waves. This portion of the preferred alternative will restore and enhance habitat by greatly increasing native vegetation cover and reducing sediment loss. It will improve the scenic value, aesthetic appeal, and recreational amenities of this site by preserving land area and beach quality, and increasing shade cover and traditional medicinal resources at the site. It will enhance opportunities for tourism, environmental education, and coastal stewardship, and will serve as an example of coastal protection using ecosystem-based adaptation strategies. It will also increase opportunities to share traditional knowledge and practices such as traditional medicines.

In the longer-term, developing additional information on the coastal hydrodynamic and sediment transport system will benefit future coastal management decision-making processes; it also has the potential to develop new partnerships with research institutions, regional scientific agencies, and fund sources. The long-term recommendation to coordinate actions of beach landowners has the potential to strengthen community relationships and coastal environment both within and outside of the project site. Rebuilding the revetment in front of the suites will benefit coral reef health and structural stability of the suites. Beach nourishment would help to protect infrastructure and beach width but methods must ensure that nearshore habitats (coral) are not impacted (e.g., burial by sudden input of sand); nourishment would be ongoing and cyclical rather than a one-time event.

Potential Impacts of the Preferred Alternative

The preferred alternative has some potential environmental impacts. Revetment reconstruction will increase erosion on adjacent beaches. Improper beach nourishment techniques could smother or otherwise impact nearshore species (coral).This plan is unlikely to have any adverse environmental consequences related to environmental pollutants, changes in the social or cultural characteristics of the site, or changes in possible future use of the site. Leaving the beachrock in place may have some impact on aesthetic value of the recreational beach. If built, structures that protect mature trees will lead to localized scouring and flanking.

The project incorporates the assumption that natural coastal processes, including erosion, will continue. This project also acknowledges the likelihood that adjacent or nearby coastal landowners may take actions to protect their coastlines, and that those actions (e.g., seawalls) may adversely impact the project site. Although the preferred alternative is expected to slow the rate of erosion by stabilizing sediment, it will not completely prevent erosion in the short-term or in the long-term. The landowner accepts that the risk of continued erosion is preferable to construction of a seawall or other strategies that would lead to a loss in sandy beach area and associated recreational values of his site. Continued erosion may eventually require the relocation of infrastructure including Eurofales, suites, and villas.

The shoreline and vegetation monitoring protocol described below will be useful not only to evaluate the success of the short-term actions but also to establish baseline conditions and future conditions and trends in shoreline position and behaviour. The lack of such datasets was a confounding situation in the development of this coastal management plan; a set of shoreline monitoring data will improve development of future management and assessment of coastal conditions.

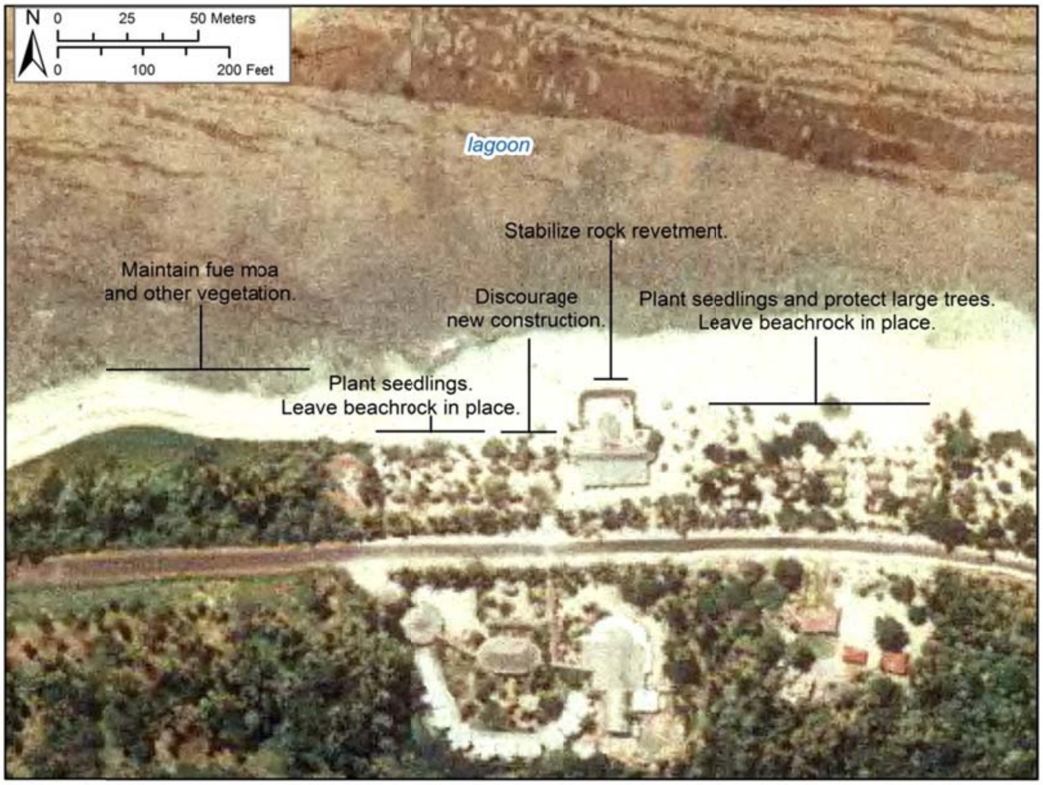

Figure 8. The preferred alternative includes several short-term strategies. Photo of ground conditions in 2004 courtesy of SPREP.

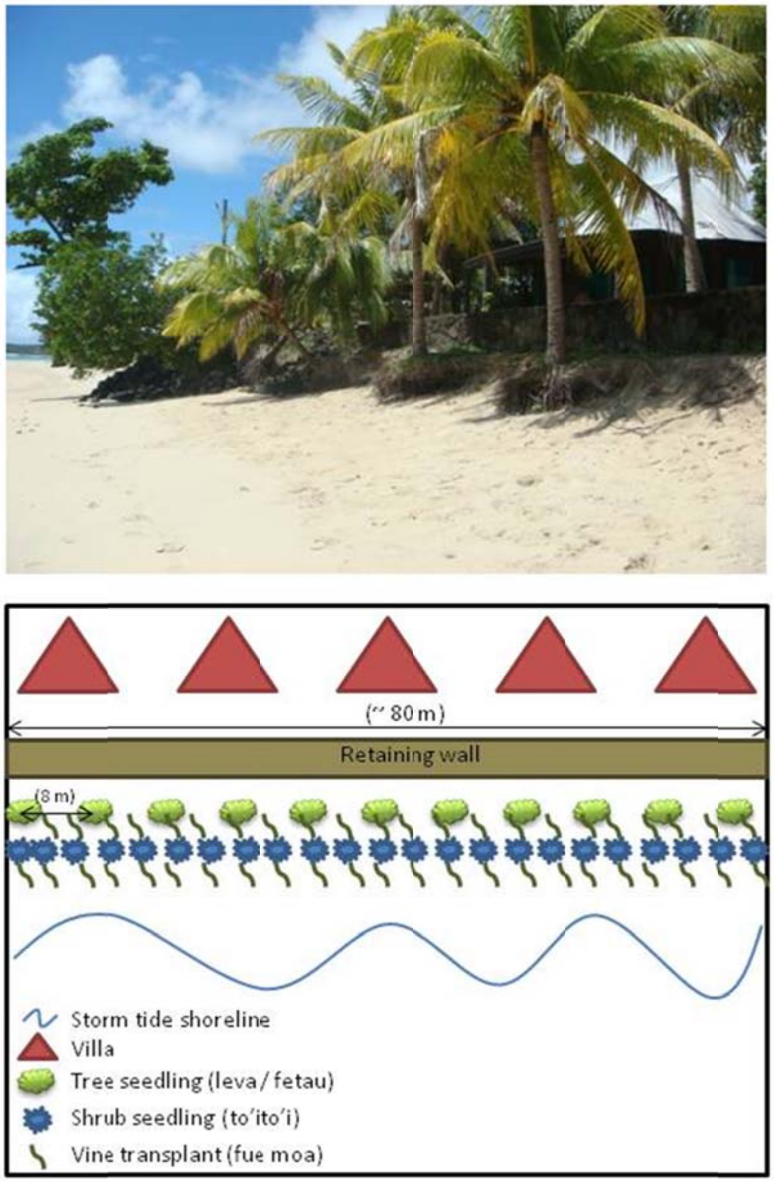

Figure 9. Native coastal trees, shrub, and vines will be planted to help stabilize sediments.

Monitoring Strategy

Monitoring methods to evaluate success of the project will include baseline and follow-up surveys of location of shoreline features, seedling survival, and landowner satisfaction. The monitoring protocol is described in more detail in Appendix C.

Location of the high tide line, the edge of vegetation (top of eroding bank), and the bottom of the eroding bank will be measured as a distance from fixed reference points along established transect lines (Figure 10). Transects are set approximately 30-40 m apart; exact distances vary to allow lines to extend from fixed reference points (structure foundation corners) where possible (Table 1). All lines are parallel and have a bearing of 364° from true North (352.5° from magnetic North).

The distance between the reference point (structure foundation) and the bank edge, bank base, and high tide line, in addition to the height of the scarped bank where applicable (Figure 11). These measurements should be documented at least once per year (preferably once every 6 months for the first 3 years) during the same season, for example, in May and November of each year. To capture a representative high-tide line, measurements should occur on normal tides, that is, not during a full or new moon and not under strong onshore or offshore wind conditions. Additional measurements should be recorded following major erosion events to capture storm impacts and typical storm recovery time period. This information will improve evaluation of the project's effectiveness under both calm and stormy conditions.

Shoreline features can be identified by several characteristics (Figure 12). The top edge of the eroding bank may be marked by the boundary between vegetation and sand (such as in front of the Eurofales and the grassy lawn), or a sudden change in slope to near-vertical (as seen in front of the villas). The base of this bank is marked by another sudden change in slope from near-vertical to near-horizontal. The high tide line can be discerned as the boundary between the wet and dry sand just after high tide. Wave run-up may extend beyond the high tide line because some waves splash or move higher on the beach. The wrack line, a line of debris (leaves and shells) carried by the water and stranded on the beach, also helps to delineate the high tide line. If tides are high and/or the beach is narrow, the high tide line may be at the base of the eroding bank or the edge of vegetation.

Monitoring should also include inspection of seedlings to confirm survival, and replacement of dying plants where necessary. Landowner satisfaction, including willingness to maintain vegetation, should also be evaluated at least annually.

These monitoring plans can be undertaken by the landowner, the designated MNRE officer, or other volunteer with a minimum of effort. The simplest materials needed to accomplish the monitoring are a map (or knowledge) of profile monitoring transect and seedling locations; a measuring tape to measure distances from the reference points; a compass to measure bearing; the vegetation appendix or other botanical reference or knowledge; and paper and pen for noting distances and species rates of survival. The designated MNRE officer should maintain a record of these measurements; it is recommended that a duplicate copy be kept with the landowner.

