Pacific Region
Infrastructure Facility

Guidance for Managing Coastal Protection Works in Pacific Island Countries

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Abbreviations

cm	Centimeters
ENSO	El Niño Southern Oscillation
GNSS	Global navigation satellite system
GPS	Global positioning system
H	Critical water depth
Hs	Significant wave height
IG	Infragravity (waves)
LiDAR	Light detection and ranging
m	Meters
mb	Millibar (unit of atmospheric pressure)
mm	Millimeters
NbS	Nature-based solutions
PIC	Pacific island country
RTK	Real-time kinematic
SSP	Shared Socioeconomic Pathway
UAV	Unmanned aerial vehicle
WACOP	Changing Waves and Coasts in the Pacific (project)

Glossary

Adaptation	The alteration or transformation of coastal-protection works to meet or improve performance where the environmental conditions have changed or are expected to change (e.g., because of climate change).
Armor	Large rock or concrete units placed on the outside of a revetment or breakwater to protect the filter layers.
Asset	An item or entity that has potential or actual value to an organization.
Asset management	Activities and practices of an organization to maintain and manage an asset throughout its life cycle.
Backshore	Area behind a beach.
Breakwater	A structure extending into the sea or lagoon with armoring on both sides, generally intended to modify waves, currents, or sediment-transport processes.
Coastal protection works	Works undertaken to protect communities or assets from coastal hazards.
Condition	The physical state of a structure, indicating how close that structure is to being as-built or like new.
Crest	The upper portion or top of a structure or of a beach.
Design event	The event that a structure has been designed and built to withstand or perform under.

Design life	The intended period during which a structure is intended to perform its function (with appropriate management).
Element	Individual component of a coastal protection structure.
Erosion (coastal)	The loss of sediments due to coastal processes, generally resulting in a receding shoreline.
Foreshore	The area of the coast that emerges between low tide and high tide.
Geotextile	Synthetic, permeable fabrics primarily intended to retain land in coastal protection works.
Groyne	A structure extending offshore from a beach, intended to trap sediment.
Inundation (coastal)	Flooding of the land by coastal processes, including tides, storm surges, waves, and rises in the sea level (may be permanent, including changes in the mean sea levels and tides; static, but episodic, including storm surges and wave setups; or dynamic, including wave run-ups and overtopping).
Maintenance	Activities that are planned and undertaken to prevent the damage or degradation of assets.
Nature-based solutions	Solutions intended to protect the shoreline from coastal hazards by replicating natural processes and/or by maintaining a healthy ecosystem.
Overtopping	Instances when waves run up above the elevation of a beach or crest of a structure and flood the backshore.
Pacific island countries	Island countries located in the Pacific Ocean.
Performance	The ability of works to achieve their intended function, or "desired service levels."
Reinforcing	The insertion of steel or other fibers into concrete to improve its strength.
Repair	Activities undertaken in response to damage of one or more elements of an asset to prevent further function loss or failure.
Revetment	Generally sloping and semipermeable structure that protects land from erosion and may reduce wave overtopping by dissipating energy.
Risk	A function of both the likelihood of an event and the consequences if it does occur.
Scour	Removal of sediment from the toe of a structure.
Seawall	A vertical or near-vertical, generally impermeable wall that protects land from erosion and may reduce coastal inundation.
Sea level rise	The long-term increase in mean sea levels.
Service level	The intended performance of a structure during a design event.
Toe	The bottom, seaward part of a structure.
UAV	Unmanned aerial vehicle (drone).

Executive Summary

Pacific island countries (PICs) are particularly vulnerable to coastal hazards and climate change, but often lack sufficient resources to support traditional engineering works. As a result, coastal protection works in PICs typically include a wide range of both engineered and "non-engineered" works. Furthermore, softer engineering works, or "nature-based solutions," are increasingly being considered together with or instead of harder works. While all structures require ongoing monitoring and management, including maintenance, repairs, and eventually upgrades or removal, this is particularly true for "non-engineered" structures and structures engineered to a lower design standard.

Asset management is critical for ensuring that works perform as intended and are maintained in good order. It contributes to an asset's longevity and to the likelihood that it will to last for or exceed its intended design life. Asset management includes only replacements or upgrades that do not place the asset at risk (i.e., through failed, unplanned, or unwarranted changes). Several guidelines present methodologies and considerations for undertaking asset management in the PICs, but they do not focus specifically on coastal protection works. Similarly, several local and international publications on monitoring coastal protection works are available, but they do not cover the wide range of engineered and non-engineered structures present in the PICs; nor do they address the limited resources available for monitoring and management. This guideline is intended to provide a simple, yet robust method for monitoring coastal protection works in PICs—including the condition and performance of the works, as well as their effects on the community and environment—and to recommend a decision-making framework for the selection of appropriate responses.

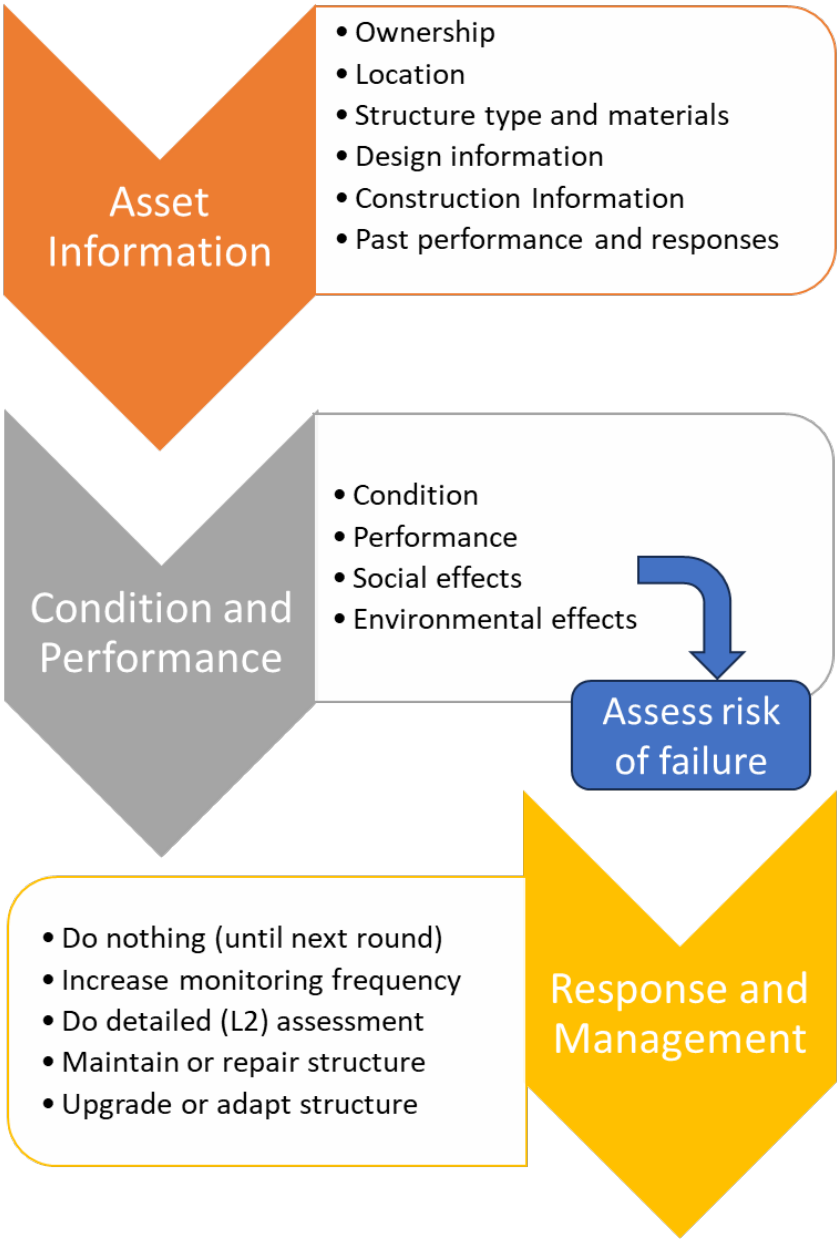
The asset management approach presented here includes three main steps:

- Collating **asset information** such as when the asset was constructed, it's design intent (what it is intended to do), the importance level of the structure, design information (e.g., the intended design event), level of performance, design life, and construction information (e.g., as-built drawings or photographs). This information provides the baseline that subsequent monitoring can be assessed against.
- Performing **asset monitoring**, whereby the physical condition and performance level of a structure is assessed on-site to determine its risk of failure without intervention and whether it is performing its intended function.
- **Managing the structure** with appropriate responses based on the level of risk determined from the condition and performance assessment. The level of risk is a function of both the condition and performance of the structure, as well as the structure's importance level, with interventions for high-importance structures given higher priority than those for lower-importance structures. Responses range from deferring interventions to the next maintenance round; carrying out more detailed assessments; and undertaking maintenance, repairs, upgrades, or adaptation works.

An overarching flow chart illustrating this process is given in the figure below, which follows the general approach set out in *Methodology for Condition Assessment of Public Sector Infrastructure Assets in Pacific Island Countries* (PRIF 2020) for determining an asset's condition and risk of failure, and for determining an investment strategy.

Asset monitoring may be undertaken at the Basic (Level 1) or Detailed (Level 2) levels. A Level 1 assessment is generally undertaken using basic visual observation methods, as well as reported or observed performance metrics; it is conducted by a nonspecialist, though one with training in asset inspection. A Level 2 assessment is generally undertaken by a specialist and may involve the use of specialized equipment, intrusive methods, and more detailed quantification of current and likely future performance. This guidance is specifically targeted at those undertaking Level 1 assessments.

Asset Management Approach



Source: The authors.

This guidance is structured as follows:

- The **guidance document** provides an overview of the management of coastal protection works in Pacific island countries.
- An **operations manual** (Part II) accompanies this guidance document, and sets out the step-by-step approach to assessing individual coastal protection works.
- An **inspection form** (Appendix 1) is used in conjunction with the operations manual to record asset information during inspection.
- An **asset management database** (Appendix 2) is used to store the asset information and inspection data.

1. Introduction

The Pacific island countries (PICs) are island nations spread across the Pacific Ocean (Figure 1). PICs are particularly exposed to coastal hazards, including coastal erosion, inundation, tsunamis, and saltwater intrusion. This exposure is due to their proximity to intense weather systems, tectonic activity, and geological instability. The PICs are particularly vulnerable to these hazards due to their fragile and interrelated ecosystems, socioeconomic conditions, and remote locations. These hazards will be exacerbated by medium- and long-term changes in the climate that will affect the temperatures, winds, waves, and sea levels.

While coastal inundation, erosion, and tsunamis are natural processes, they become hazards when communities, livelihoods, land, and infrastructure (such as roads, water supply and treatment systems, waste management systems, maritime facilities, and aviation networks) are put at risk. While avoidance of hazards is the most robust long-term solution, this approach is often not feasible where land availability is limited, or when infrastructure needs to be located at the coast. In these cases, the land and assets will require protection.

This guideline has been prepared to support asset owners and managers in PICs in their ongoing management of coastal protection works.

Figure 1: Pacific Island Countries

Source: Pacific Region Infrastructure Facility (PRIF).

1.1 Why This Guide is Needed

The PICs are particularly vulnerable to coastal hazards and climate change, but often lack sufficient resources to support traditional engineering works. As a result, coastal protection works in PICs typically include a wide range of both engineered structures, such as rock revetments and concrete seawalls, and “non-engineered” works, such as gabion baskets and sand-cement bag walls. They typically use stacked coral rock, grouted coral rock, and other materials of opportunity.

In 2017 the Pacific Region Infrastructure Facility (PRIF) published *Affordable Coastal Protection in the Pacific Islands* (PRIF 2017a) and *Guidance for Coastal Protection Works in Pacific Island Countries* (PRIF 2017b). *Affordable Coastal Protection* classifies and evaluates various approaches being used to protect shorelines, while *Guidance for Coastal Protection Works* provides advice on the design of protective structures. While all structures require ongoing monitoring and maintenance, this is particularly true for "non-engineered" structures or structures engineered to a lower design standard. Such structures may be necessary if the budget or locally available materials and resources are limited. In such cases, monitoring, maintenance, repair, and timely upgrade and adaptation are critical for preventing damage and ultimate failure of the structures protecting land or assets.

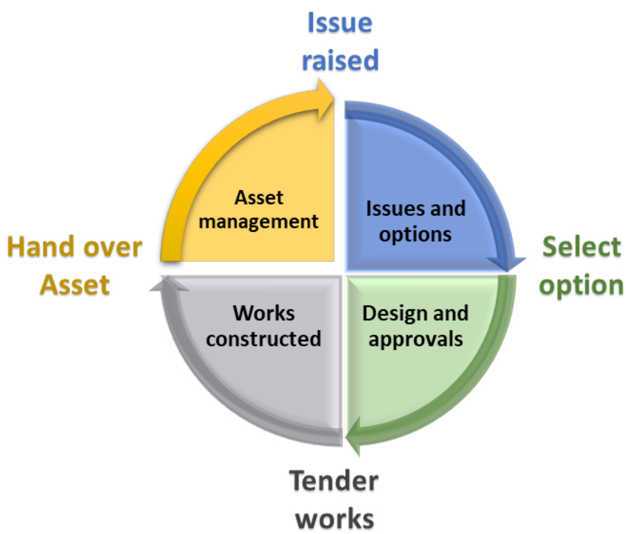
Several guidelines present methodologies and considerations for undertaking asset management in the PICs (World Bank Group 2017; PRIF 2022, section 8), but they do not focus specifically on coastal protection works. Similarly, several local and international publications on the monitoring of coastal protection works are available (e.g., Oliver et al. 1998; CIRIA 2007; PIANC 2013, section 8), but they do not cover the wide range of engineered and non-engineered structures present in the PICs; nor do they address the limited resources available for monitoring and management. This guideline is intended to provide a simple, yet robust method for monitoring coastal protection works in the PICs—including the condition and performance of the works, as well as their effects on the community and environment—and then to recommend a decision-making framework for the selection of appropriate responses.