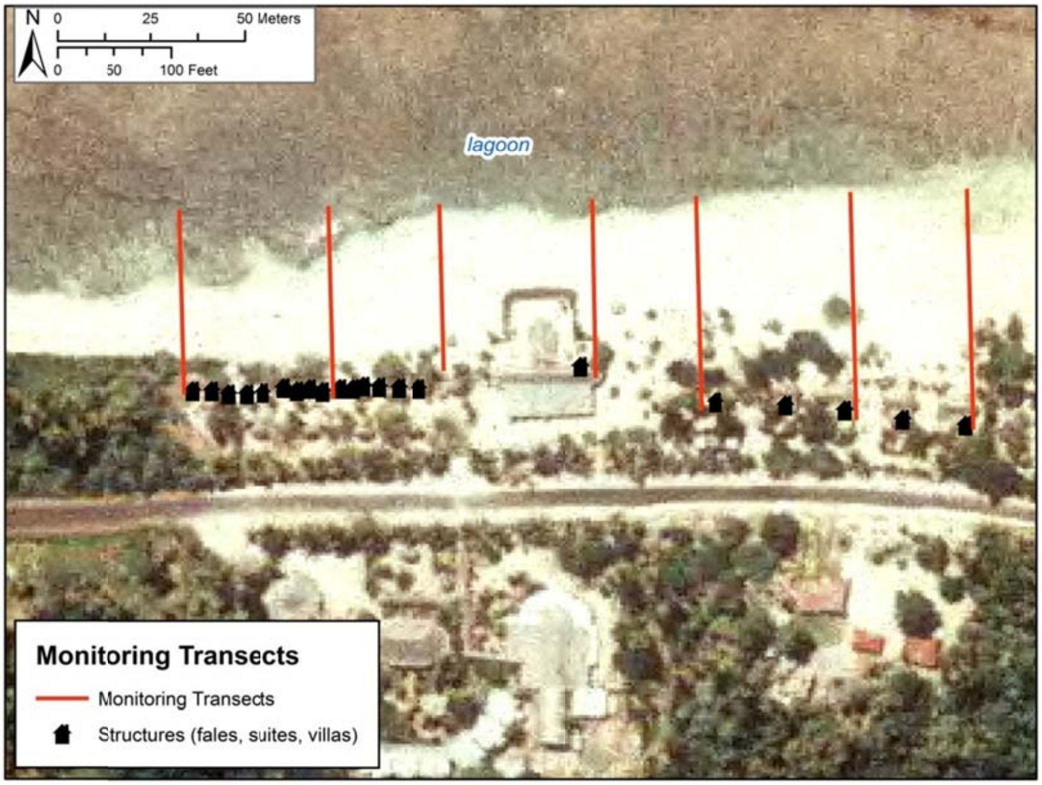

Figure 10. The monitoring plan includes measuring changes in the positions of shoreline features along seven transect lines. Photo of ground conditions in 2004 courtesy of SPREP.

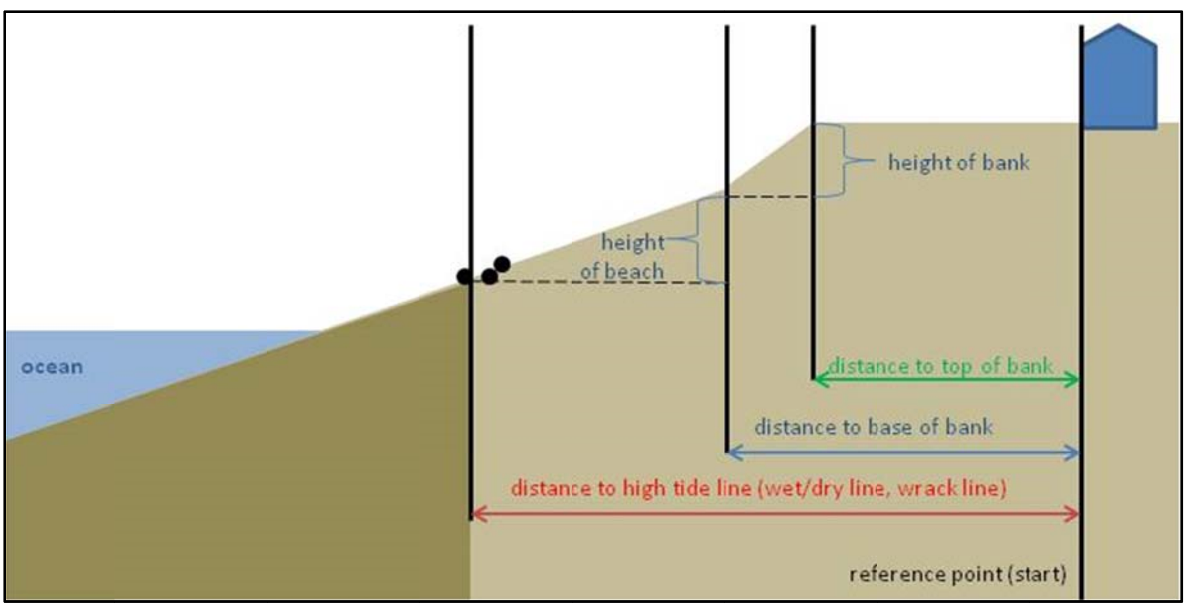

Figure 11. Distances between the reference point and each shoreline feature, in addition to the height of the scarped bank where applicable, should be measured at least once per year.

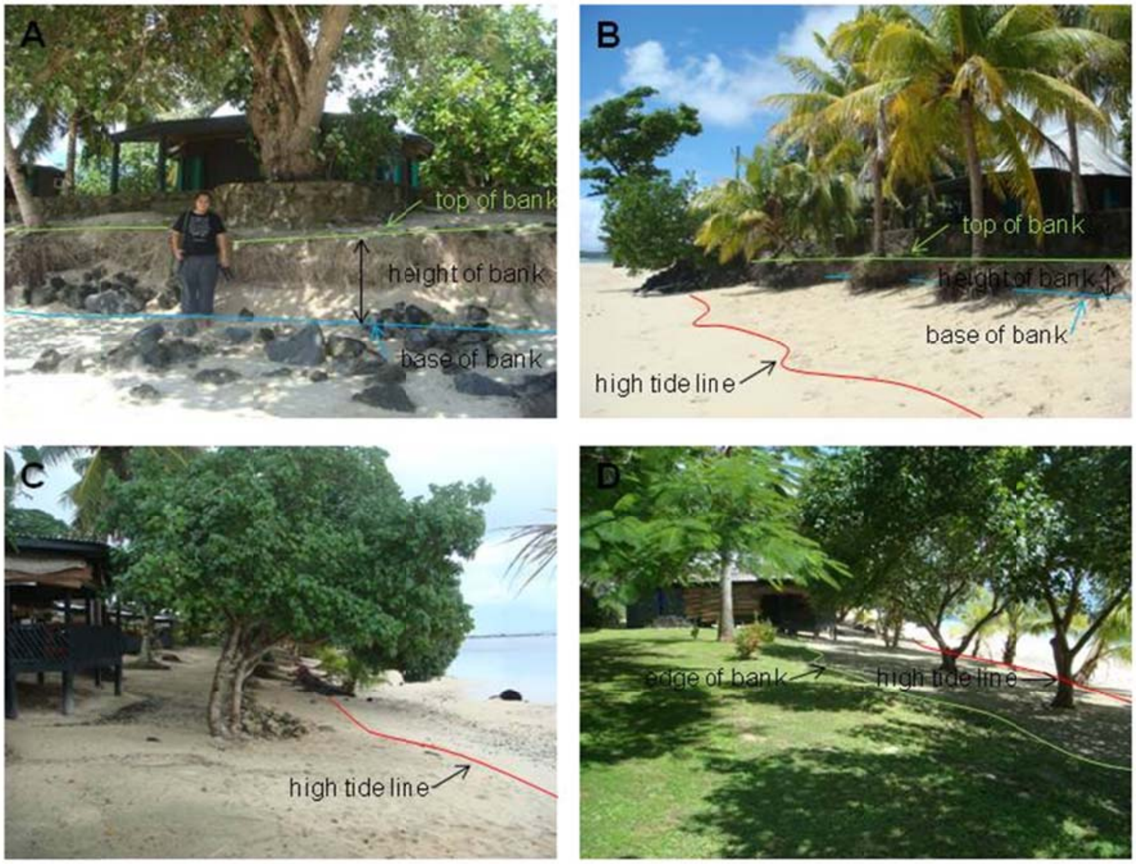

Figure 12. Several characteristics assist in the identification of shoreline features including the top, base, and height of the eroding bank (where applicable), and the normal high tide line as a proxy for shoreline position. A) The scarped bank is evident in front of the villas in addition to B) the wet-dry line indicating the position of the last high tide. C) In front of the Eurofales, there is no scarp. D) The edge of the vegetation bank should be recorded, in addition to the high tide line visible as a wet-dry line; there is no scarped bank to measure under conditions captured by this photograph. All photographs were taken in April 2013.

Evaluation Strategy

Metrics to evaluate performance over short term (1 year) and intermediate term (4 years)

In the first year of the project, all relevant resort staff should receive instructions to leave beachrock and native vegetation in place. Planting according to the finalized site plan should be completed. When seedlings are planted appropriately, an 80% survival rate is expected (personal communication, Suemalo Talie Foliga, MNRE-Forestry, 19 April 2013). Plans for new construction should evaluate the possibilities for more landward placement. Signage and other outreach strategies describing project goals should be created and enacted within one year of plantings. If the project is unsuccessful in meeting any of these goals, follow-up actions described below should be undertaken by the designated MNRE officer.

Additionally within the first year, potential partners for the research effort should be identified, and a project plan and funding needs should be detailed. Options for funding reconstruction of the revetment should be explored. Preliminary discussions for a coastal landowner committee should begin.

Within the next four years, the rock revetment should have been rebuilt by a coastal engineer. There should be no new structures along the shoreline. Straps or structures to protect mature trees should be constructed where necessary. A research plan to gather additional information should have been developed and funded in cooperation with identified partners, and new information should be synthesized and publicized. Manase coastal landowners should be communicating and cooperating on issues related to beach management activities.

Metrics to evaluate performance over longer term (10-50 years)

Natural coastal processes, cyclones, and climate-related changes are expected to impact this site over the next few decades. The site will experience erosion during this time period. It is also likely to be impacted by the coastal modifications of adjacent and regional landowners responding to the same coastal changes. This project intends to enhance site resilience to these events by slowing the erosion rate while still allowing for the presence of an aesthetically pleasing beach and recreational access to the site.

Success over the long term will include healthy, mature native coastal vegetation, an absence of new infrastructure (both amenities and protective structures) in the areas most vulnerable to erosion, and community recognition of the value of EbA strategies to enhance coastal resilience (as demonstrated at this site). The mature trees protected by temporary structures will likely have been undermined by erosion, but the new seedlings planted behind those trees should be healthy and mature.

According to Gibb's (2000) calculations of erosion rates along this beach between 1959 and 1999, once an appropriate suite of coastal protection measures are established, the erosion rate should return to a mean of -0.11 m/year or slower, excluding major erosional events (e.g., a cyclone) or human modifications to adjacent beaches (e.g., sand mining), and should not exceed a short-term fluctuation of -5 m/yr in any one year. However, multiple anthropogenic changes occurring after the 2000 study are suspected to have modified the natural sediment transport system, indicating that the system must reach a new equilibrium (i.e., the beach is likely being reshaped into a new configuration, after which time a new mean erosion rate may be established). Determination of whether the beach has reached its new equilibrium state, and the modern mean shoreline erosion rate, will require additional data collection as described in the preferred alternative.

Thresholds indicating the need for follow-up actions or mitigation

Individual seedlings should be replaced in-kind if dead. Species vary in their tolerance for light and exposure to salt spray. If seedlings of any one species have less than 80% survival rate, the type of species planted in those locations should be reconsidered. MNRE Division of Forestry at Asau should be contacted for advice on replacement.