1.2 Where This Guide Is Applicable

Engineering projects, including those involving coastal protection, generally follow a life cycle (Figure 2), which proceeds as follows:

- An **issue is raised**, such as land being flooded or a road being undermined by erosion. An **issues-and-options** assessment is undertaken to discover the cause of the issue, potential options for mitigating it, and the effectiveness (performance) and potential effects of those options.
- Based on the options presented, a **preferred option** is selected, often based on multi-criteria and/or cost–benefit analysis. **Engineering design** is undertaken and the necessary regulatory, environmental, and social **approvals** are obtained.
- Once the works are approved and funding agreed upon, the **works are constructed** either by a private construction company or by a public works department.
- The asset is then **handed over** to the owner, whose **management of that asset** should ensure that it continues to function as required. This process is often dependent on funding being available for this stage.

Figure 2: Typical Life Cycle of an Engineering Project



Source: The authors.

The asset-management step is critical for ensuring that the assets perform as intended; are maintained in good order, so as to meet or exceed their intended design life; and that they are later replaced or upgraded without risk (e.g., through failure or unplanned replacement).

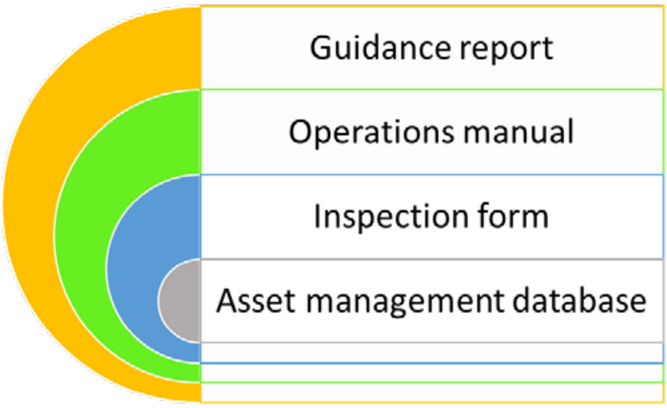
The build-neglect-rebuild cycle has been recognized as a challenge in the PICs for many years (PRIF 2013), and considerable effort has been invested in developing guidance for assessments of the condition of infrastructure assets in PICs (e.g., World Bank Group 2017; PRIF 2022). This guidance document continues this effort, but with a focus specifically on coastal protection works.

1.3 How to Use This Guide

This guidance is structured as follows:

- The **Guidance Document** provides an overview of the management of coastal protection works in Pacific Island Countries.
- An **Operations Manual** (Part II) accompanies this guidance document and sets out the step-by-step approach to assessing individual coastal protection works.
- An **Inspection Form** (Appendix 1) is used in conjunction with the Operations Manual to record asset information during inspection.
- An **Asset Management Database** (Appendix 2), available in electronic form only, is used to store the asset information and inspection data. This should be developed and owned by the asset owner to best suit their business and integrate with other assets they may be managing. At this preliminary stage, a simplified spreadsheet database has been provided which may be expanded upon to suit each users' requirements.

Figure 3: Structure of This Guidance Document



Source: The authors.

2. What Causes Coastal Hazards?

2.1 Introduction

Development in the Pacific Island Countries is often concentrated on the coast, where land is relatively flat and accessible by road and maritime transport. Development close to the coast is also attractive for tourism; access to fishing grounds; and for proximity to ports and harbors to support local fisheries, imports, and exports. Both high islands and low-lying atolls also generally have a coastal ring road encircling the island or atoll close to shore, interconnecting coastal villages and tending to be used as the main thoroughfare. This means that most of the vital infrastructure (roads and utilities) are situated along the coasts, and therefore at risk from coastal hazards, in turn risking the severance of both evacuation and supply routes.

The development of Pacific island shorelines has resulted in an increasing exposure of communities to coastal hazards, including erosion, inundation, and tsunami waves. The impact of coastal hazards is now becoming manifest, with chronic erosion undermining sections of coast, tropical cyclones causing episodic severe inundation, and king tides (i.e., very high spring tides) submerging areas of low-lying atoll islands. The exposure of communities to coastal erosion and inundation hazards is projected to increase with sea level rise caused by global climate change.

2.2 Typical Types of Coastlines on Pacific Islands

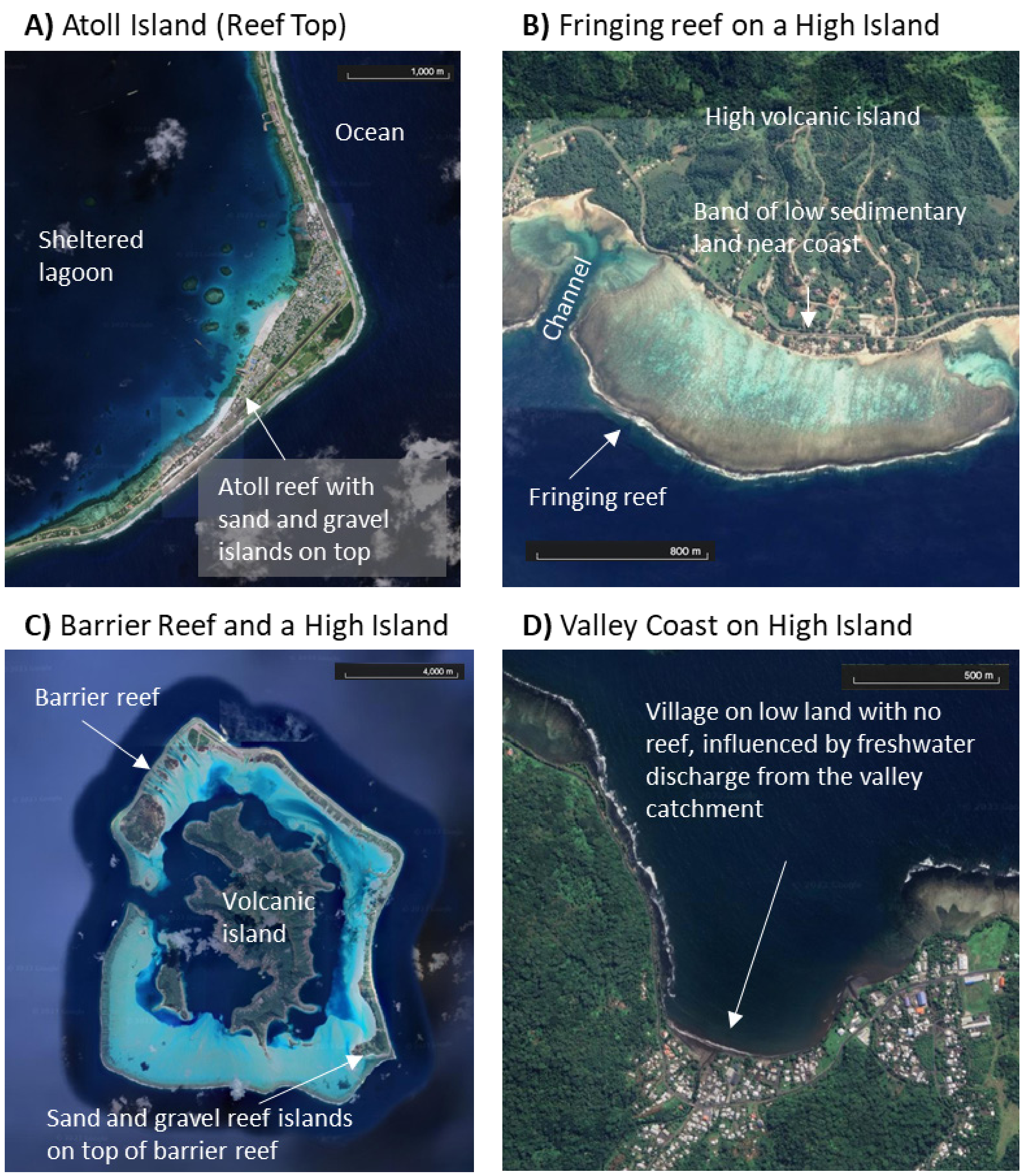
Pacific islands include a mixture of high volcanic islands and adjacent fringing reefs or barrier reefs, as well as atoll islands located on top of coral reefs (Figure 4). The coastlines of these islands include those fringed with reefs, those serving as low-energy harbors, and valley coasts with no adjacent reefs. On atoll islands, all development occurs along the low coastal margins; while on the high islands most communities are also established near the coastal margins, where land is typically low and flat in comparison to the volcanic hills found on the high islands.

This chapter outlines the different typical types of coasts in the Pacific and introduces the coastal processes and hazards that need to be appreciated in the context of coastal protection works. A visual summary of typical coastal types on Pacific islands is presented in Table 1, with schematic profiles highlighting key geomorphic features.

2.2.1 Atoll Islands

Atoll islands (e.g., Arno Atoll in Figure 5) are situated across the lower latitudes of the Pacific Ocean, including the territory of Tokelau (New Zealand) and the nations of Kiribati, the Marshall Islands, and Tuvalu. Distinguishing features of atoll islands include the lack of volcanic land and the concentration of development on the coral reefs. Atolls are reef-derived sedimentary islands, with unconsolidated deposits of biologically derived sand and gravel sediments supplied by the breakdown of coral reefs. They are formed on top of coral reefs, created by wave-induced transport and the shaping of reef-derived sediments. The process of reef island formation typically takes thousands of years, with most atoll islands having been formed in the late Holocene geological epoch (covering the last approx. 5,000 years), when sea levels were relatively stable (Kench 2013). Atoll islands typically have an exposed ocean (or "windward") side, where energetic ocean waves are dissipated across a shallow coral reef before reaching the shoreline. The lagoon shorelines of atoll islands are typically sheltered from ocean swells, but are often lower in elevation. Moderate-energy-wind waves can be generated inside large atoll lagoons such as Funafuti and Majuro, Marshall Islands, during storms conditions.

Figure 4: Types of Pacific Island Coasts



Note: Photo A shows an atoll island in Funafuti, Tuvalu; photo B shows a reef-fringed coast on Viti Levu, Fiji; photo C shows a barrier reef and volcanic island in Bora Bora, French Polynesia; and photo D shows a valley coast with no reef on Upolu, Samoa. Source: Google Earth.

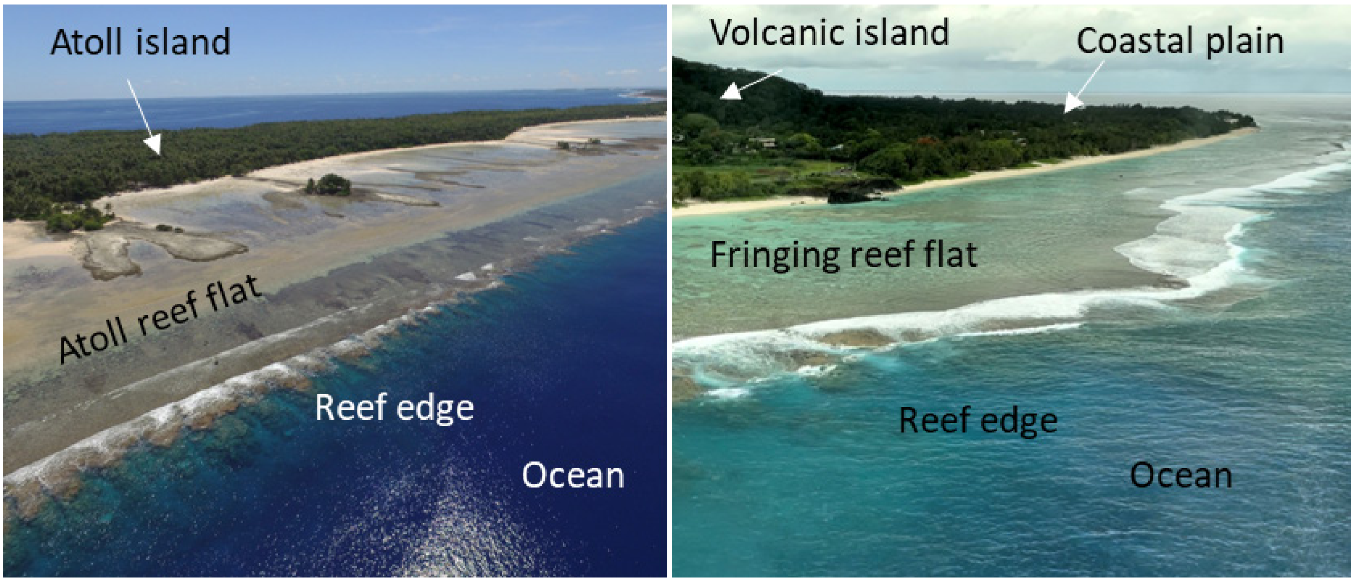
2.2.2 Fringing Reefs

High islands in the Pacific are characterized by volcanic land that is often steep and heavily vegetated. High islands have a range of coastline types, including fringing reefs, which occur where a coral reef is connected to the underlying volcanic shoreline. Fringing reefs are common around the Cook Islands, Fiji, and Samoa. A fringing reef coast is strongly influenced by the adjacent coral reef, which regulates the energy of waves reaching the shoreline, and produces sediment for constructing sand and gravel beaches. Fringing reefs may be intersected by freshwater channels where no reefs exist, and coastlines may also receive sediment input from nearby terrestrial sources such as river discharge and cliff erosion.

2.2.3 Barrier Reefs

Barrier reefs are detached from the mainland by wide and deep lagoons, but still regulate the energy of ocean waves reaching the island shoreline. Examples of barrier reef systems include Bora Bora and Morea, both in French Polynesia. In some instances, a reef-top island (similar to an atoll island) can be present on the barrier reef (e.g., Figure 4, photo C). The mainland of barrier reef coasts is typically sheltered like a harbor or atoll lagoon-side shoreline. In some locations, this can allow colonization by coastal vegetation such as mangroves.

Figure 5: An Atoll Island Coast and a Fringing Reef Coast



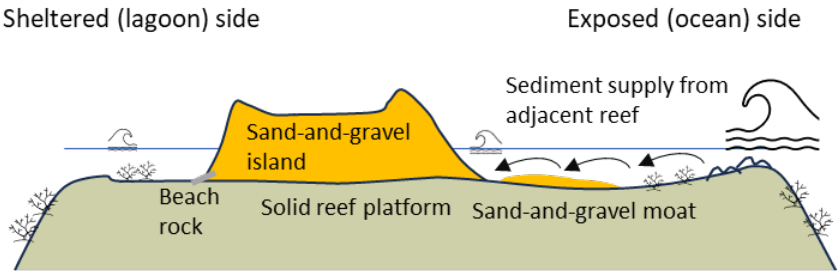
Note: The atoll island coast, shown in the image to the left, is in Arno Atoll, Marshall Islands; and the fringing reef coast, shown in the image to the right, is in Rarotonga, Cook Islands.
Source: Eddie Beetham, November 2017 (Arno Atoll) and January 2023 (Rarotonga).

2.2.4 Valley Coasts

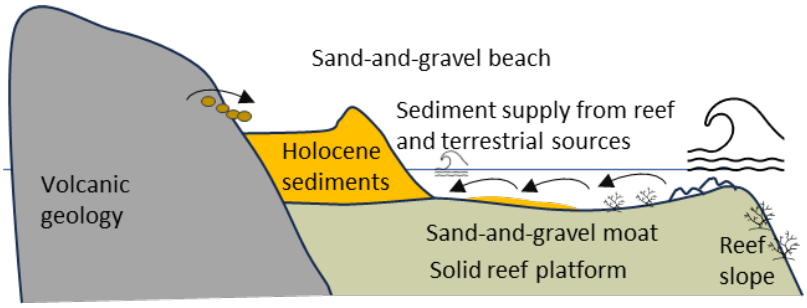
Freshwater discharge from high islands can prevent coral reef formation and result in valley coasts that do not have fringing or barrier reefs (e.g., Figure 4, photo D). These sections of coast are often developed, and may be exposed to a combination of catchment flooding and coastal hazards. Valley coasts may have beaches or coastal plains formed by terrestrial sediments, or delta formations where coastal vegetation is present.

Table 1: Types of Coasts in the Pacific Islands

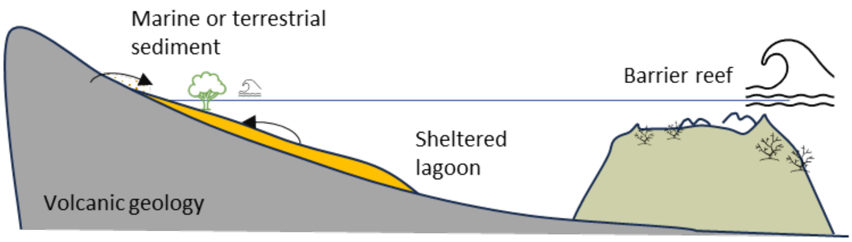
<table>
<tr><th>Type</th><th>Description</th></tr>
<tr><td>Reef-top islands are low-lying, wave-built deposits of biogenic sand and gravel sediment generated by adjacent coral reefs. Reef islands are poorly consolidated. They were generally formed during the last 5,000 years of stable sea levels, in the late Holocene geological epoch. Lagoon coasts on atoll islands are generally sheltered from waves, and they are lower in elevation.</td><td>Reef-top islands (including atoll islands)



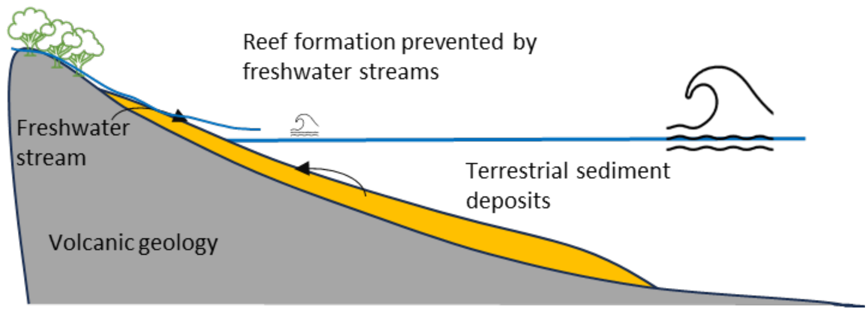
</td></tr>
<tr><td>Reef-fringed beaches are located on high islands where a reef is connected to volcanic land. Coastal sediments may form a low-lying sedimentary plain deposited during the late Holocene epoch (i.e. the past 5,000 years). Beaches can be made of reef-derived sand and gravel, or from terrestrial sediment supplied by rivers and cliffs.</td><td>Fringing reef beaches



</td></tr>
<tr><td>Sheltered coasts exist on high islands in the lee of barrier reefs or inside natural harbors. These coasts are not typically dynamic, and may be affected by marine and terrestrial sediment supply. Mangroves and other salt-tolerant wetland vegetation may be present.</td><td>Low-energy coasts on high islands (e.g., inside barrier reefs)



</td></tr>
<tr><td>Valley coasts are often present within the gaps between coral reefs, where freshwater streams in valleys discharge to the ocean and prevent reefs from forming in their paths. Valley coasts are often low lying and have sedimentary features created by terrestrial sediment.</td><td>Valley shorelines



</td></tr>
</table>

Source: The authors.

2.3 Coastal Processes

Coastal processes include changes in water levels caused by tides and waves; ocean currents; and movements of sediment, along with sedimentary land forms created over long periods. An understanding of coastal processes is important for implementing and managing coastal protection works.

2.3.1 Water Levels

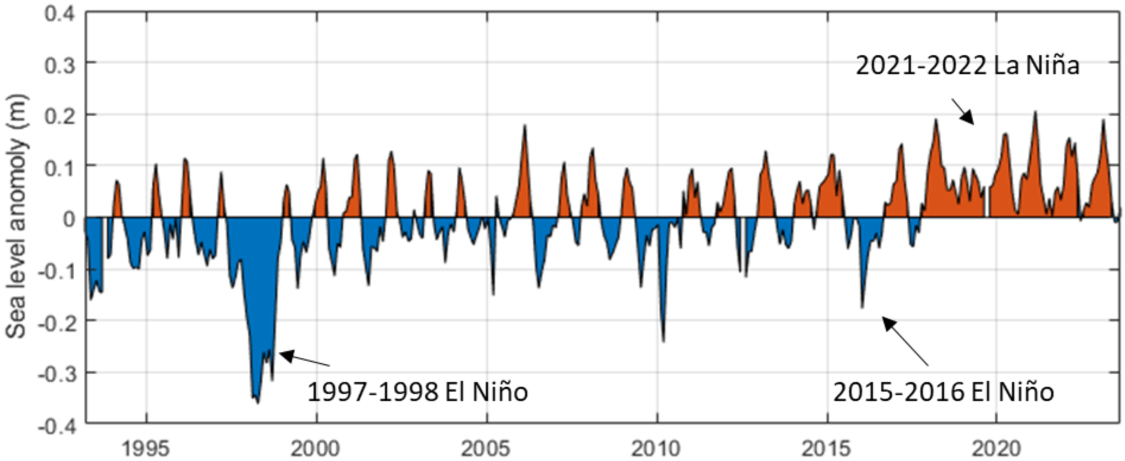
Water levels in the Pacific Ocean vary over time. Across centuries and millennia, mean sea levels are controlled by the volume of water in the ocean, which is influenced by geological-scale processes of planet warming and cooling, and by changes in land elevation due to subsidence, uplift, and earth surface processes. An important boundary condition for present-day coastlines in the Pacific is the period of relatively stable sea levels in the late Holocene epoch (i.e., during the last 5,000 years), which has resulted in the formation of intertidal coral reefs, sedimentary reef-top islands, and beaches at the shorelines of high islands.

Mean sea level in the Pacific Ocean has increased over recent decades of monitoring by tide gauge networks (from the 1970s) and satellites (since 1993). This measured sea level rise has been in the order of 2–6 millimeters (mm) per year since 1993[1]. Subsidence of volcanic islands can also create a relative rise in sea levels.[2] This is noticeably the case in Samoa, where the relative sea level rises are roughly 10 mm per year, based on recent tide gauge data. Geodetic monitoring of land elevation is undertaken to identify areas of land subsidence that could be causing relative sea level rises (Australian Government 2023).

Mean sea level rises caused by climate change are projected to increase 0.35– 0.45 meters (m) over the next 50 years, and 0.7–1.1 m over the next 100 years, depending on emissions pathway, which is discussed further in section 2.5.

Mean sea levels across the Pacific Ocean vary seasonally and annually because of ocean-scale climate processes. For example, the La Niña phase of the El Niño Southern Oscillation (ENSO) typically results in higher sea levels in the Western Pacific, and the El Niño phase results in lower-than-average sea levels. This oscillation can be in the order of ±20–30 centimeters (cm). For example, there are anomalies in the mean sea levels around Funafuti Atoll, as shown in Figure 6. Variations in mean sea levels at seasonal and annual intervals are driven by wind processes across the Pacific.

Figure 6: Anomalies in Monthly Sea Levels around Funafuti Atoll, Based on Tide Gauge Data (m)



m = meters. Source: University of Hawaii. Sea Level Center. https://uhslc.soest.hawaii.edu/data/ (accessed December 2023).

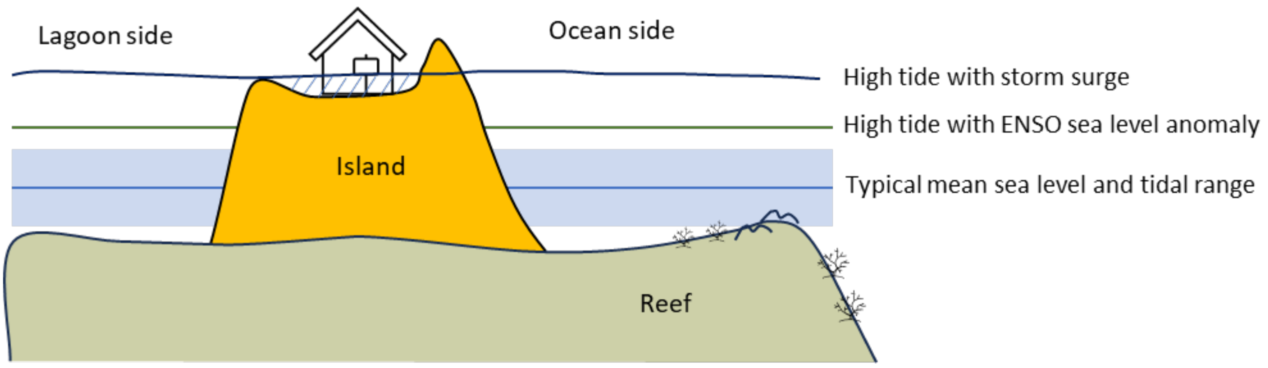
1 Source: University of Hawaii Sea Level Centre (https://uhslc.soest.hawaii.edu/), and E.U. Copernicus Marine and Environment Monitoring Service (https://marine.copernicus.eu/).
2 A relative sea level change is the rise or fall in the height of the ocean surface relative to nearby land, in contrast to an absolute sea level change, which is the rise or fall in the height of the ocean surface above the center of the Earth, without regard to whether nearby land is rising or sinking.

Astronomic tides create daily oscillations in ocean water levels. Many Pacific islands have micro- or meso-tides, with a spring tide range of 1–2 m, and diurnal or semidiurnal oscillations producing one to two high tides per day. Spring, or "king," tides occur a few times annually, when the gravitational pull from the moon and sun combine to create the largest tides of the year.

A storm surge is a temporary increase in sea level generated by a combination of low atmospheric pressure and a strong onshore wind. The "inverse barometer" effect causes a 1 cm increase in sea level for every 1 millibar (mb) of decrease in pressure. During tropical cyclones, atmospheric pressure can drop from a typical ambient pressure of 1,010 mb to a low at the cyclone center of 950 mb, which creates a 0.6 m increase in the mean sea level. Onshore winds can also "stack up" water against the shoreline or reef, creating a local increase in water level that is influenced by the shoreline geometry and wind characteristics. Storm surge events can be localized and directly influenced by the track of a particular storm or tropical cyclone.

Extreme water levels occur when multiple processes coincide to create an unusually high sea level. For example, coastal inundation caused by an elevated water level can occur at high tide during a La Niña phase or when a storm surge coincides with a high tide in the spring. On many Pacific islands, the extreme water levels measured by tide gauge sensors can be up to 1 m above the typical level at high tide. The effect of different processes that contribute coastal inundation are shown in Figure 7.

Figure 7: Components That Influence Coastal Sea Levels in the Pacific



ENSO = El Niño Southern Oscillation.
Source: The authors.