Bank (vegetation) retreat of more than 5 m during the 5 year period following implementation would indicate that the mitigation measures are inadequate for stabilizing the sediments. Higher erosion rates should first be considered in light of any major events that may have accelerated erosion, such as meteorological events (e.g., a cyclone) or an anthropogenic change to regional coastal processes (e.g., seawall construction along a nearby beach). If vegetation is destroyed and significant erosion (more than 5 m) is caused by meteorological events, new seedlings should be planted following the guidance in this plan, landowner preferences, and the advice of MNRE Division of Forestry at Asau. If impacts are caused by manipulation of adjacent coastlines or sediment supply (such as sand mining), these impacts should be addressed directly where possible. If adjacent coastal manipulations cannot be prevented or undone, or if the strategies in this plan have proved inadequate under expected conditions, then additional strategies along the site beach may be required. Strategies may include sand replenishment or relocation of infrastructure.

If the landowner is dissatisfied by unexpected outcomes (e.g., tourist response to vegetation growth or presence of beachrock), the MNRE Division of Forestry staff at Asau can offer suggestions on pruning or replacing vegetation, and other steps such as enhanced communication efforts could be implemented.

Proposed Outreach Materials

Outreach efforts will demonstrate to communities the benefits of intact coastal biodiversity and community implementation of coastal adaptation measures using EbA principles. Outreach materials will be developed by a communication specialist in collaboration with the consultant. These materials will likely include signage at the property, printed materials for distribution, and interactive events.

The best way to reach villagers will likely be to host a special event at the village primary school, in collaboration with the teachers and the village's Women's Committee, in which children have speaking roles and other involvement, because this type of event engages village leaders and other parents (personal communication, Tapu Tuailemafua, University of the South Pacific-Alafua, 7 May 2013). To describe the project actions and goals to tourists and other site visitors, and to enhance the ecotourism value of the site, it is recommended that an interpretive sign be developed and erected at the site. To build capacity at MNRE, it is recommended that a presentation or field site visit with appropriate MNRE staff (Department of Environment and Conservation, Planning and Urban Management Agency, and Disaster Management Office) detail implementation methods, monitoring protocols, and lessons learned. To enhance the ability to identify plant species as native, introduced, and invasive, and to recognize the implications of planting choices, it is recommended that a short brochure with images is produced in both Samoan and English languages. Posting digital versions of the brochure and interpretive sign on the Stevensons Resort website would reach prospective guests and virtual visitors.

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Appendix A: Plant Species Considered for Coastal Stabilization

This appendix describes coastal species that were considered for use in the project "Coastal Management Adaptation to Climate Change using Ecosystem-based Adaptation Methods—Samoa Component." All species described here are currently found along Samoa's coastline. Species were screened for invasive potential using several references including GISD (2013), Meyer (2000), PIER (2013), and Whistler (1992). This document also describes the potential for the roots of each species to stabilize the eroding sandy beachfront and to resist erosion, and whether seedlings or cuttings were readily available for planting.

There were several known sources of seedlings. Five of the suitable species were available from the Ministry of Natural Resources and Environment (MNRE) Forestry Division nursery at Togitogiga, Upolu: fetau (*Calophyllum inophyllum*), futu (*Barringtonia asiatica*), leva (*Cerbera manghas*), malili (*Terminalia richii*), milo (*Thespesia populnea*), and talie (*Terminalia catappa*). The MNRE Forestry Division nursery at Maota, Savai'i had fetau, futu, milo, and tauanave (*Cordia subcordata*); and the associated nursery at Asau, Savai'i had talie Samoa (*Terminalia samoensis*). The local variety of niu, or coconut *(Cocos nucifera*), and several types of coconut hybrids were available from the Nu'u nursery run by the Ministry of Agriculture and Fisheries outside Apia.

Additional plants considered include the shrubs tausuni (*Taournefortia argentea*) and to'ito'i (*Scaevola taccada*); the tree known as fau or beach hibiscus (*Hibiscus tiliaceus*), and herbaceous plants fue fai va'a (*Canavalia rosea*), fue moa or beach morning glory (*Ipomoea pes-caprae*), and fue fue sina or beach pea (*Vigna marina*). These plants are not currently available from a known nursery source but are present on the island and may be grown from seeds or cuttings.

Fau or beach hibiscus (*Hibiscus tiliaceus*)

This plant grows as a shrub or a tree at about 0.75 – 1.5 m/year up to 10 m or more in height (Elevitch and Thomson 2006). It withstands salt spray and is adapted to a wide range of soils, but can fall over when subjected to high winds. It has a highly spreading, near-surface lateral root system that often has only a few main roots (Elevitch and Thomson 2006). Its long, spreading branches root where they touch the ground, enhancing the tree's ability to stabilize soil on slopes and shores exposed to moderate coastal tides. It has some potential to invade undisturbed native plant communities, particularly when introduced into moist environments, and it is difficult to control its spread (Elevitch and Thomson 2006). Its wood is used for timber, fish-net floats, firewood, and kirikiti (cricket) bats; inner bark fibers are used to make traditional dancing skirts, cordage, mats, and fishing line; and leaves are used for wrapping food (Whistler 1992). Parts of the plant are also used in traditional Samoan medicines (Whistler 1992). Mature trees were present at the Stevensons Resort Manase site and elsewhere on the island.

Fetau (*Calophyllum inophyllum*)

This tree protects coastlines and stabilizes sandbanks, and the dense foliage shelters more sensitive plants from salt spray. It withstands cyclones, wind, salt spray, drought, and occasional flooding common to beach environments (Friday and Okano 2006). It may initially grow 1 m per year, although usually much more slowly, up to a height of 8-20 m (Friday and Okano 2006). It grows best in direct sunlight in sandy, well-drained soils on the beach- right down to the high-tide mark-- and in coastal forests. This tree has a shallow, spreading root system that spreads at least as far as the canopy and that rise up above the surface of the soil. The tree provides heavy shade, and has low potential to become invasive (Friday and Okano 2006). An infusion of the leaves (ADAP 2001) and the oil extracted from the nuts are used for external medicinal purposes, but the nuts can be poisonous if eaten (Friday and Okano 2006). The wood is used for making canoes, bowls, furniture, and houses (Whistler 1992). Seedlings were available from the Ministry of Natural Resources and Environment (MNRE) Forestry Division nurseries at Togitogiga, Upolu and Maota, Savai'i. Mature trees were present at the Stevensons Resort Manase site, the Vaiula Beach Fales Tafatafa site, and elsewhere on the island.

Fue fai va'a (*Canavalia rosea*)

Photo from Gann et al. (2013)

This vine is an important species for beach and dune stabilization (Highland et al. 2010). It grows just above the high tide level, predominantly grows prostrate on sandy beaches and rocky shores, but sometimes climbs into low vegetation (Whistler 1992). It grows quickly and tolerates drought and salt spray, but does not tolerate long-term flooding by salt or brackish water (Gann et al. 2013). The seeds and seed pods are poisonous (Gann et al. 2013). It is one of several species of littoral vines, both native and invasive, that are often not distinguished by Polynesians (Whistler 1992), including Samoans, who use the general term "fue".

Fue moa or beach morning glory (*Ipomoea pes-caprae*)

This trailing vine is abundant on rocky and sandy beaches. It grows just above the high tide line along coastal beaches, forming large mats that assist in stabilizing sands and preventing erosion (Hill 2001). It is also common in scrub areas and some upland areas. Branches may reach 10 m in length while the tap-root is deep and fleshy. It withstands salt spray and wave splash, and it recovers well following cyclones and storms that inundate beach areas with sea water and heavy winds (Hill 2001). The leaves are used in traditional Samoan medicines (ADAP 2001). It is one of several species of littoral vines, both native and invasive, that are often not distinguished by Polynesians (Whistler 1992), including Samoans, who use the general term "fue". This species is present at the western end of the Stevensons Resort Manase site, the middle of the Vaiula Beach Fales Tafatafa site, and elsewhere on the island. There are differing reports over whether it is not invasive (personal communication, Foliga, 19 April 2013) or recently designated as invasive (personal communication, Peteli Pese, MNRE-Forestry, 8 May 2013).

Fue fue sina or beach pea (*Vigna marina*)

This vine grows on sandy and sometimes rocky shorelines, growing prostrate or climbing over low vegetation (Whistler 1992). This plant fixes nitrogen, increasing the nitrogen content of the sand and fertilizing the growth of other adjacent plants. It will tolerate some salt spray and sandblast but usually does not survive complete burial under windblown sand (Queensland Government 2013). It prefers full sun. Stems are 2-3 m long. The leaves and roots are used for multiple treatments in traditional Samoan medicines (Whistler 1992, ADAP 2001). It is present at the Vaiula Beach Fales Tafatafa site, the fields around the Ministry of Natural Resources and Environment (MNRE) Forestry Division nursery at Togitogiga, Upolu, and elsewhere on the island.

Note: There is another species known as fue saina (*Mikania micrantha*) that is invasive, widespread in Samoa, and very difficult to control; it is considered a major pest species (Space and Flynn 2002). It does not grow below the high tide line because it cannot tolerate salt spray or salt water (personal communication, Foliga, 19 April 2013).

Futu (*Barringtonia asiatica*)

Photo from NTBG (2013)

This is a large tree (reaching up to 20 m in height) that grows as a mangrove associate on sandy and rocky shores (NTBG 2013). It grows very quickly (personal communication, Foliga, April 2013). It has no aerial roots, and may have one long tap root. . The flowers open at night (NTBG 2013). All parts of the tree contain saponin, which is poisonous to fish but not humans (NTBG 2013), and is used to stun fish, causing them to float to the surface (Whistler 1992). The leaves are used for external treatments in traditional Samoan medicines (ADAP 2001). Seedlings were available from the Ministry of Natural Resources and Environment (MNRE) Forestry Division nurseries at Togitogiga, Upolu and Maota, Savai'i.

Leva (*Cerbera manghas*)



This tree can grow up to 12 m tall (Whistler 1992). It grows in littoral forest and disturbed coastal areas (Whistler 1992) and is often associated with mangrove forests (NTBG 2013). *Cerbera* species are generally associated with water and occurs along rivers or streams, in swamp forests and behind mangroves (Globinmed 2013). The milky latex and the fruit are poisonous to humans (Whistler 1992). The roots are used in traditional Samoan medicines (Whistler 1992, ADAP 2001). There is a mature tree currently growing at the eastern end of the Stevensons Resort Manase site and elsewhere on the island. Seedlings were available from the Ministry of Natural Resources and Environment (MNRE) Forestry Division nursery at Togitogiga, Upolu.

Malili (*Terminalia richii*)

This tree has good cyclone stability and is used for soil stabilization and windbreak among other purposes (Thomson 2006). Trees have a spreading, near-surface lateral root system and likely also have deep sinker roots. It grows moderately quickly (2 – 2.5 m/yr) in its early years, then more slowly (1.3 – 1.5 m/yr) after 14-22 years. It reaches 25-35 m high when mature. It grows in lowlands and is associated with remnant forest. It prefers fertile, well-drained neutral clay loams but is adapted to most soil types of volcanic origin and those overlying coralline limestone, and can grow on wet or periodically waterlogged sites (Thomson 2006). It has little potential to become invasive and provides moderately heavy shade

(Thomson 2006). Seedlings were available from the Ministry of Natural Resources and Environment (MNRE) Forestry Division nursery at Togitogiga, Upolu.