2.3.2 Wave Climate

Waves are an important driver of coastal processes and hazards on Pacific islands. Waves also generate currents that entrain and transport sediment that may control shoreline accretion, stability, or erosion. High-energy wave events associated with coastal storms or powerful swells can cause episodic shoreline erosion. Storm and swell events can also directly cause coastal inundation, through a combination of surf-zone, runup, and overtopping processes.

A comprehensive summary of the regional Pacific wave climate, and of local wave climates around specific Pacific islands, was undertaken by the Changing Waves and Coasts in the Pacific (WACOP) project (WACOP 2023). Wave climate in the Pacific is influenced by distant source swell waves, regional wind waves, and local extreme waves from tropical cyclones (Figure 8). Significant wave height (Hs), the most common description of waves, is the average height of the top 33% of waves recorded over a period of time (usually at 1 hour intervals).

A useful indicator of the wave climate is the "wave period," a variable that describes the time between successive wave crests. In general, the longer the wave period, the faster and more powerful the wave.

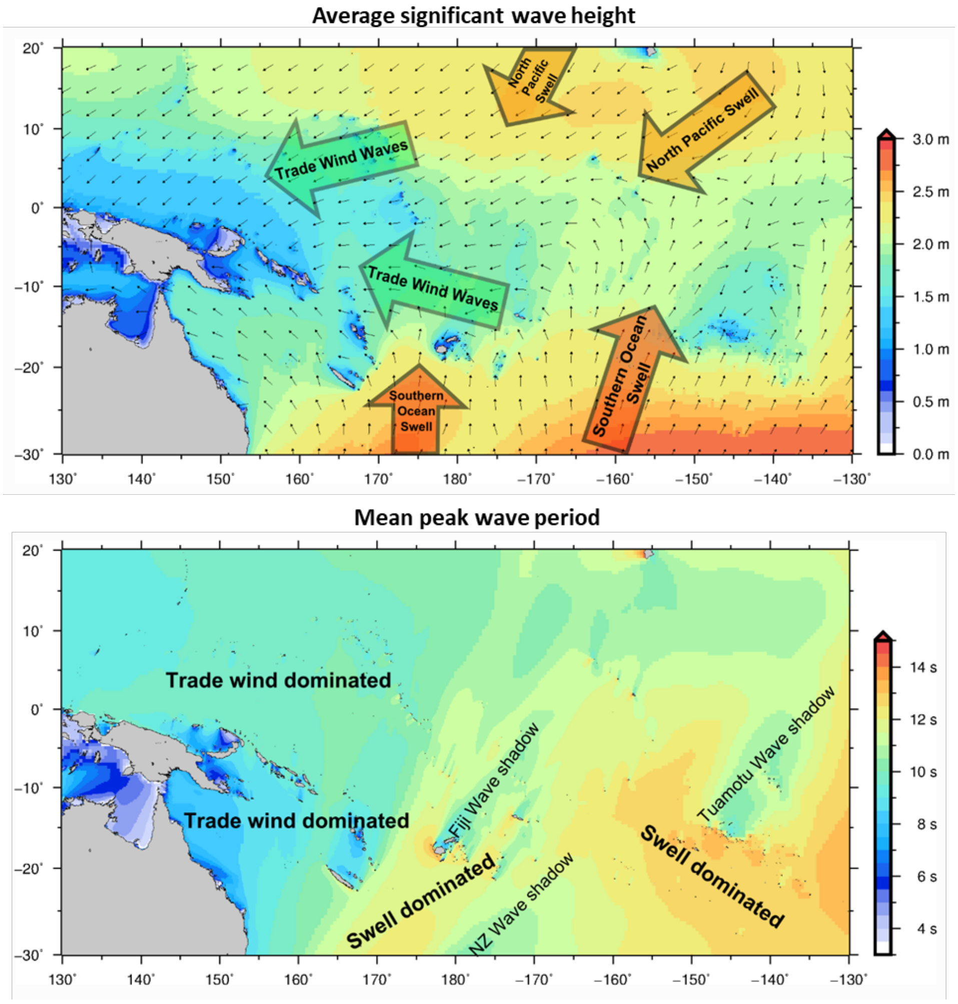
Various types of waves and the lengths of their periods are:

- wind waves (also referred to as "sea waves") have short periods of 3–7 seconds, and are generated by local wind action;
- short-period swell waves, with periods of 8–11 seconds, are generated by regional wind action;
- mid-period swell waves, with periods of 12–14 seconds, are generated by distant storms before propagating across the ocean; and
- long-period swell waves, with 15–25 seconds between crests, are generated by very powerful distant storms, and can propagate across the Pacific Ocean.

The Pacific islands are exposed to waves generated by different sources, as presented in Figure 8, which is based on the research of the WACOP project. These include:

- distant storms in the South Pacific, Southern Ocean, and North Pacific that produce long-period, energetic swell waves;
- regional easterly trade winds, which produce a mix of moderate-energy short- and mid-period swells;
- local low-pressure systems that create high-energy waves with short periods; and
- local tropical cyclones that create extreme mid-period waves locally and can send long-period waves to distant islands.

Figure 8: Pacific Wave Climate Summary Maps



m = meters, NZ = New Zealand, s = seconds.
Note: These maps show the average significant wave heights and mean peak wave periods in the South Pacific, as annotated by the Secretariat of the Pacific Community to show general wave origins.
Source: Changing Waves and Coasts in the Pacific (WACOP) project. Pacific Wave Atlas—Mean Regional Wave Parameters. https://wacop.gsd.spc.int/RegionalMeanWaves.html (accessed November 2023).

2.3.3 Wave Transformation Processes

Wave energy received on the coast is an important consideration in understanding coastal hazards, and in the design, maintenance, and damage of coastal protection works. Wave energy at the shoreline is a function of offshore or "incident" wave conditions, and how that offshore wave energy is transformed across the surf zone.

Wave transformation involves a series of key phases that are described below and presented in figures and photos over the next few pages:

- **Shoaling and refraction** occur when a wave starts to interact with the seabed and slows down. This results in shoaling, which produces a shorter wavelength and taller wave crest. Refraction occurs on curved seabed contours, when the wave slows down in shallow water, but maintains speed in deep water, causing the wave train to bend. Wave refraction can either focus or divert wave energy approaching different sections of coast.
- **Wave breaking** occurs when waves become unstable and topple over in relatively shallow water depth, compared with the wave height (photos below). Wave breaking typically occurs at a critical water depth (h) when the breaking wave height (Hb) is between 0.5 to 1.2 times the water depth, depending on the slope, wave period, and wind direction (theoretical value of Hb = 0.78 h for gently sloping beaches). Wave breaking on coral reefs is a rapid and energetic process caused by a steep sloping reef face that quickly transitions from deep to shallow water. Wave breaking dissipates a considerable amount of wave energy on the outer reef flat. On coral reefs, more energy is dissipated through breaking at low tide, compared with high tide, due to changes in reef submergence.

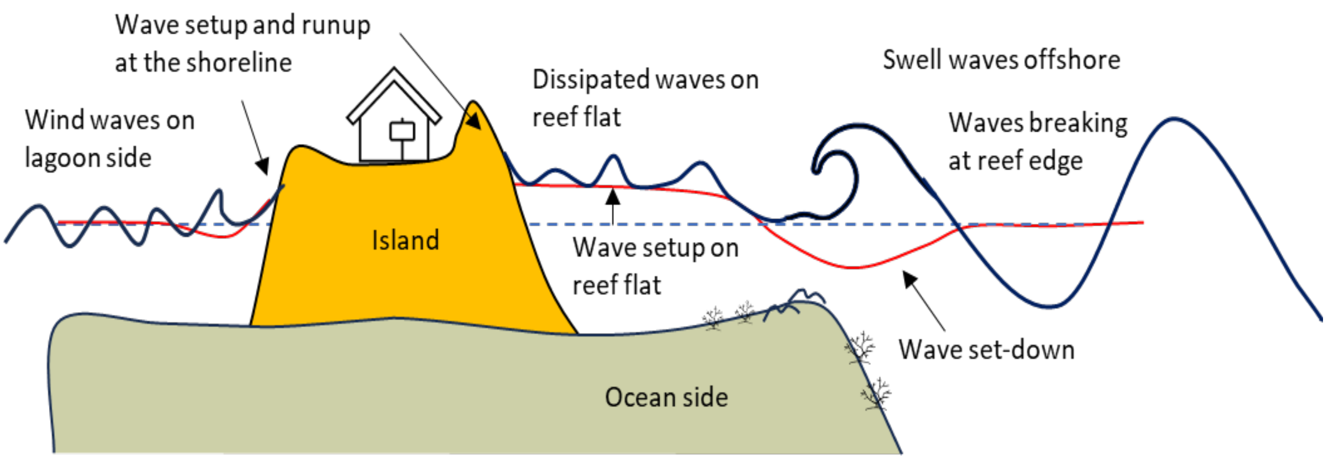
Examples of wave breaking. These images show waves breaking on a shallow coral reef in the Marshall Islands (photos by Eddie Beetham).

- **Wave dissipation** is the continued attenuation of wave energy through white water in the surf zone. In the surf zone, wave height is limited vis-à-vis water depth, and waves typically continue to dissipate until wave height is below 55% of the water depth. Once dissipated below 0.55 h, waves may re-form back into swell motions (unbroken) and continue to travel towards the shoreline. Broken or re-formed waves are further dissipated by friction on coral reefs, but may reach the shoreline and create a secondary breaking area on the beach. Since wave breaking and dissipating are both controlled by water depth, the largest waves impact island shorelines at high tide. Future sea level rises will result in even larger waves at high tide, and relatively higher waves throughout the tide cycle.
- **Wave setup** is the super elevation of the mean water level in the surf zone. Wave setup is caused by a process called "radiation stress," and is associated with a setdown of the mean water level at the breakpoint, and with a setup of water level landward of the breakpoint (Figure 9). On narrow reefs, a setup can extend from the reef edge to the shoreline, but on wide reefs it may only be present on the outer reef

flat. Wave setup on coral reefs can increase mean water level by an order of 1 m in extreme cases, and is typically larger at low tide (up to 30% of Hs) and lesser at high tide (< 10% of incident Hs). This is because wave setup is proportional to the amount of wave energy dissipated in the surf zone. Wave setup is an important component of coastal inundation hazards, as the mean water level can be elevated above land level and cause flooding. Wave setup is also an important consideration in the design of coastal structures, as the increase in mean water level from wave setup allows larger depth-limited waves to pass across the reef and reach the shoreline.

- **Infragravity (IG) waves** are long-period secondary wave motions that are created by groups, or "sets," of incident sea or swell waves. IG waves have periods ranging 25–300 seconds, and have been identified as a key contributor to wave runup on coral reef–lined coastlines. Unlike sea and swell waves, IG waves can shoal across the reef flat and increase in wave height towards the shoreline (Figure 10). This only occurs when the reef flat is relatively narrow compared with the IG wavelength. IG wave motions are typically 10%–40% of the indicant wave height, but can directly influence wave runup motions and can temporarily super-elevate the water level for dissipated indicant waves running up at the shoreline. During extreme cyclones, IG waves can resonate on fringing reefs and cause disastrous flooding in the form of "tsunami-like waves," as reported by Roeber and Bricker (2015).

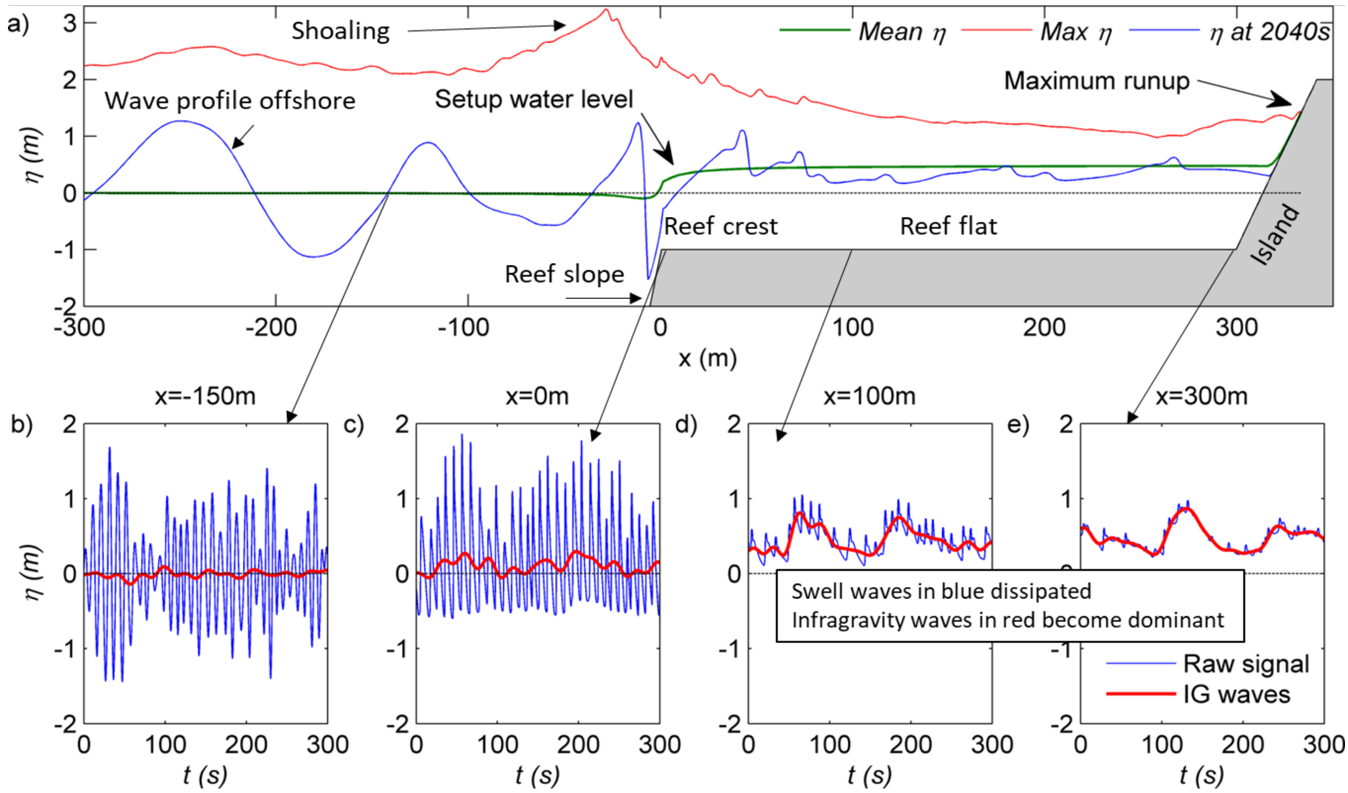
Figure 9: Schematic Diagram of Wave Processes on Reef-Fringed Coasts



Source: The authors.