Milo (*Thespesia populnea*)


Photo from Friday and Okano (2006)

This tree is valuable as a coastal windbreak because it is highly resistant to wind and salt spray and grows well in sandy, saline soils (Friday and Okano 2006). It has shallow roots that spread on the surface, particularly in shallow, rocky, or occasionally flooded soils; in porous soils, it will develop a long taproot to access deep water sources (Friday and Okano 2006). It is a small tree with a moderate growth rate (0.6 – 1 m/yr) for the first few years (Friday and Okano 2006), but can grow up to 12 m in height (Whistler 1992). It grows in littoral forest, on the margins of mangrove swamps, and along estuaries, but rarely becomes a dominant species. It thrives on sandy coastal soils and full sunlight, and tolerates drought conditions. It propagates easily but does not grow well in shade (Friday and Okano 2006).It has the potential to become an invasive weed and should not be introduced to new areas. The wood is used to make bowls, paddles, and handicrafts (Whistler 1992). The leaves and bark are used in traditional Samoan medicines (Whistler 1992, ADAP 2001). Seedlings were available from the Ministry of Natural Resources and Environment (MNRE) Forestry Division nurseries at Togitogiga, Upolu and Maota, Savai'i.

Niu or coconut (*Cocos nucifera*)

Coconut trees grow up to 500 m in elevation (Whistler 1992) and produce large fruits surrounded by a hard shell with a fibrous husk. It is a valuable agricultural tree; the meat can be used for food and oil; the liquid for drinking; the shells for cups and charcoal; the husks for kindling and to make sennit for ropes and cords; the leaves for weaving and plaiting; and the trunk for timber (Whistler 1992). They have a shallow root system that does stabilize sediment until undermined, but this undermining happens more quickly than for trees with deeper and wider root systems. Several types of coconut grow in Samoa. The hybrids are shorter and produce more nuts, and quickly (within 3-5 years), and so are preferred for agricultural purposes. The coconut proposed for this project is a local variety that produces fewer nuts, and more slowly (5-10 years), but a richer cream; this variety also grows taller and more slowly, and has denser wood (personal communication, Suemalo Talie Foliga, MNRE-Forestry, 19 April 2013). Traditional knowledge indicates that the local variety is better able to withstand coastal erosion and undermining (personal communication, Muliaga David Peterson, Vaiula Beach Fales, 14 April 2013). Seedlings of several varieties of coconuts (local, niu vai, hybrid, and niu afa) were available from the Nu'u nursery run by the Ministry of Agriculture and Fisheries outside Apia.

Talie (*Terminalia catappa* and *Terminalia samoensis*)


Talie provides good erosion control because it has a spreading, fibrous, near-surface lateral root system that may also be deep rooted in sand (Thomson and Evans 2006). This vast root system binds together both sands and poor soils. The natural habitat of the species is in areas just inland from ocean beaches, near river mouths, and on coastal plains. It is tolerant of drought and salt spray and is a promising species for reforestation of sandy areas (ICRAF 2013). The tree has a fast growth rate in its early years (about 2 m/yr) (ICRAF 2013) and can grow up to 25 m tall (Whistler 1992). It also provides heavy shade (Thomson and Evans 2006). It loses its leaves twice a year in most areas, with a brilliant red-and-yellow display of leaf colour before doing so (ICRAF 2013). This results in a lot of rubbish and may reduce landowner interest in planting it (personal communication, Peterson, 13 February 2013). The edible kernel of the fruit can be eaten, and infusion of the bark is used in traditional Samoan medicines (Whistler 1992, ADAP 2001).

Talie Samoa (*T. samoensis*) grows more slowly than the *T. catappa* species, which can grow up to 25 m in 10 years (personal communication, Foliga, 19 April 2013). There is a mature talie (*T. catappa)* currently growing at the western end of the Vaiula Beach Fales Tafatafa site and elsewhere on the island. Talie Samoa (*T. samoensis*) seedlings were available from the Ministry of Natural Resources and Environment (MNRE) Forestry Division nurseries at Togitogiga, Upolu and Asau, Savai'i.

Tauanave (*Cordia subcordata*)

Photo: Friday and Okano (2006)

Photo : Friday and Okano (2006)

This tree has a shallow and extensive root system that is useful for the conservation of eroding coastal areas (Friday and Okano 2006). Through natural regeneration, it can form dense stands of trees that protect coastal areas. It grows rapidly (1 m/yr) in early years, and mature trees are up to 10 m in height (Whistler 1992). It grows in littoral forest and thickets on sandy shores, but rarely very far inland (Whistler 1992). It prefers direct sunlight and withstands frequent salt spray. It can spread easily by seeds, but is native to Pacific Islands so is not considered invasive (Friday and Okano 2006). The wood is used to make plank canoes, bowls, and paddles; the flowers are used to make leis; and the seeds are edible (Whistler 1992). Seedlings were available from the Ministry of Natural Resources and Environment (MNRE) Forestry Division nursery at Maota, Savai'i.

Tausuni (*Tournefortia argentea*)

Photos: Manner and Elevitch (2006)

It provides a barrier to salt spray and is useful as a windbreak and in coastal stabilization. It has very strong vertical and lateral roots that anchor it even in the harshest coastal conditions, including salt spray, strong and steady winds, and occasional waves washing over its root system or battering the lower trunk and roots (Manner and Elevitch 2006). It can grow near the ocean and tolerates shallow, saline, and nutrient-poor sands and rocky soils. It is commonly found on sandy beaches and rocky coral limestone slopes where soils are very thin. This tree is slow-growing (<0.75 m/yr) and can grow up to 6 m tall. It is rarely considered a pest, but has the potential for becoming invasive when introduced to new coastal environments (Manner and Elevitch 2006). The wood is sometimes used to make tool handles and carved handicrafts (Whistler 1992). The leaves are used in traditional Samoan medicines (ADAP 2001).

To'ito'i (*Scaevola taccada*)

To'ito'i is a dense, spreading shrub used for coastal stabilization in some parts of the Pacific. It is one of the most common littoral shrubs in Polynesia. It often forms dense thickets on rocky and sandy costs in the region, with shrubs up to 3 m in height (Whistler 1992). It is adapted to salt-sprayed coastal environments with shifting sandy substrate and variable salinity (GISD 2010), and can survive being inundated by waves (personal communication, Foliga, 19 April 2013). In some countries it has become an invasive plant, and is difficult to remove and to control once established (GISD 2010). The bark and leaves are used in traditional Samoan medicines (ADAP 2001). It would be a suitable choice for focusing foot traffic towards limited beach access points, discouraging foot traffic across these plants. It currently grows along the coastal walk within the MNRE-managed Togitogiga Forest on the south side of Upolu, and elsewhere on the island.

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Appendix B: Site Visits

Table B.1. Purpose and attendance of meetings related to Vaiula Beach Fales (Tafatafa) project site.

Date	Purpose of Visit	Location	Attendance
2 August 2012	Evaluate site suitability	Tafatafa	Consultant (Schupp) SPREP (Anderson, Jungblut)
5 December 2012	Final site selection	MNRE, Apia	Consultant (Schupp) SPREP (Anderson, Carruthers, Jungblut) MNRE-DEC (Afioga, Kwan)
13 February 2013	Evaluate landowner interest and gather information	Tafatafa	Consultant (Schupp) MNRE-DEC (Kwan) Landowner (Peterson)
13 March 2013	Confirm Forestry participation	Togitogiga nursery	Consultant (Schupp) MNRE-Forestry (Pese, Tuita'alili)
14 March 2013	Gather information, identify nursery species, develop site plan	Togitogiga nursery, Tafatafa	Consultant (Schupp) MNRE-DEC (Kwan) MNRE-Forestry (Tuita'alili) Landowner (Peterson)
20 March 2013	Gather information, develop site plan	Tafatafa	Consultant (Schupp) MNRE-Forestry (Pese, Tuita'alili) Landowner (Peterson)
26 March 2013	Deliver and plant seedlings	Tafatafa	Consultant (Schupp) MNRE-Forestry (Pese, Tuita'alili) Landowner (Peterson)
19 April 2013	Review and improve site plan	Vailima Botanical Reserve	Consultant (Schupp) MNRE-Forestry (Foliga)
8 May 2013	Present revised site plan, deliver additional seedlings, provide planting instructions	Togitogiga nursery, Tafatafa	Consultant (Schupp) MNRE-Forestry (Pese) Family of Landowner
1 October 2013	Review and improve interpretive sign design and content	SPREP	Consultant (Schupp) SPREP (Anderson, Deo, Jungblut, Iacovino)
30 October 2013	Landowner review and approval of signage and finalized implementation plan; Advance request for seedlings from nursery	Tafatafa	Consultant (Schupp) Landowner (Peterson) MNRE-Forestry (Tuita'alili)
19 November 2013	Deliver and plant seedlings, perform baseline monitoring	Tafatafa	Consultant (Schupp) SPREP (Anderson, Jungblut) MNRE (Kwan) Landowner (Peterson)

Table B.2. Purpose and attendance of meetings related to Stevensons Resort (Manase) project site

Date	Purpose of Visit	Location	Attendance
11 August 2012	Evaluate site suitability	Manase	Consultant (Schupp)
5 December 2012	Final site selection	MNRE, Apia	Consultant (Schupp) SPREP (Anderson, Carruthers, Jungblut) MNRE-DEC (Afioga, Kwan)
17 April 2013	Evaluate landowner interest and gather information	Stevenson's Lawyers, Apia	Consultant (Schupp) MNRE-DEC (Kwan) SPREP (Anderson) Landowner (Stevenson)
19 April 2013	Identify appropriate plant species	Vailima Botanical Reserve	Consultant (Schupp) MNRE-Forestry (Foliga)
23 April 2013	Gather information, develop site plan	Manase	Consultant (Schupp) MNRE-DEC (Kwan) MNRE-DMO (Simi) Landowner (Stevenson) General Manager (Tuipoloa Elizabeth Betham)
26 April 2013	Gather and share information	Manase	Consultant (Schupp) Landowner (Stevenson)
11 October 2013	Present Manase suggestions and learn about DMO plans to address Manase erosion	MNRE, Apia	Consultant (Schupp) MNRE-DMO (Nelson) SPREP (Anderson, Carruthers, Jungblut)

Appendix C: Monitoring Protocol and Baseline Data for Vaiula Beach Fales, Tafatafa, Samoa

The following monitoring protocol is designed for simplicity, so that data can be collected by the landowner, a designated officer from the MNRE Division of Forestry in Togitogiga Upolu, or other volunteer with a minimum of effort and supplies. At this time, an MNRE officer, Samantha Kwan, has been designated to maintain the survey and survey data.

Schedule survey date

For the first three years of the project, the coastal features should be monitored at least once per year and preferably every 6 months. Thereafter, one annual survey during the same season each year (for example, every June) should be sufficient. Additional measurements should be recorded following major erosion events to capture storm impacts and typical storm recovery time period.

Check moon phase and tidal cycles for the desired survey month and identify appropriate days for surveys. To capture a representative normal high tide line, measurements should occur on normal tides, that is, not during a full or new moon and not under strong onshore or offshore wind conditions. Surveys should take place during daylight hours within one hour following high tide.

Tidal prediction calendars for South Pacific islands can be accessed on the Australian Bureau of Meteorology website:
http://www.bom.gov.au/oceanography/projects/spslcmp/tidecalendars.shtml#samoa

Confirm access with landowner

Although the site has public access for use as beach fales, the landowner or his family should be contacted to request access for each monitoring survey.

As of January 2013, Muliaga David Peterson could be reached on his mobile phone at 7792754.

Gather materials

Two field technicians will need the following items to accomplish the survey:

- Pen and monitoring chart
- 50 meter metric measuring tape
- Emery rods (to measure height)
- Compass
- Appendix A (coastal vegetation guide), or other botanical reference to aid in seedling identification
- Map of transect locations
- Map of seedling locations

Collect data

Shoreline Features

There are seven established transect lines (Figure C.1): six transects across the restoration site, and a seventh transect on an adjacent property to the west of the site where beachrock has been removed from the nearshore area and no vegetation has been planted. Each transect starts at a fixed reference point (e.g. utility pole, corner of fale foundation) and extends to the high tide line (Table C.1). All lines are parallel and have a bearing of 175.5° from magnetic North, which is what the compass measures (this is equivalent to 187° from true North, which is used on most maps).