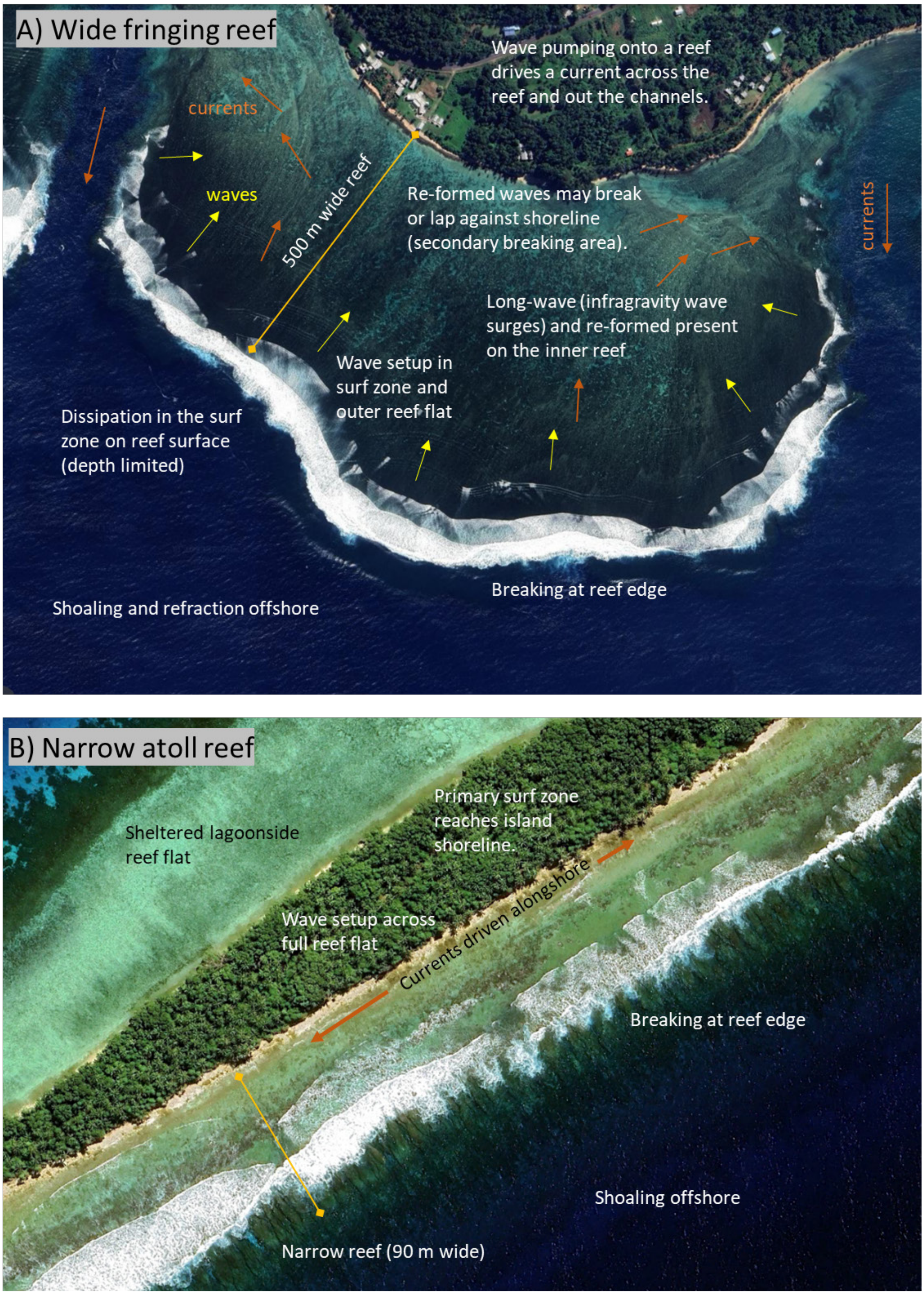
- **Wave runup** is used to describe the elevation on the shoreline that waves reach. The motion of waves lapping against the shoreline is called the "swash," and the upper limit of the swash reach is the called the "runup limit." Wave runup is typically defined as 2% over the runup mark as measured over a period of time (e.g., 30 minutes). Wave runup elevation is a function of offshore wave height and period, but also of wave processes in the surf zone, including wave setup and IG waves. A generalization is that at a given shoreline, the runup level increases proportional to wave height and period. Wave runup is measured above the still tidal water level. Therefore, the potential for runup to reach developed sections is usually limited to a short window at high tide.
- **Wave-driven currents** are generated by a combination of wave orbital velocities (instantaneous flows), wave setup–generated currents, alongshore currents, rip currents (or channelized return currents), and undertow. Currents on reef coasts are typically directed onshore in the surf zone, and alongshore against island shorelines. Where reefs are intersected by channels, wave-driven currents flow from the reef to the channels and offshore out to sea.

Figure 10: Diagram of Wave Transformation Processes on Coral Reefs, Based on Numerical Modeling Simulations



IG = infragravity, m = meters, n (eta) = water surface level, s = seconds, t = time.
Note: Graphs b–e show time-series information on water level that highlights the transfers of energy from swell waves to IG waves.
Source: Beetham, Edward. 2016. *Field and Numerical Investigations of Wave Transformation and Inundation on Atoll Islands.* PhD diss. Auckland, New Zealand: University of Auckland.

Figure 11: Annotations of Key Wave Processes on Coral Reefs

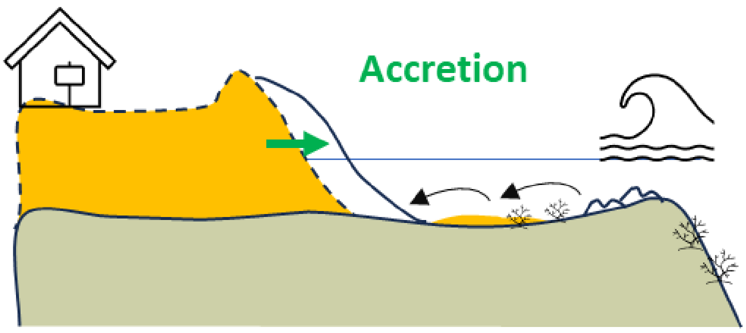
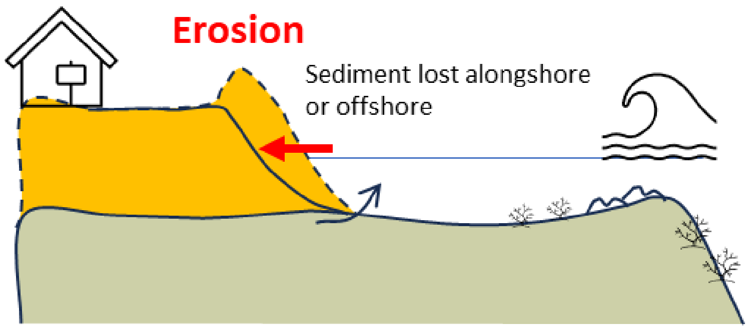
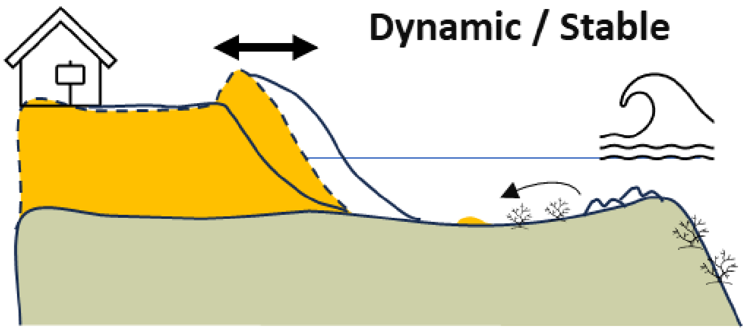


m = meters.
Note: The wide fringing reef, shown in image A, is located at Coral Coast, Fiji; and the narrow linear atoll reef, shown in image B, is located in Funafuti, Tuvalu.
Source: Google Earth.

2.3.4 Shoreline Change

Shoreline change is a topical issue in the Pacific islands, where landward movement of the shoreline can expose and undermine coastal development, with devastating consequences to property and infrastructure. Coastal erosion is a key reason for implementing coastal protection works in the Pacific, where coastal land is scarce and valuable. Shoreline change can be broadly summarized by four descriptions that are presented in Table 2, depending on whether a shoreline is: progressively moving seaward (accreting), progressively moving landward (eroding), periodically moving seaward and landward (dynamically stable), or not moving at all (stable). When the sea level and wave energy are stable over the long term, for decades or even centuries, the shoreline change trend is a function of the sediment budget, which is the balance between sediment supply and loss. If more sediment is being deposited at a section of shoreline than is being removed, shoreline accretion occurs.

Table 2: Schematic Diagrams of Types of Shoreline Changes

Type of Coastal Change	Description
Accreting Coast Sediment supply to the coast is greater than sediment supply removed. Shoreline moves seaward.	
Eroding Coast Sediment supply to the coast is less than the sediment supply removed. Shoreline moves landward.	
Dynamically Stable Coast Sediment supply to the coast is balanced by the sediment supply loss in the long term. Shoreline moves back and forth at seasonal and interannual time scales.	

Source: The authors.

The different time scales that need to be considered when studying coastal change are as follows:

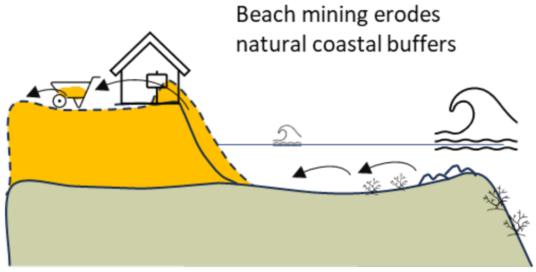
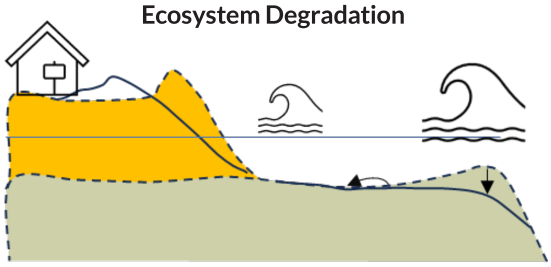
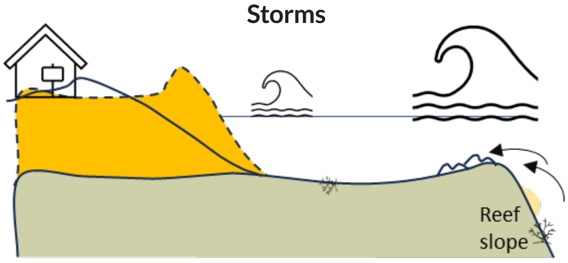
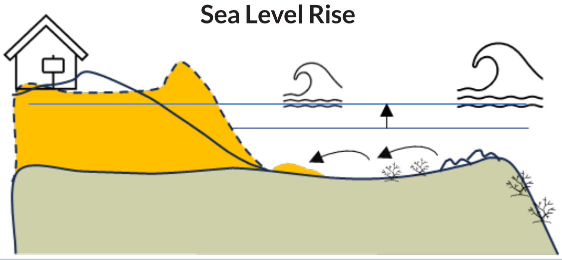
- **Long-term trends** in shoreline position over decades or centuries can be a function of changing energy (e.g., wave climate or sea level rise) or changes in sediment supply. On Pacific island coasts, sediment supply can be from terrestrial sources (high islands) or adjacent reefs (atolls and fringing reef coasts). Changes in land use, such as reef degradation, damming of catchments, mining, or construction of harbors and breakwaters, can locally alter sediment movement and change the long-term trend of accretion or erosion downstream.
- The mapping of coral reef island shorelines over the last several decades indicates that sedimentary coral reef islands in the Pacific are generally becoming larger in area, but these landforms are dynamic at the island scale (McLean and Kench 2015). A typical trend of island mobility is erosion on the windward shoreline and accretion on lateral or lagoonal shorelines, with a net stability or increase in area over several decades. Therefore, it is important to understand the historic shoreline movements when considering the design, performance, or impact of coastal structures.
- **Medium-term changes** in shoreline position occur at annual or sub-decadal time scales, and occur in locations that are sensitive to climate cycles on a seasonal or interannual time scale. For example, the changing winds, waves, sediment supply, and sea level patterns during the El Niño Southern Oscillation (ENSO) cycles may cause periods of erosion and accretion in different locations. These cycles can be important for understanding the drivers of change that are observed during coastal structure monitoring.
- **Short-term changes** in shoreline position are driven by storm erosion events. Storm erosion in Pacific islands is typically associated with extreme cyclone events, when offshore waves can reach a height of 10–15 m and extreme waves can be sustained for multiple tidal cycles. Extreme storm events can cause severe erosion to the shorelines of Pacific islands. Sandy shorelines are more susceptible to coastal erosion during storm events, when episodic erosion on the order of 10-plus meters may occur.
- In comparison, gravel shorelines are generally resilient to coastal storms, and may actually receive new sediment during storms, which is transported landward from adjacent reefs. Examples of gravel deposition on islands and reefs were evident during tropical cyclone Bebe in Funafuti (1972) and tropical cyclone Ofa in Samoa (1990).
- Another phenomenon on sand-and-gravel islands is wave overwash, which occurs when storms push sediment from the beach onto the island surface. Overwash deposits during storms and high energy swells have been documented across the Pacific (Smithers and Hoeke 2014). Shoreline recovery may occur naturally following a storm, if sediment is deposited maintained within the active sediment exchange. A heightened risk of coastal erosion occurs when a sequence of large storms occurs during the same season, creating a compounding impact on the coast before any natural recovery or engineering implementation.