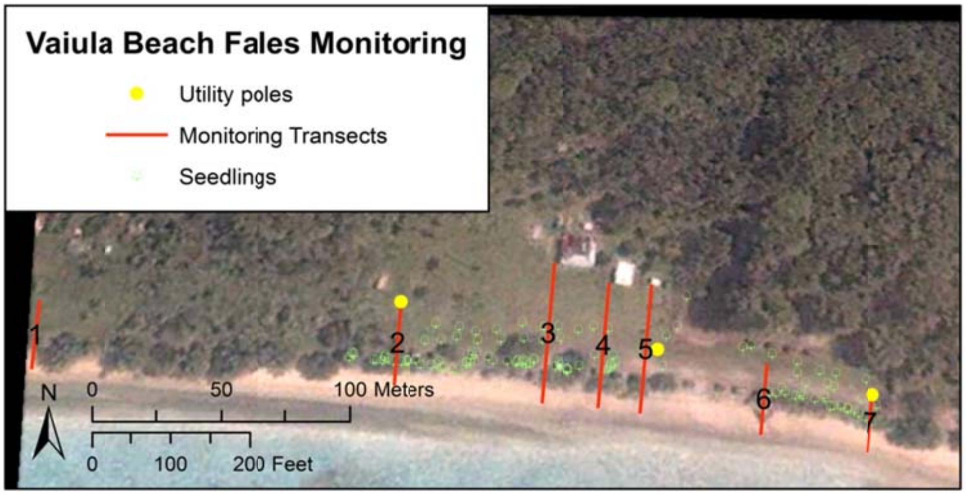

Figure C.1. Numbered monitoring transects and reference points from which to measure the distance to shoreline features. Photo of conditions on 27 January 2010 from Google Earth (2013).

Table C.1. Description of landward starting point for each of seven monitoring transects.

Transect Number	Reference (Starting) Point
1	Adjacent property to west; southwest corner of toilet block
2	Western edge of property - utility pole near two-story bar fale
3	Main residential fale - southwest corner of house walls (not concrete pad)
4	Bar/restaurant fale - southwest corner of concrete pad
5	Mens toilet block - southwest corner of concrete pad
6	Eastern side of river - toilet block- southwest corner of concrete pad
7	Eastern edge of property- Eastern side of river - utility pole

Changes in distances and heights relative to the established reference start point will be measured along each transect line at the edge of vegetation, the top of eroding bank (often concurrent), the bottom of the bank, the high tide line, and other features of interest (e.g., a noticeable change in beach slope between the base of the bank and the high tide line) (Figure C.2). Appearance of these features may vary; examples are provided in Figure C.3. Use or reproduce the table included in this protocol to record these measurements for each transect line (Table C.2).

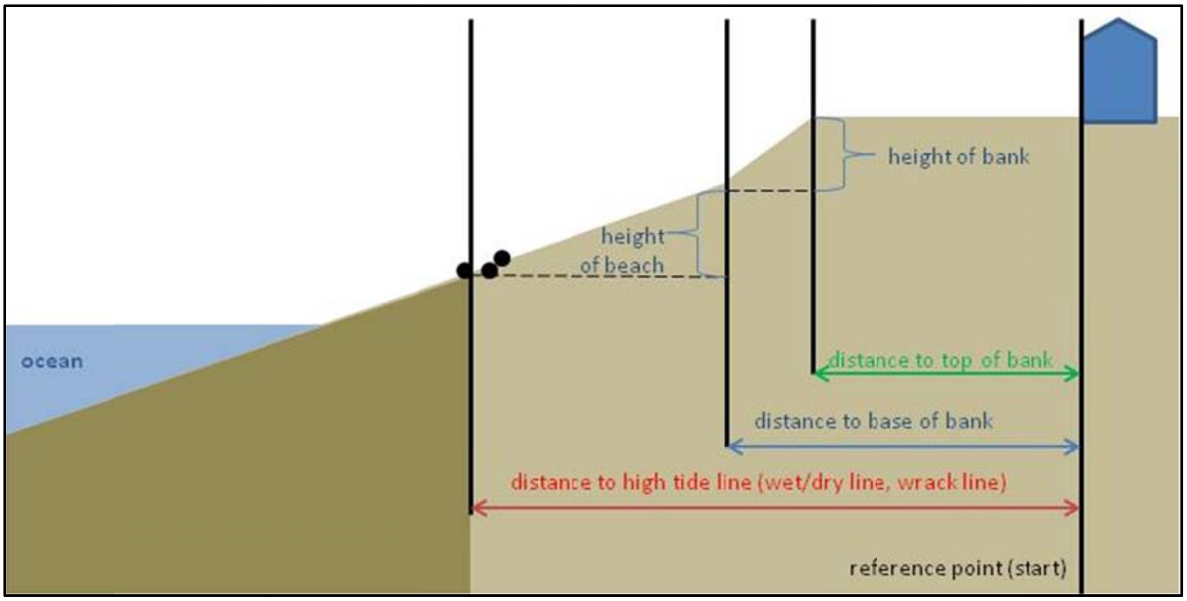

Figure C.2. It is important to monitor changes in height and distances between the reference start point and each shoreline feature.

Figure C.3. Several characteristics assist in the identification of shoreline features including the top, base, and height of the eroding bank, and the normal high tide line as a proxy for shoreline position.

Table C.2. Table for use in recording distance and change in height between the reference (start) point and various shoreline features. Shoreline features may vary between transects (for example, edge of vegetation may or may not be concurrent with the top of the bank). Additional features or points may be inserted as necessary or desired (e.g., a noticeable change in beach slope between the base of the bank and the high tide line).

Transect Number	**Shoreline Feature**	**Distance from last measured point (m)**	**Change in Height from last measured point (m)**	**Total Distance from Start Point (m)**	**Total Height Difference from Start Point (m)**
1	Start point	0	0	0	0
1	Edge of vegetation				
1	Top of bank				
1	Base of bank				
1	Change in beach slope				
1	Other feature				
1	High tide line				
1					

Starting from the reference point, use the compass to find the appropriate bearing (175.5° from magnetic North) and choose a visual marker along that line (for example, a tree, or a field assistant waved into place). Extend the measuring tape from the start point to the visual marker to establish the line location and direction (Figure C.4). Measure the distance (in decimal meters) to the first shoreline feature (edge of vegetation, which is likely also the top of the eroding bank) and in Table C.2, write this distance in the column labeled "Distance from last measured point (m)". For this entry, the total distance from the reference (start) point is equal to the distance from the last measured point (which was also the reference point); record this in the appropriate column. Next, measure the distance between the first shoreline feature and the second shoreline feature (e.g., between the edge of vegetation and the top of the eroding bank; if those two features were in the same location, then measure the distance between the edge/top and the bottom of the eroding bank). Record this distance (in decimal meters) in the column labeled "Distance from last measured point (m)". Add this distance to the preceding entry in the column labeled "Total distance from start point (m)" and record the total in that column.

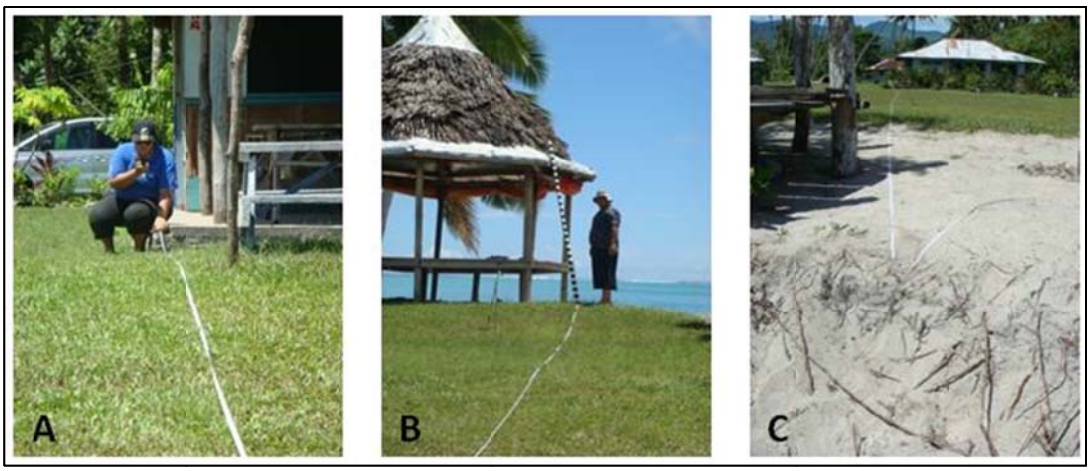

Figure C.4. A) Use the compass to find the appropriate bearing from the reference (start) point (here, the southwestern corner of the fale foundation). B) Lay the measuring tape along the transect line. C) The first shoreline feature to measure is the edge of vegetation (background), which is sometimes but not always concurrent another shoreline feature, the top of the eroding bank (foreground).

After measuring the distance between a pair of features, measure the change in height between those same two points on the features. Use the pair of Emery rods to measure the change in height between two points. The Emery rods, named after the scientist who designed this simple survey technique (Emery 1961), are painted with stripes that are each 0.05 m wide and are labeled with measurements starting from the bottom.

One field observer holds an Emery rod with the bottom placed on a shoreline feature (e.g., top of bank), ensuring the rod is vertical. The second field observer holds the other Emery rod with the bottom placed on the next shoreline feature to be measured (e.g., bottom of bank), directly on the point used for the distance measurement, and also ensuring that the rod is vertical.

The observer holding the landward rod aligns his eye with three points simultaneously: the horizon, a stripe on the rod he is holding, and a stripe on the seaward rod (Figure C.5). The line of sight is assumed to be level. He then notes the height of the stripe above the bottom of his landward rod (as marked on the rod), and notes where the horizon appears to cross the seaward rod (the person holding the seaward rod will need to move his finger along the rod until the landward observer says that it is in the right place). The seaward observer reads out the height of that point above the ground on the seaward rod). The height difference between the identified points on the landward and seaward rods is therefore the change in height betweeen the two features. That height difference should be recorded in Table C.2 in the column labeled "Change in Height from last measured point (m)".

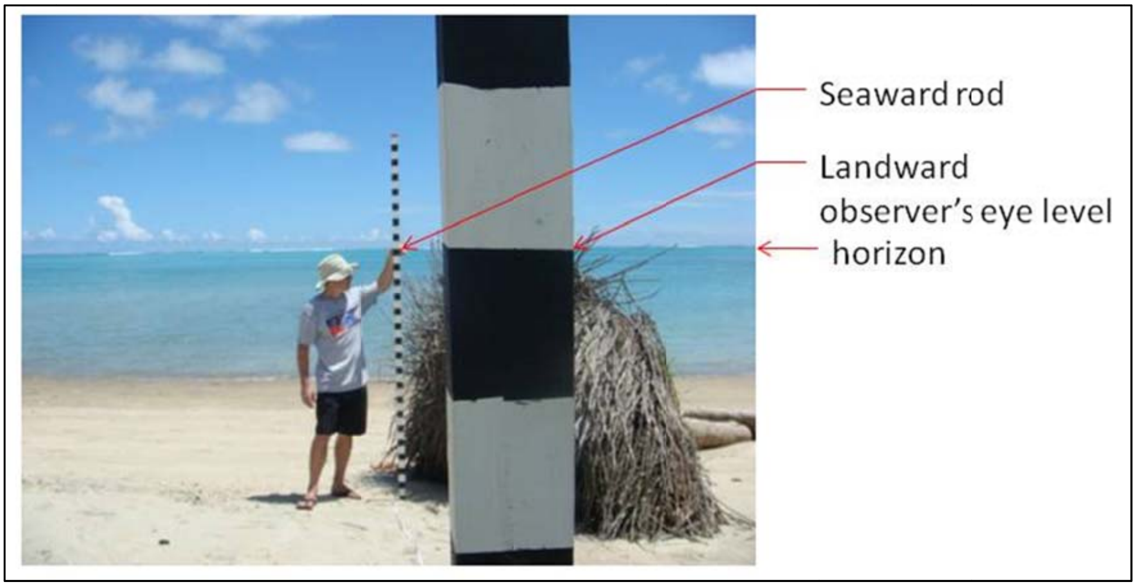

Figure C.5. The landward observer lines up three points: the horizon, the point where the horizon appears to cross the landward rod, and the point where the horizon appears to cross the seaward rod (indicated by seaward observer's hand position). The difference between the height measurement on each rod is equal to the change in height between the two shoreline features.