2.4 Coastal Hazards

2.4.1 Outline

The main coastal hazards facing Pacific island shorelines are coastal inundation and coastal erosion. Several factors can contribute to coastal hazards, including natural processes and the influence of human development on the coast. A visual summary of the causes of coastal erosion and inundation is presented in Table 3.

Table 3: Causes of Coastal Hazards along Pacific Shorelines

Erosion	Description	Inundation
Coastal development, including leveling, structures, and sand mining within the dynamic zone of the coast can interfere with sediment supply and exacerbate coastal erosion.	**Coastal Development**  	The lowering of natural beach berms for development can increase exposure to coastal inundation from wave overtopping.
The degradation of coral reef ecosystems exposes the shoreline to higher wave energy, causing coastal erosion. Degraded reefs may produce less sediment supply for the shoreline.	**Ecosystem Degradation** 	Degraded reefs dissipate less wave energy, resulting in higher waves at the shoreline. Larger waves increase the runup level and susceptibility to wave overtopping.
Storm erosion occurs when large waves attack the shoreline and move sediment alongshore or offshore. Storms can transport shingle and boulders from the reef slope to the reef top.	**Storms**  	Storm inundation occurs when elevated water levels from storm surge, and from large waves flood coastal areas with sea water.
A sea level rise causes the shoreline to shift landward and the profile to adjust to higher water levels. On reef coasts, erosion can be exacerbated by sea level rises because less wave energy is dissipated across the reef.	**Sea Level Rise** 	A sea level rise can directly flood low terrain at high tide, and it exacerbates other inundation hazards during storm events.

Source: The authors.

2.4.2 Factors Influencing Coastal Erosion Hazards

"Coastal erosion" refers to the loss of sediments due to coastal processes, generally resulting in a landward retreat of the shoreline. It can be a natural process driven by physical changes, such as those in sediment supply, sea level, or wave energy. As outlined in section 2.3.4, coastal erosion can result from:

- short-term erosion events at the time scale of storms or storm sequences;
- medium-term oscillations in the shoreline position at the time scales of seasons and interannual climate cycles;
- long-term deficits in the sediment budget and historic landward movement of the shoreline; and
- landward retreat of the shoreline driven by a sea level rise.

Coastal erosion can also be caused or exacerbated by development on the coast, including:

- the mining of beach sediments for aggregate;
- leveling of coastal berms for development;

- degradation of coral reefs, whereby a loss of coral cover can increase reef submergence and result in greater wave energy at the shoreline (a reduction in reef ecology may also reduce biogenic sediment production and reduce natural sediment supply to the coast);
- the removal of coastal vegetation, including shoreline plants that stabilize sediment or intertidal plants such as mangroves, thus making shorelines more susceptible to erosion; and
- the development of coastal structures that can alter coastal processes in the following ways:
  - Groynes that block alongshore transport can cause downstream erosion.
  - Seawalls that block the movement of sediment from the reef to the shoreline can prevent new sediment from accumulating on the beach.
  - Offshore breakwaters can alter nearshore currents and cause flank erosion in adjacent shoreline areas, as sediments are redistributed and end up creating a salient or tombolo behind the breakwater.
  - Rock revetments can occupy wide cross-sections of the beach and "lock up" sediment, preventing it from reaching the dynamic area of the beach.
  - All coastal structures and seawalls have the potential to cause a localized scour at the toe, which can lower the active beach level through wave reflection.
  - Seawalls and revetments can cause erosion through "end effects" if not appropriately tied back at their ends.

Coastal erosion only becomes a hazard when a retreating shoreline intersects with coastal development. Historic developments on the coast are sometimes located within the naturally dynamic coastal edge, and small changes in shoreline position can result in the perception of a serious coastal erosion issue. Where development is located within 10 m of the coastal edge, chronic erosion or a storm event may undermine buildings or roads, causing significant damage. One example can be seen in the photo below, which shows green space that has retreated due to coastal erosion that, if unstopped, may eventually endanger the road itself.

Erosion of a coast. This is an example of coastal erosion in Samoa. In this case, erosion has caused the loss of green park space along a road. The erosion scarp shown here is unstable, which may lead to problems with access to the coast. If the trend continues, the road could eventually be undermined by a severe storm or by a sea level rise (photo by Tom Shand).

2.4.3 Factors Influencing Coastal Inundation Hazards

Coastal inundation occurs when the sea level is super elevated, producing saltwater flooding of land that is typically dry at high tide. Coastal inundation can either be static, when the still water level at high tide exceeds the land level, or dynamic, when wave motions push the water level landward of the typical coastal edge, resulting in flooding.

Static inundation is caused by extremely high tides, which may be influenced by mean sea level anomalies and storm surges, as discussed in section 2.3.1. Examples of static inundation include king tide inundation, such as that seen in Tuvalu on 28 February 2006, and discussed in Lin, Ho, and Cheng (2014).

Dynamic inundation occurs when wave runup processes exceed the typical coastal edge (e.g., the beach or seawall crest) and wash onto the island surface. The term "wave overtopping" is used to describe the process when wave runup exceeds the crest of the coastal edge. Wave overtopping is influenced by all water-level processes, including the sea level, tide level, storm surges, wave setups, and swash. The processes that contribute to wave overtopping on coral reef–fringed shorelines vary, depending on reef submergence and the tide level (Beetham et al. 2016). At low tide, the contributions of low-frequency processes of wave setups and IG waves are the dominant factors determining wave runup and overtopping. At higher tides, when more incident wave energy is transmitted across the reef, swell and wind waves become the dominant mechanisms for wave overtopping.

An example of coastal inundation from wave overtopping occurred in the Cook Islands in July 2022, when long-period swell waves coincided with a high tide. The powerful swell waves created a large setup in the lagoon, with waves washing across a road and through buildings, as shown in the photo below.

Wave overtopping is also influenced by the morphology of the coastline, and by the presence of any structures. "Freeboard" is the elevation of the coastal edge above the still water level, and is a key parameter in determining susceptibility to wave overtopping. If the freeboard is low relative to wave height at the shoreline, then wave overtopping may occur. The configuration of the coastal edge can also influence overtopping, with some coastal structures (e.g., groynes, jetties, seawalls) designed to absorb or reflect wave motions to minimize overtopping.

Inundation in the Cook Islands. Swell waves caused coastal inundation in the Cook Islands in July 2022
Source: https://x.com/MattBlacka/status/1547845848364507139).

On natural coral reef coastlines, wave overtopping can also be a constructive process. This is especially true on gravel coasts, where shingle material is built into a storm berm during overtopping events. This process increases the height of the coastal edge, which in turn builds resilience to the next flooding event. On developed coasts, wave overtopping can be a destructive hazard that damages infrastructure and crops, and contaminates freshwater reservoirs.

Coastal inundation can also be caused or exacerbated by development on the coast in the following ways:

- The lowering of natural berms and coastal ridges for development actively reduces island freeboard and makes land more susceptible to wave overtopping.
- Degradation of coral reefs can result in less wave attenuation and higher runup at the shoreline, which increases the risk and occurrence of wave overtopping.
- Removal of coastal vegetation can make some low-energy shorelines more susceptible to inundation from storm surges and waves.

2.5 Effects of Climate Change

2.5.1 Potential Effects on Pacific Island Coasts

The Pacific islands are generally considered one of the most vulnerable regions to the impacts of global climate change. Sea level rise from climate change will significantly exacerbate coastal hazards on these islands, with shorelines shifting landward (or lagoon-ward on atolls) due to erosion, and inundation occurring more frequently at high tides and from lower-energy storm and swell events.

In addition to sea level rise, climate change is also threatening the persistence of healthy coral reefs in the Pacific Ocean. Higher sea surface temperatures will result in more frequent coral bleaching events, and ocean acidification may result in less carbonate production. Degradation of coral reefs due to climate change will likely exacerbate coastal erosion and inundation hazards on reef-lined coasts, where a decrease in reef friction or reef submergence (reef elevation relative to sea level) will allow larger waves to erode and inundate island coastlines.

Climate change may also increase the severity of tropical cyclones in the Pacific Ocean, with warmer sea surface temperatures potentially changing the mechanics of cyclone formation. The potential impact of increasing cyclone energy is poorly understood, but may become a key factor that will impact local communities before the full effects of the sea level rise are realized.

In some cases, sea level rise poses a risk to the populations of atoll countries and territories such as Kiribati, the Marshall Islands, Tokelau, and Tuvalu, where no volcanic or high land is available for in-country relocation. The modeling of atoll islands using remote-sensing methods indicates that some natural islands are likely to persist through geomorphic adaptation, as these islands could roll over lagoon-ward with the sea level rise (Masselink et al. 2020). However, establishing a resilient community on a mobile island may not be possible, and engineering solutions to raise and protect atoll islands have considerable logistics and cost challenges.

2.5.2 Sea Level Rise Projections

Sea level rise and the associated coastal hazards are presented in the publication *Guidance for Managing Seal Sevel Rise Infrastructure Risk in Pacific Island Countries* (PRIF 2022), which provides an overview of historic and projected sea level rises for the Pacific island countries (PICs). Sea level rise is the most predictable way that climate change will be realized in the Pacific Ocean. If all emissions stop this century, the effects of previous emissions will still cause the sea level to rise for several centuries (Mengel et al. 2018). However, the rate and magnitude of sea level rise that are predicted based on different planning time frames is still uncertain, and will depend on future emission scenarios and ice-melt feedbacks. The Sixth Assessment (AR6) report by the Intergovernmental Pannel on Climate Change (IPCC) presents the latest comprehensive assessment of global sea level rise, including projections specific to many PICs (Fox-Kemper et al. 2021).

The AR6 report assesses sea level rise using different Shared Socioeconomic Pathways (SSPs) that represent different emission trajectories. The SSPs most typically used in coastal hazard and planning assessments are outlined in Table 4. Sea level rise projections for each SSP have been modeled by the IPCC based on a "medium confidence" scenario associated with moderate polar ice melt, and on a "low confidence" scenario associated with rapid polar ice melt. Each modeled scenario also includes sea level rise magnitudes associated with a range of confidence levels (e.g., 5th, 17th, 50th, 83rd, and 95th percentiles) that are suitable for different applications. The IPCC's AR6 data are referenced to the mean sea level in 2005, averaged between 1995 and 2014.

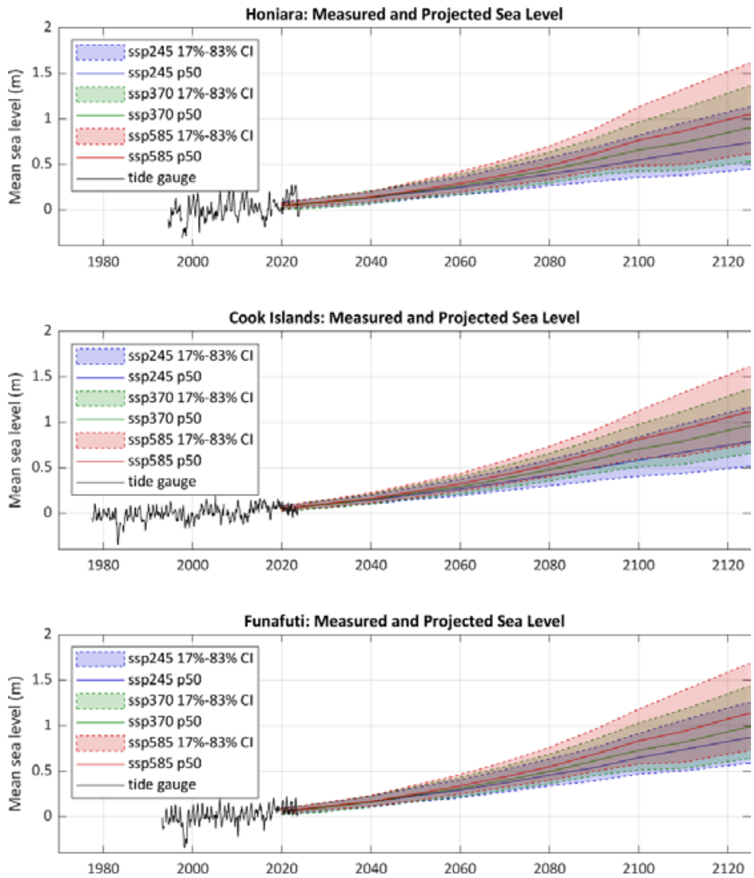
Examples of sea level rise projections for the "medium confidence" model are presented in Figure 12 for different Pacific islands. Future sea level rise projections show an increase in mean sea levels between approximately 0.2 and 0.6 m by 2060, with the range depending on the confidence level and SSP scenario. Sea level rise by 2100 is protected to be between 0.3 and 1.5 m, with the more likely range between 0.6 and 0.9 m. More details on sea level rises and PICs, including sea-level-rise projections, can be found in the PRIF's Guidance (2022), which focuses specifically on the sea-level-rise risk in the PICs.

Table 4: Descriptions of Selected Shared Socioeconomic Pathways

Specific SSP	Description
SSP2-4.5	Moderate emissions resulting in an increase in temperature of 2.7°C. This is the current pathway assuming global activation of existing policy settings.
SSP3-7.0	High emissions resulting in an increase in temperature of 3°C.
SSP5-8.5	A highly unlikely scenario with very high emissions resulting in an increase in temperature of >4°C.

C = Centigrade, SSP = Shared Economic Pathway. Source: https://www.searise.nz/shared-socioeconomic-pathways.

Figure 12: Sea Level Rise Trajectories for Shared Socioeconomic Pathways in the Pacific Islands



CI = Confidence interval, m = meters, p = percentile, SSP = Shared Socioeconomic Pathway.
Notes:
1.This figure shows examples of SSPs, as defined by the Intergovernmental Pannel on Climate Change (IPCC), for four Pacific islands. It includes past and projected sea level rises based on sea level measurements by tide gauges.
2.The IPCC data are from National Aeronautics and Space Administration and the tide gauge data are from the University of Hawaii.
Sources: Government of the United States, National Aeronautics and Space Administration (NASA). 2023. *Sea Level Projection Tool*. https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool (accessed November 2023). Washington, DC; University of Hawaii. Sea Level Center. https://uhslc.soest.hawaii.edu/data/ (accessed November 2023).

3. Coastal Protection in the Pacific

3.1 Impacts of Coastal Hazards

While coastal processes such as erosion, accretion, elevated water levels and wave overtopping are natural processes, they have the potential to adversely affect community well-being by:

- affecting road infrastructure and utilities, potentially resulting in loss of connection;
- causing loss of land and assets;
- causing flooding of land adjacent to the coast;
- threatening public safety due to wave overtopping or unstable edges; and
- impacting access to and along the coast.

Erosion is of particular concern for transport infrastructure and utilities, as they often run along coastal edges and provide critical lifeline connections. The loss or interruption of service due to erosion can result in significant costs and social repercussions.

The risk that coastal hazards pose to infrastructure and communities is a function of both the likelihood of the hazard occurring and the consequences of its occurrence. This has been discussed in detail by PRIF (2017b), which notes that the resultant risks influence the selection of appropriate responses.

Erosion's dangerous effects. Coastal erosion is undermining roads (left) and utility infrastructure (right) in South Tarawa, Kiribati. Photo: Tom Shand.

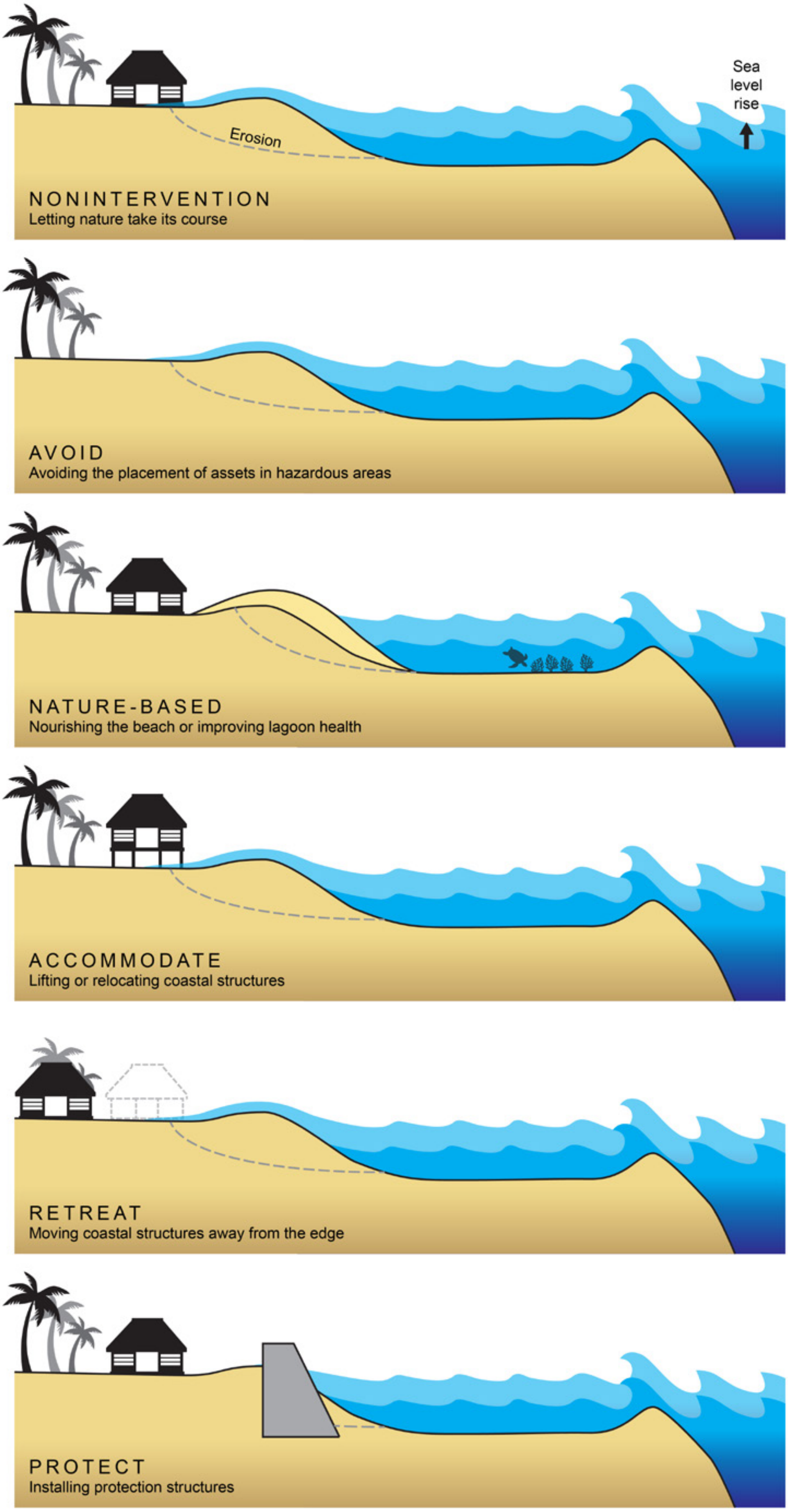
3.2 Responses to Coastal Hazards

Options for managing coastal hazard risks should be considered based on a hierarchy of options, with preference given first to the less intrusive and less potentially socially and environmentally damaging options, and then to the more intrusive and expensive options only afterward. The hierarchy is as follows (Figure 13):

- Non-intervention.
- Avoid.
- Nature-based.
- Accommodate.
- Retreat.
- Protect.

In many cases, a combination of options may be necessary, and the chosen strategies may need to change over time.

Figure 13: Adaptation Options for Managing Coastal Hazard Risks



Source: The authors, graphics design: Anna Blacka

3.2.1 Non-intervention

A nonintervention, or "do nothing," option allows natural coastal processes to proceed without interference. In situations where the risks posed by coastal hazards are acceptably low or there are few assets or little development on land that is exposed to a hazard, nonintervention can be considered a suitable adaptive response. When evaluating the costs and benefits of other options, nonintervention should be the baseline option with which all other strategic adaptation actions should be compared.

3.2.2 Avoid

Avoiding coastal-erosion hazards primarily involves planned measures to prevent people and assets from being exposed to such hazards. Policies and planning regarding the types of activities that can be undertaken in areas exposed to coastal hazards will generally place limits on further development in the exposed locations. Setbacks from coastal edges are an example of how to avoid coastal erosion hazards.

3.2.3 Nature-based

Nature-based adaptation options employ "soft" (often referred to as "green" or "blue") protections, such as improving lagoon and reef health, supporting mangrove establishment, and adding shoreline plantings to reduce the impact of natural hazards and create or restore the ecological processes and functions of coastal habitats. Nature based solutions (NbS) can reduce coastal hazards through wave attenuation, sediment accumulation, and stabilization. NbS are generally lower cost than traditional "hard" ("grey") engineered coastal protections, and have the potential to enhance social and ecological values in coastal environments and provide associated benefits such as carbon sequestration and improved water quality. However, NbS may not meet the same level of protection confidence provided by an engineered structure.

3.2.4 Accommodate

Accommodating coastal hazards enables the ongoing use of coastal land by modifying existing assets and developments or by designing new developments to accommodate coastal hazards. Examples of options that accommodate hazards include raising buildings in areas that are flooded or subject to wave overtopping; designing structures to be relocatable once erosion reaches a certain point; and providing warnings and signage to alert people to the dangers, and to inform them on what actions can be taken to keep safe (e.g., tsunami evacuation signage).

3.2.5 Retreat

Managed retreat applies to existing development and involves moving assets, infrastructure, and/or people and activities away from areas that are susceptible to coastal hazards. Retreat can be applied to individual assets and structures. One example is the relocation of a section of coastal road away from an area that is susceptible to coastal erosion; another is the relocation of entire communities or migration paths of coastal species that are currently in hazard-exposed locations.

3.2.6 Protect

Coastal protection measures are implemented when a decision is made to invest in defending coastal land or coastal assets over the short to medium term. It is important to acknowledge that coastal protection structures generally do not function indefinitely, and that in future alternative protection measures or a pivot towards retreat or another adaptation strategy may be necessary.

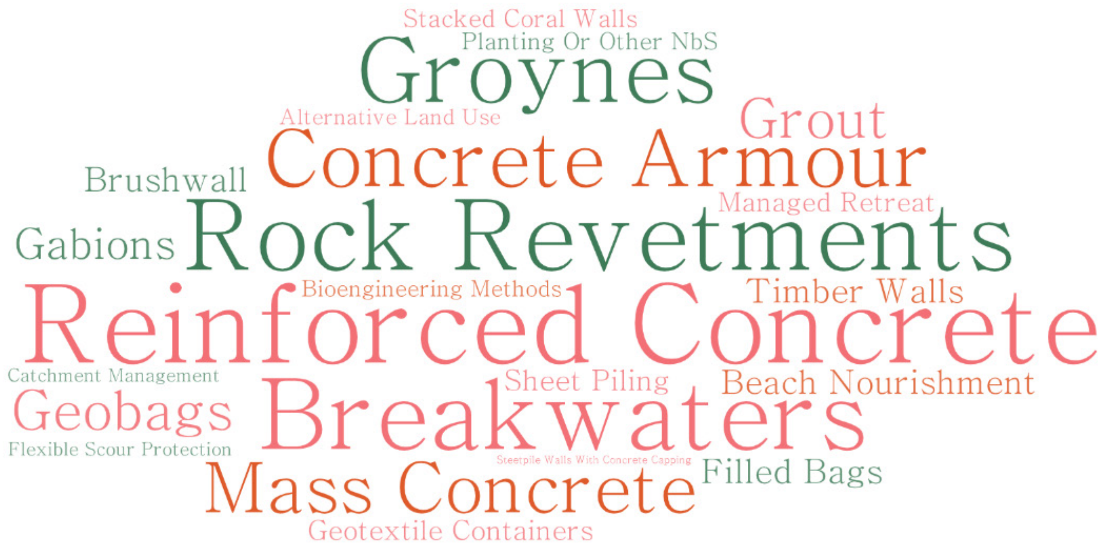
Engineered protection measures modify coastal processes to prevent or delay coastal erosion or reduce inundation and overtopping. However, their use can result in unintended impacts such as increased erosion along adjacent coasts if the sediment supply is being reduced, or increased wave reflection and turbulence.

Additionally, the presence of coastal protection structures can encourage further development in exposed locations, thereby increasing risk in the long term. Due to these limitations, coastal-protection options should only be considered once all other options have been assessed and deemed not to be viable.

3.3 Typical Coastal Protection Works

A wide range of coastal protection works have been built in the PICs. These are comprehensively reviewed and evaluated in PRIF (2017a) and summarized, along with design guidance for specific types of protection, in PRIF (2017b). Figure 14 illustrates the many types of coastal structures reported by survey responders as being used in their countries.

Figure 14: Types of Coastal Protection Structures Reported in the Pacific Island Countries



Source: The authors.

For the purposes of this guide, coastal protection structures have been broken down into broad categories based on their general characteristics. These include the following structures:

3.3.1 Seawalls

Seawalls are rigid structures that protect the land by resisting coastal processes. They may be vertical, sloping, or stepped; and they are traditionally constructed of mass or reinforced concrete, grouted rocks or blocks, and timber or steel sheet piling or timber posts. They require a well-founded toe, preferably deeply piled or installed on hard substrate, to avoid scours and undermining. Additional toe protection using a semirigid structure may also be required to prevent scours and undermining. The structures must be robust due to the high wave loading, so they tend to be either massive structures or better suited to low- to medium-wave environments where wave loading is moderate. Runups and overtopping are concerns, as rigid structures do not tend to dissipate wave energy effectively. Backshore protection is thus often required to limit damage by wave overtopping.