The distances and heights between each subsequent shoreline feature of interest should be measured and recorded in the same way. If possible, update the GIS shapefiles, tables, and associated metadata with new observations and dates, and create figures as needed to illustrate the shoreline changes and to detect trends. The baseline measurements recorded in November 2013 are provided in Table C.4 and provide examples of how to complete the table and the magnitude of values expected at each transect.

Seedling survival

Inspect the 119 seedling locations and note the date and condition (e.g., live, dead, or missing) of each seedling on the monitoring chart (Table C.3) in order to evaluate success of the plantings during future project assessments. If possible, update the GIS shapefiles, tables, and associated metadata with new observations and dates. Individual seedlings should be replaced in-kind if dead; contact Peteli Pese at the MNRE Division of Forestry at Togitogiga for assistance.

As of January 2013, the MNRE nursery could be contacted via mobile phones for Peteli Pese (7243383) and Loto Tuita'alili (7204115).

Landowner satisfaction

The landowner's satisfaction with the project is crucial to its continued existence and success. Landowner satisfaction, including willingness to maintain vegetation, should also be evaluated at least annually. Note any comments or requests related to this project, and follow-up with appropriate audiences.

Duplicate data

It is recommended that the data collected be copied into a notebook to be kept with the landowner.

Archive data at MNRE

The designated MNRE officer should maintain a record of these measurements in accordance with MNRE data archiving procedures.

Baseline Monitoring Results

On 19 November 2013, 119 seedlings and cuttings representing four species were planted at the site (Figures C.5 and C.6). Fetau and milo were planted landward of the fales on both sides of the river, at 8 m spacing in two offset rows; they were also planted along the river banks. To'ito'i and fue moa were planted along the eroding bank to reduce erosion. To'ito'i were also planted between alternating fales to reduce foot traffic across the eroding bank. The location and species of each seedling were recorded (Table C.3) using a handheld GPS, and later converted to a GIS shapefile. Fetau and milo were marked with sticks to increase visibility and thereby reduce the risk of being damaged by vehicles.

Baseline data were collected along the seven transects on 19 November 2013 according to the methods described in this Appendix. Results are recorded in Table C.5 and illustrated in Figure C.7. During the baseline data collection on 19 November 2013, data indicate that beach slope and beach width vary alongshore, with a very steep and narrow beach along the eastern end of the property.

Figure C.5. Three rows of seedlings were planted including A) fetau and milo landward of the fales, and B) to'ito'I and fue moa between and seaward of the fales. C) Seedlings landward of the fales were marked to increase visibility and thereby deter damage by vehicles. D) Two rows of marked seedlings are visible landward of the fales.

Figure C.6. Location of each seedling with ID numbers for correlation to Table C.3. Current shoreline position is landward of location in this graphic. Photo of conditions on 27 January 2010 from Google Earth (2013).

Table C.3. ID number and species of the 119 seedlings and cuttings, corresponding to locations marked in Figure C.6.

ID	Species name	Samoan name	Notes
0	*Calophyllum inophyllum*	fetau	
1	*Thespesia populnea*	milo	
2	*Calophyllum inophyllum*	fetau	
3	*Thespesia populnea*	milo	
4	*Calophyllum inophyllum*	fetau	
5	*Thespesia populnea*	milo	
6	*Calophyllum inophyllum*	fetau	
7	*Thespesia populnea*	milo	
8	*Calophyllum inophyllum*	fetau	
9	*Thespesia populnea*	milo	
10	*Thespesia populnea*	milo	
11	*Calophyllum inophyllum*	fetau	
12	*Thespesia populnea*	milo	
13	*Calophyllum inophyllum*	fetau	
14	*Thespesia populnea*	milo	
15	unknown	unknown	Unknown species
16	*Thespesia populnea*	milo	
17	*Calophyllum inophyllum*	fetau	
18	*Thespesia populnea*	milo	
19	*Calophyllum inophyllum*	fetau	
20	*Ipomoema pes-caprae*	fue moa	
21	*Scaevola taccada*	to'ito'i	
22	*Ipomoema pes-caprae*	fue moa	
23	*Ipomoema pes-caprae*	fue moa	
24	*Ipomoema pes-caprae*	fue moa	
25	*Ipomoema pes-caprae*	fue moa	
26	*Ipomoema pes-caprae*	fue moa	
27	*Ipomoema pes-caprae*	fue moa	
28	*Ipomoema pes-caprae*	fue moa	
29	*Ipomoema pes-caprae*	fue moa	
30	*Scaevola taccada*	to'ito'i	
31	*Ipomoema pes-caprae*	fue moa	
32	*Ipomoema pes-caprae*	fue moa	
33	*Scaevola taccada*	to'ito'i	
34	*Scaevola taccada*	to'ito'i	
35	*Ipomoema pes-caprae*	fue moa	
36	*Ipomoema pes-caprae*	fue moa	Two adjacent plants
37	*Ipomoema pes-caprae*	fue moa	

38	*Ipomoema pes-caprae*	fue moa	
39	*Ipomoema pes-caprae*	fue moa	
40	*Scaevola taccada*	to'ito'i	
41	*Scaevola taccada*	to'ito'i	
42	*Scaevola taccada*	to'ito'i	
43	*Ipomoema pes-caprae*	fue moa	
44	*Ipomoema pes-caprae*	fue moa	
45	*Ipomoema pes-caprae*	fue moa	
46	*Ipomoema pes-caprae*	fue moa	
47	*Ipomoema pes-caprae*	fue moa	
48	*Ipomoema pes-caprae*	fue moa	
49	*Scaevola taccada*	to'ito'i	
50	*Scaevola taccada*	to'ito'i	
51	*Scaevola taccada*	to'ito'i	
52	*Ipomoema pes-caprae*	fue moa	
53	*Ipomoema pes-caprae*	fue moa	
54	*Ipomoema pes-caprae*	fue moa	Bottom of bank
55	*Ipomoema pes-caprae*	fue moa	Top of bank
56	*Ipomoema pes-caprae*	fue moa	Top of bank
57	*Scaevola taccada*	to'ito'i	
58	*Scaevola taccada*	to'ito'i	
59	*Scaevola taccada*	to'ito'i	
60	*Ipomoema pes-caprae*	fue moa	Top of bank
61	*Ipomoema pes-caprae*	fue moa	Top of bank
62	*Ipomoema pes-caprae*	fue moa	Top of bank
63	*Scaevola taccada*	to'ito'i	
64	*Scaevola taccada*	to'ito'i	
65	*Ipomoema pes-caprae*	fue moa	
66	*Scaevola taccada*	to'ito'i	
67	*Ipomoema pes-caprae*	fue moa	
68	*Ipomoema pes-caprae*	fue moa	
69	*Ipomoema pes-caprae*	fue moa	
70	*Scaevola taccada*	to'ito'i	
71	*Ipomoema pes-caprae*	fue moa	
72	*Scaevola taccada*	to'ito'i	
73	*Scaevola taccada*	to'ito'i	
74	*Ipomoema pes-caprae*	fue moa	
75	*Scaevola taccada*	to'ito'i	
76	*Ipomoema pes-caprae*	fue moa	Two adjacent plants: one at top of bank and one at bottom
77	*Scaevola taccada*	to'ito'i	
78	*Scaevola taccada*	to'ito'i	

79	*Scaevola taccada*	to'ito'i	
80	*Scaevola taccada*	to'ito'i	
81	*Thespesia populnea*	milo	Along river bank
82	*Thespesia populnea*	milo	Along river bank
83	*Calophyllum inophyllum*	fetau	Along river bank
84	*Calophyllum inophyllum*	fetau	Along river bank near river mouth
85	*Calophyllum inophyllum*	fetau	
86	*Thespesia populnea*	milo	
87	*Calophyllum inophyllum*	fetau	
88	*Calophyllum inophyllum*	fetau	
89	*Calophyllum inophyllum*	fetau	
90	*Calophyllum inophyllum*	fetau	
91	*Calophyllum inophyllum*	fetau	
92	*Calophyllum inophyllum*	fetau	
93	*Thespesia populnea*	milo	
94	*Thespesia populnea*	milo	
95	*Calophyllum inophyllum*	fetau	
96	*Thespesia populnea*	milo	
97	*Calophyllum inophyllum*	fetau	
98	*Scaevola taccada*	to'ito'i	
99	*Scaevola taccada*	to'ito'i	
100	*Calophyllum inophyllum*	fetau	
101	*Scaevola taccada*	to'ito'i	
102	*Scaevola taccada*	to'ito'i	
103	*Thespesia populnea*	milo	
104	*Scaevola taccada*	to'ito'i	
105	*Scaevola taccada*	to'ito'i	
106	*Scaevola taccada*	to'ito'i	
107	*Calophyllum inophyllum*	fetau	
108	*Calophyllum inophyllum*	fetau	Fetau planted 26 March 2013. Yellowing on 19 Nov 2013
109	*Scaevola taccada*	to'ito'i	
110	*Calophyllum inophyllum*	fetau	Fetau planted 26 March 2013
111	*Scaevola taccada*	to'ito'i	
112	*Thespesia populnea*	milo	
113	*Scaevola taccada*	to'ito'i	
114	*Scaevola taccada*	to'ito'i	
115	*Thespesia populnea*	milo	
116	*Scaevola taccada*	to'ito'i	

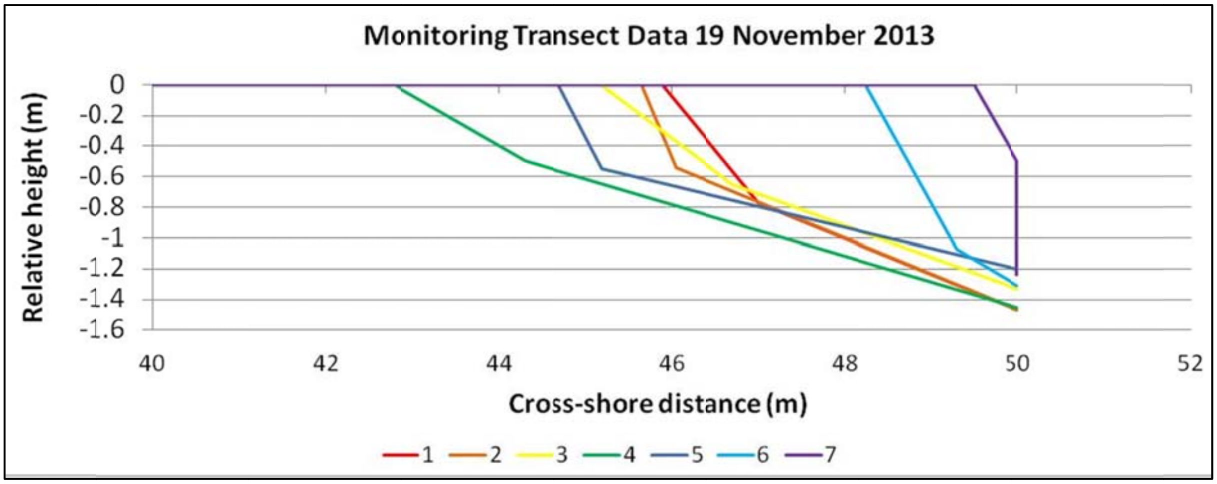

Figure C.7. Comparison of baseline conditions along 7 monitoring transects, shifted in a horizontal direction to overlay the high water line locations for comparison.

Table C.4. Baseline data collected on 19 November 2013 for shoreline features along 7 monitoring transects.

Transect	Shoreline feature	Change in Distance (m)	Change in height (m)	Total Distance (m)	Total Height Difference (m)	Notes
1	Starting point	0	0	0	0	Adjacent property to west; southwest corner of toilet block
	Top of bank	38.2	0	38.2	0	Eroding sand
	Base of bank	1.1	-0.77	39.3	-0.77	
	High water line	3	-0.7	42.3	-1.47	

Transect	Shoreline feature	Change in Distance (m)	Change in height (m)	Total Distance (m)	Total Height Difference (m)	Notes
2	Starting point	0	0	0	0	Western edge of property - utility pole near two-story bar fale
	Top of bank	24.8	0	24.8	0	
	Base of bank	0.4	-0.54	25.2	-0.54	
	High water line	3.95	-0.93	29.15	-1.47	

Transect	Shoreline feature	Change in Distance (m)	Change in height (m)	Total Distance (m)	Total Height Difference (m)	Notes
3	Starting point	0	0	0	0	Main fale - southwest corner of house walls (not concrete pad)
	Edge of vegetation	40.9	0	40.9	0	Edge of grass
	Top of bank	3.6	0	44.5	0	Eroding sand
	Base of bank	1.5	-0.65	46	-0.65	
	High water line	3.3	-0.68	49.3	-1.33	

Transect	Shoreline feature	Change in Distance (m)	Change in height (m)	Total Distance (m)	Total Height Difference (m)	Notes
4	Starting point	0	0	0	0	Bar/restaurant area - southwest corner of concrete pad
	Top of bank	35.14	0	35.14	0	Eroding sand
	Base of bank	1.5	-0.5	36.64	-0.5	
	High water line	5.7	-0.95	42.34	-1.45	

Transect	Shoreline feature	Change in Distance (m)	Change in height (m)	Total Distance (m)	Total Height Difference (m)	Notes
5	Starting point	0	0	0	0	Mens toilet block - southwest corner of concrete pad
	Top of bank	36.7	0	36.7	0	
	Base of bank	0.5	-0.55	37.2	-0.55	
	High water line	4.8	-0.65	42	-1.2	

Transect	Shoreline feature	Change in Distance	Change in height (m)	Total Distance (m)	Total Height Difference (m)	Notes

		(m)				
6	Starting point	0	0	0	0	East side of river - toilet block- southwest corner of concrete pad
	Top of bank	26.4	0	26.4	0	steep, loose sand and coral rubble
	Base of bank	1.05	-1.07	27.45	-1.07	
	High water line	0.7	-0.24	28.15	-1.31	

Transect	Shoreline feature	Change in Distance (m)	Change in height (m)	Total Distance (m)	Total Height Difference (m)	Notes
7	Starting point	0	0	0	0	Eastern edge of property- East side of river - utility pole
	Top of bank	14.2	0	14.2	0	steep, loose sand and coral rubble
	Base of bank	0.5	-0.5	14.7	-0.5	
	High water line	0	-0.74	14.7	-1.24	coconut root ball; vertical bank

Literature Cited

Emery, K.O. 1961. A simple method of measuring beach profiles. Limnology and Oceanography (6): 90-93.

Appendix D: Monitoring Protocol for Stevensons Resort, Manase, Samoa

The following monitoring protocol is designed for simplicity, so that data can be collected by the landowner, the designated MNRE Division of Forestry (Asau) officer, or other volunteer with a minimum of effort and supplies.

Schedule survey date

For the first three years of the project, the coastal features should be monitored at least once per year and preferably every 6 months. Thereafter, one annual survey during the same season each year (for example, every June) should be sufficient. Additional measurements should be recorded following major erosion events to capture storm impacts and typical storm recovery time period.

Check moon phase and tidal cycles for the desired survey month and identify appropriate days for surveys. To capture a representative normal high tide line, measurements should occur on normal tides, that is, not during a full or new moon and not under strong onshore or offshore wind conditions. Surveys should take place during daylight hours within one hour following high tide.

Tidal prediction calendars for South Pacific islands can be accessed on the Australian Bureau of Meteorology website:
http://www.bom.gov.au/oceanography/projects/spslcmp/tidecalendars.shtml#samoa

Confirm access with landowner

Although the site has public access, the landowner or his family should be contacted to request access for each monitoring survey. The number for Stevensons Resort in Savai'i is 58219, and the landowner Trevor Stevenson can be contacted at his Apia office at 21751.

Gather materials

Two field technicians will need the following items to accomplish the survey:

- Pen and monitoring chart
- 50 meter metric measuring tape
- Emery rods (to measure height)
- Compass
- Appendix A (coastal vegetation guide), or other botanical reference to aid in seedling identification
- Map of transect locations
- Map of seedling locations

Collect data

Shoreline Features

There are seven established transect lines (Figure D.1). Each transect starts at a fixed reference point (e.g. utility pole, corner of fale foundation) and extends to the high tide line (Table D.1). All lines are parallel and have a bearing of 175.5° from magnetic North, which is what the compass measures (this is equivalent to 187° from true North, which is used on most maps). Location of the high tide line, the edge of vegetation (top of eroding bank), and the bottom of the eroding bank will be measured as a distance from fixed reference points along established transect lines (Figure D.1) with the locations described in Table D.1. Use or reproduce the table included in this protocol to record these distances for every transect line (Table D.2). (Note: Transect 3 will have to be determined during the first baseline data collection visit, due to construction of a beach bar after the reconnaissance visit and transect location selection; the planned transect originated from the large tree in the center of the grassy lawn, but is believed to have been removed for construction.)

Use the compass to ensure that the measurements are taken along the appropriate bearing. All lines are parallel and have a bearing of 364° from true North (352.5° from magnetic North). Transects are set approximately 30-40 m apart, but exact distances vary to allow lines to extend from fixed reference points (tree, corners of structure foundations) where possible.

Changes in distances and heights relative to the established reference start point will be measured along each transect line at the edge of vegetation, the top of eroding bank (often concurrent), the bottom of the bank, the high tide line, and other features of interest (e.g., a noticeable change in beach slope between the base of the bank and the high tide line) (Figure D.2). Appearance of these features may vary; examples are provided in Figure D.3. Use or reproduce the table included in this protocol to record these measurements for each transect line (Table D.2).

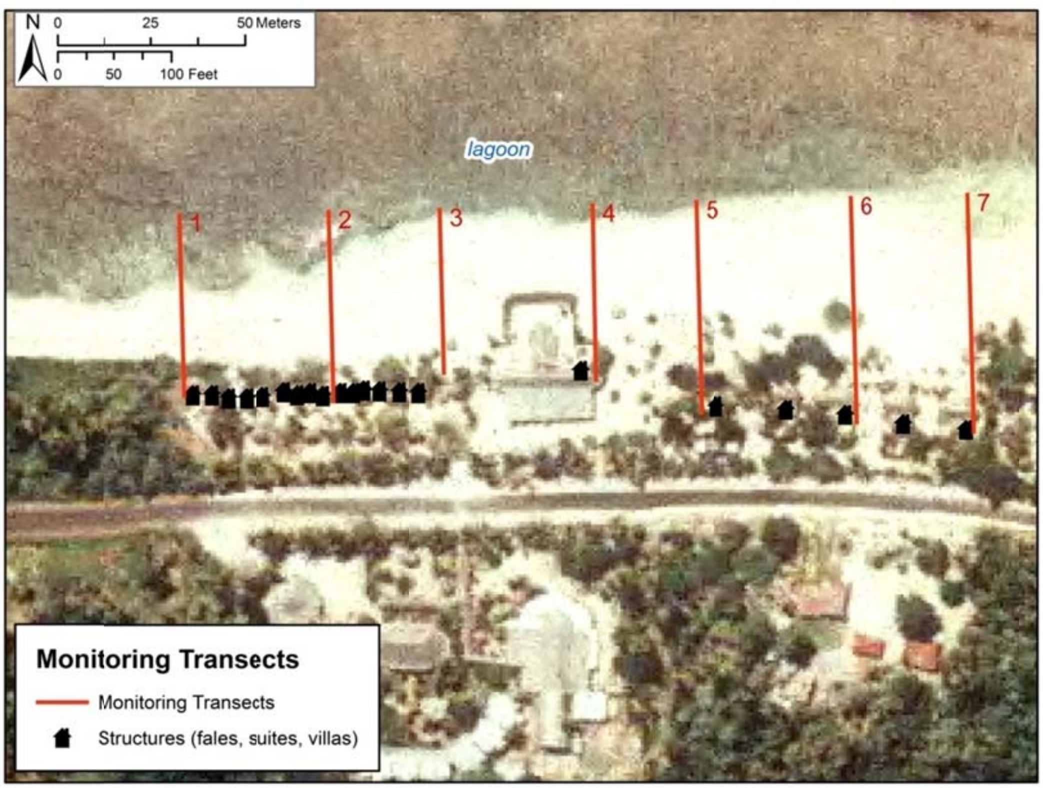

Figure D.1. Numbered monitoring transects and reference points from which to measure the distance to shoreline features. The proposed location of transect 3 may need to be modified before baseline data is collected due to recent construction in this area. Photo of ground conditions in 2004 courtesy of SPREP.

Table D.1. Description of landward starting point for each of seven monitoring transects.

Transect Number	Reference Point
1	Western seaward corner of westernmost Eurofale
2	Western seaward corner of middle Eurofale
3	Large tree on grassy lawn, or TBD piling of beach bar built after our reconnaissance visit
4	Eastern seaward corner of suite foundation
5	Western seaward corner of foundation on westernmost villa
6	Eastern seaward corner of foundation of middle villa
7	Eastern seaward corner of foundation of easternmost villa

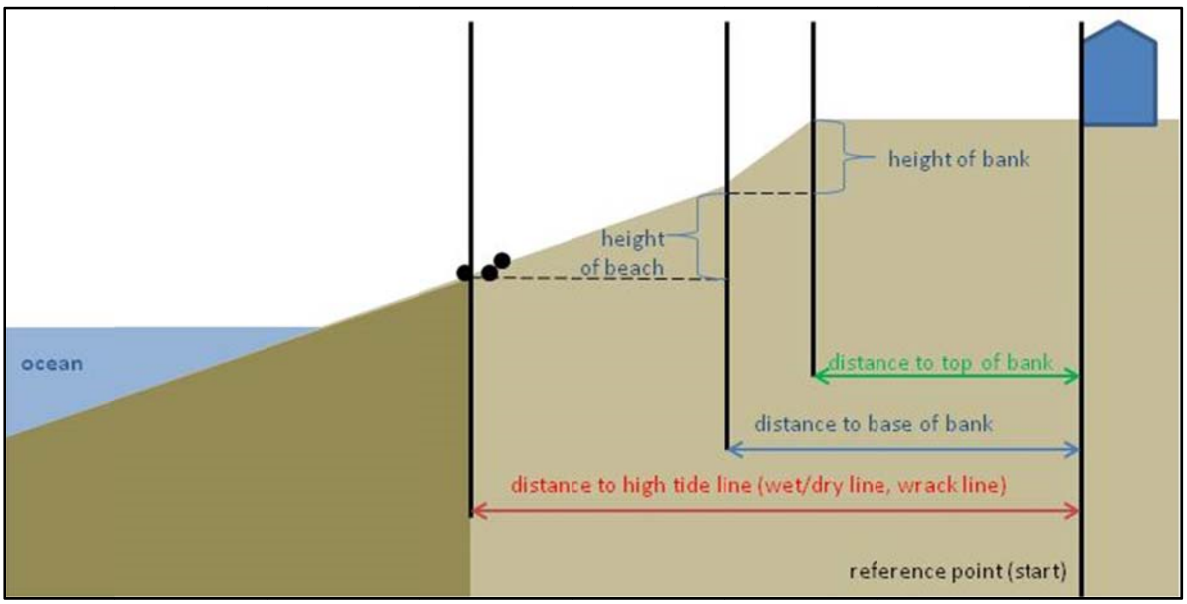

Figure D.2. It is important to monitor changes in height and distances between the reference start point and each shoreline feature.

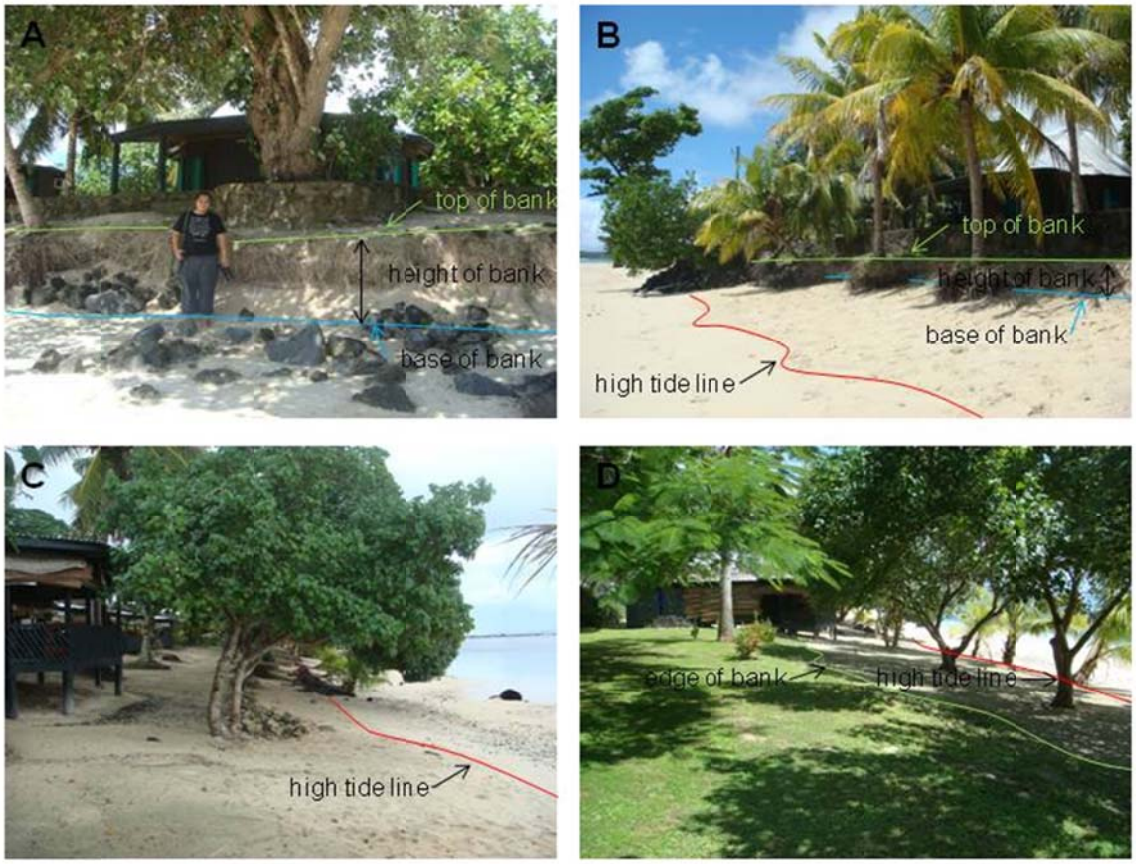

Figure D.3. Several characteristics assist in the identification of shoreline features including the top, base, and height of the eroding bank (where applicable), and the normal high tide line as a proxy for shoreline position.

Transect Number	Shoreline Feature	Distance from last measured point (m)	Change in Height from last measured point (m)	Total Distance from Start Point (m)	Total Height Difference from Start Point (m)
1	Start point	0	0	0	0
1	Edge of vegetation				
1	Top of bank				
1	Base of bank				
1	Change in beach slope				
1	Other feature				
1	High tide line				
1					

Starting from the reference point, use the compass to find the appropriate bearing (175.5° from magnetic North) and choose a visual marker along that line (for example, a tree, or a field assistant waved into place). Extend the measuring tape from the start point to the visual marker to establish the line location and direction (Figure D.4). Measure the distance (in decimal meters) to the first shoreline feature (edge of vegetation, which is likely also the top of the eroding bank) and in Table D.2, write this distance in the column labeled "Distance from last measured point (m)". For this entry, the total distance from the reference (start) point is equal to the distance from the last measured point (which was also the reference point); record this in the appropriate column. Next, measure the distance between the first shoreline feature and the second shoreline feature (e.g., between the edge of vegetation and the top of the eroding bank; if those two features were in the same location, then measure the distance between the edge/top and the bottom of the eroding bank). Record this distance (in decimal meters) in the column labeled "Distance from last measured point (m)". Add this distance to the preceding entry in the column labeled "Total distance from start point (m)" and record the total in that column.

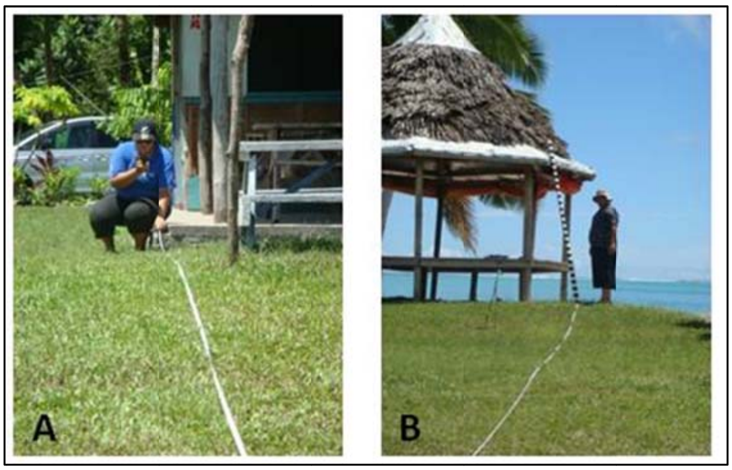

Figure D.4. A) Use the compass to find the appropriate bearing from the reference (start) point (here, the southwestern corner of the fale foundation). B) Lay the measuring tape along the transect line.

After measuring the distance between a pair of features, measure the change in height between those same two points on the features. Use the pair of Emery rods to measure the change in height between two points. The Emery rods, named after the scientist who designed this simple survey technique (Emery 1961), are painted with stripes that are each 0.05 m wide and are labeled with measurements starting from the bottom.

One field observer holds an Emery rod with the bottom placed on a shoreline feature (e.g., top of bank), ensuring the rod is vertical. The second field observer holds the other Emery rod with the bottom placed on the next shoreline feature to be measured (e.g., bottom of bank), directly on the point used for the distance measurement, and also ensuring that the rod is vertical.

The observer holding the landward rod aligns his eye with three points simultaneously: the horizon, a stripe on the rod he is holding, and a stripe on the seaward rod (Figure D.5). The line of sight is assumed to be level. He then notes the height of the stripe above the bottom of his landward rod (as marked on the rod), and notes where the horizon appears to cross the seaward rod (the person holding the seaward rod will need to move his finger along the rod until the landward observer says that it is in the right place). The seaward observer reads out the height of that point above the ground on the seaward rod). The height difference between the identified points on the landward and seaward rods is therefore the change in height between the two features. That height difference should be recorded in Table D.2 in the column labeled "Change in Height from last measured point (m)".

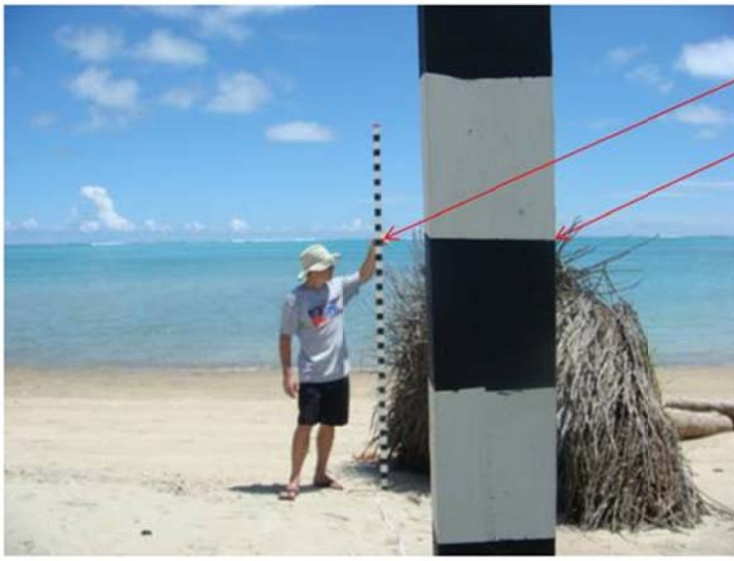

Figure D.5. The landward observer lines up three points: the horizon, the point where the horizon appears to cross the landward rod, and the point where the horizon appears to cross the seaward rod (indicated by seaward observer's hand position). The difference between the height measurement on each rod is equal to the change in height between the two shoreline features.

The distances and heights between each subsequent shoreline feature of interest should be measured and recorded in the same way. If possible, update the GIS shapefiles, tables, and associated metadata with new observations and dates, and create figures as needed to illustrate the shoreline changes and to detect trends. The baseline measurements recorded for the Tafatafa Vaiula Beach Fales site (Appendix C, Table C.4) provide examples of how to complete the table.

Seedling survival

When seedlings are planted, their locations should be mapped using a GPS, and data should be archived. A map and table of these seedling species and locations should be produced for use in the field; the materials produced for the Tafatafa Vaiula Beach Fales site (Appendix C) provide examples.

Inspect the seedlings and note any dead or dying plants on the monitoring chart in order to evaluate success of the plantings during future project assessments. Individual seedlings should be replaced in-kind if dead; contact So'oalo Tito Alatimu at the MNRE Division of Forestry at Asau, Savai'i for assistance.

Landowner satisfaction

The landowner's satisfaction with the project is crucial to its continued existence and success. Landowner satisfaction, including willingness to maintain vegetation, should also be evaluated at least annually. Note any comments or requests related to this project, and follow-up with appropriate audiences.

Duplicate data

It is recommended that the data collected be copied into a notebook to be kept with the landowner.

Archive data at MNRE

The designated MNRE officer should maintain a record of these measurements in accordance with MNRE data archiving procedures.