3.3.2 Revetments

Revetments are generally sloping, semirigid structures that are able to move under wave loading, allowing some energy to dissipate and the structure to settle as the seabed or backshore changes form due to erosion or settlement. For this reason, semirigid structures are often better suited than rigid structures to higher-wave and dynamic environments, such as sandy beaches. Semirigid structures are generally sloped revetments, so they use more space than rigid structures.

Examples of semirigid structures include:

- rock revetments;
- concrete armor unit revetments;
- articulated blocks and blanket structures;
- cut and stacked blocks; and
- sand-filled geotextile bags held under gravity.

Due to the flexibility of the outer layer of a semirigid structure, a filter layer is required to contain the fine land material behind. This filter may be made of smaller aggregates or geotextile fabric. This filter essentially forms the barrier between land and sea, with the armor protecting the filter from wave attacks.

3.3.3 Breakwaters and Groynes

Breakwaters and groynes interact with wave and sediment-transport processes to either contribute to hydrodynamics (wave energy and flow direction) or trap sediment. Breakwaters and groynes can be constructed of many of the same materials as seawalls and revetments, but they have two sides rather than land in back of them.

The structures may be emergent, semi-submerged, or submerged. Submerged and semi-submerged structures act by breaking or refracting waves, rather than by absorbing or reflecting them, to dissipate energy and to slow the transport of sand (but not completely stop it). While less visually intrusive, they are less effective than emergent structures, particularly during high water-level and wave conditions, and this can result in beach erosion.

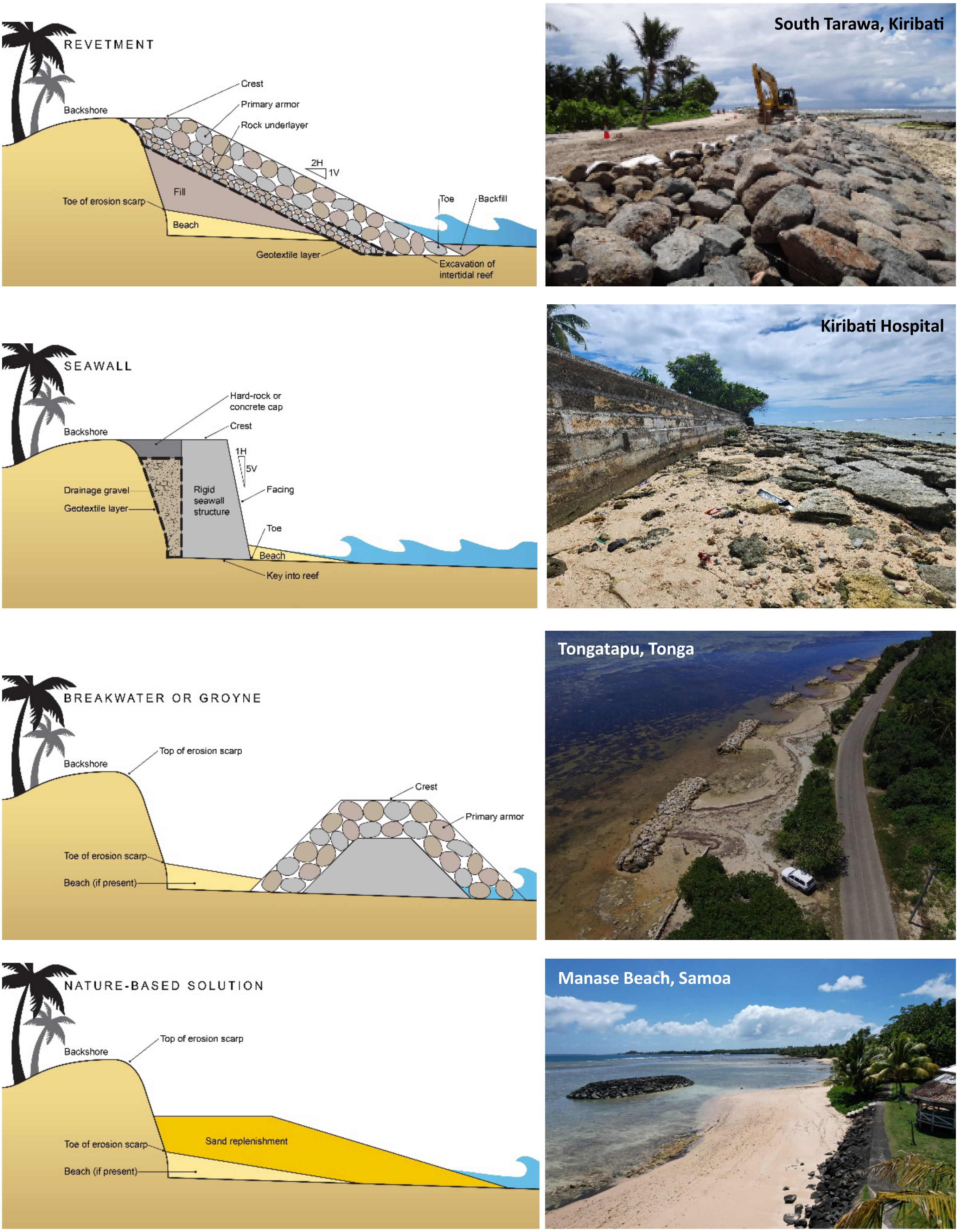
3.3.4 Nature-based Solutions (NbS)

NbS, also referred to as "ecosystem-based approaches" (e.g., in PRIF 2017b) or as "blue–green solutions," aim to protect the shoreline from coastal hazards by replicating natural processes and/or by maintaining healthy ecosystems. These may include the installation of offshore vegetation, such as artificial reefs or mangroves, to dissipate wave energy before it reaches the shoreline (generally applicable only in sheltered locations); the installation of backshore vegetation to reduce the extent of wave runups, reduce damage potential, trap wind-blown sand, and improve ecological connectivity between the land and sea; and the improvement of coral reef health to ensure that coral sand production is maintained and that beaches are nourished, using sustainable sources to dissipate energy, protect the shoreline, and to improve the amenity value. NbS generally take some time to implement, and they require higher levels of maintenance, compared with hard protection structures (PRIF 2017b).

3.4 Typical Failure Mechanisms

Coastal protection works can fail through a number of different mechanisms. Typical failure mechanisms are described in Figure 15, with a diagram and photo to demonstrate each one. Further details on identifying failure mechanisms are provided in subsection 6.2.3, and on potential repair strategies in section 7.2.

Figure 15: Common Types of Coastal Protection Solutions in Pacific Island Countries



Sources: The authors; James Lewis, Kiribati Hospital photo; Tom Shand, South Tarawa and Manase Beach photo; A. Webb, Tongatapu photo.

Table 5: Potential Failure Mechanisms in Seawalls and Revetments, and Indicative Damage

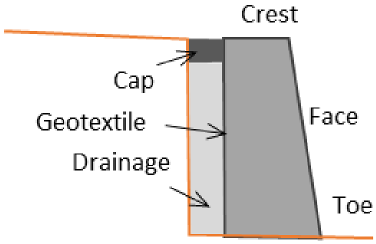
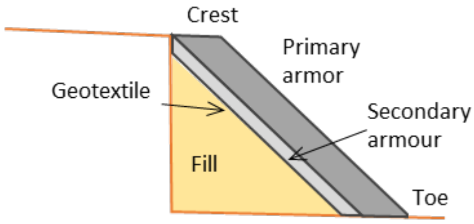
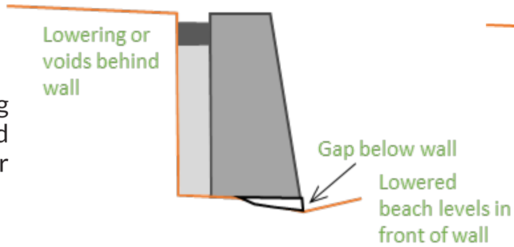
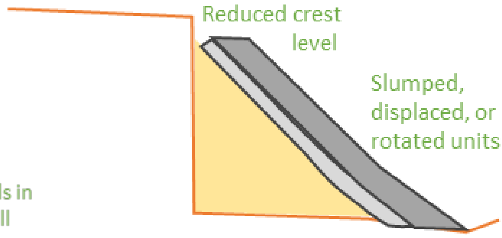
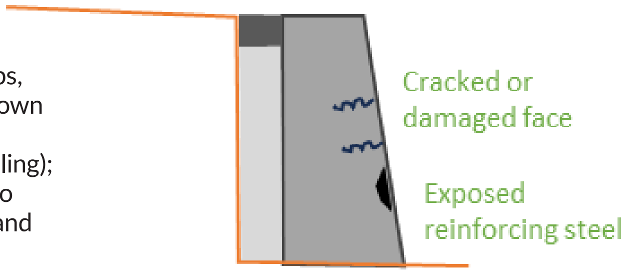
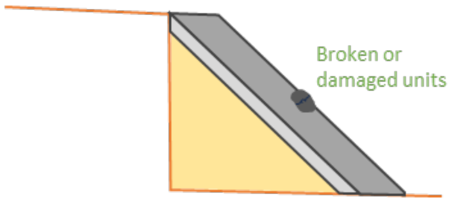
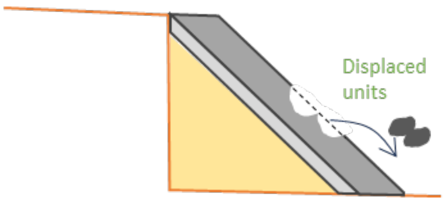
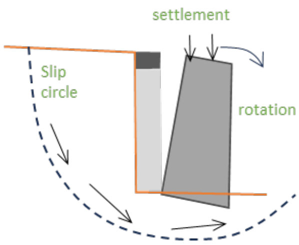
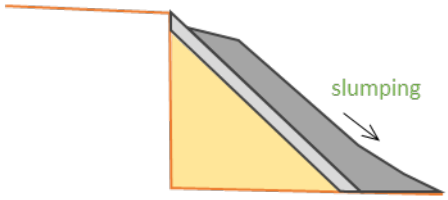
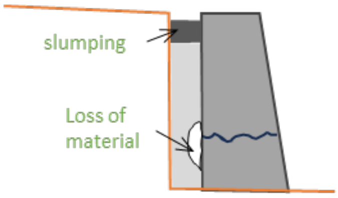
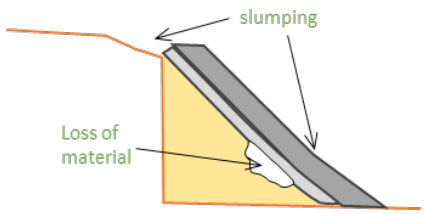
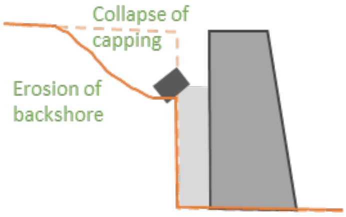
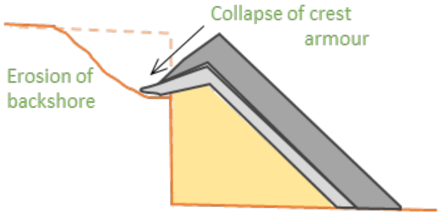
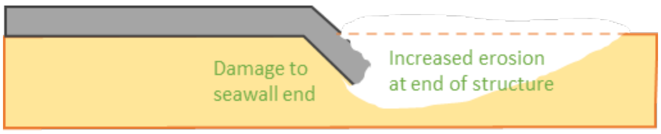
	Seawall	Revetment
Potential Failure Mechanism		
Toe Erosion When the level of the foreshore or of the beach in front of a structure drops below the footing of the structure, leaving a gap and causing the wall to subside and/or collapse into the gap		
Structural Degradation Degradation of the faces of rigid seawalls or access steps, or of the concrete cap or crown wall (including corrosion, abrasion, cracking, and spalling); possibly leading over time to loss of strength in the wall and eventual collapse or loss of internal material		
Armor Damage Damage to individual units, rocks, or bags within a revetment, possibly be due to: poor quality of the rock-armor unit, incorrect filling or placement of geotextile containers, or vandalism		
Armor Displacement Displacement or loss of individual units within a revetment, possibly due to undersized or incorrectly placed rock or armor.		
Geotechnical Failures Failures associated with movements of the structure over the ground, including settlement (sinking into the ground), outward rotation (when the crest rotates out), or slip circle failures (when the toe rotates out)		

Table 5: Potential Failure Mechanisms in Seawalls and Revetments, and Indicative Damage (continued)

	Seawall	Revetment
Loss of Internal Materials Loss of materials within or behind the structure due to piping (flow paths established through the structure) and/or failure of the geotextile, causing a lowering of land levels at and behind the structure crest, also possibly causing the structure to slump or crack		
Crest Damage Damage to the crest of the structure and backshore, usually caused by wave overtopping, resulting in scours and the potential collapse of the crest		
Outflanking and End Erosion Erosion adjacent to a structure that may be exacerbated by turbulence at the structure's ends, causing the structure to be "outflanked," resulting in loss of support from behind the structure and collapse		

Notes:
1. All images are cross-sections unless otherwise indicated.
2. An empty cell indicates that the column head does not apply.
Source: The authors.

Figure 16: Examples of Typical Failure Mechanisms in Coastal Protection Works on Pacific Islands

Source: The authors, except where noted.

3.5 Potential Effects of Coastal Protection Works

Coastal protection works are generally undertaken for a specific purpose, such as land protection, reclamation, or the reduction of wave overtopping and inundation. When coastal protection works are in the design stage, consideration should be given to the potential positive and adverse effects of such works on local communities and the environment.

3.5.1 Negative Effects on Coastal Processes

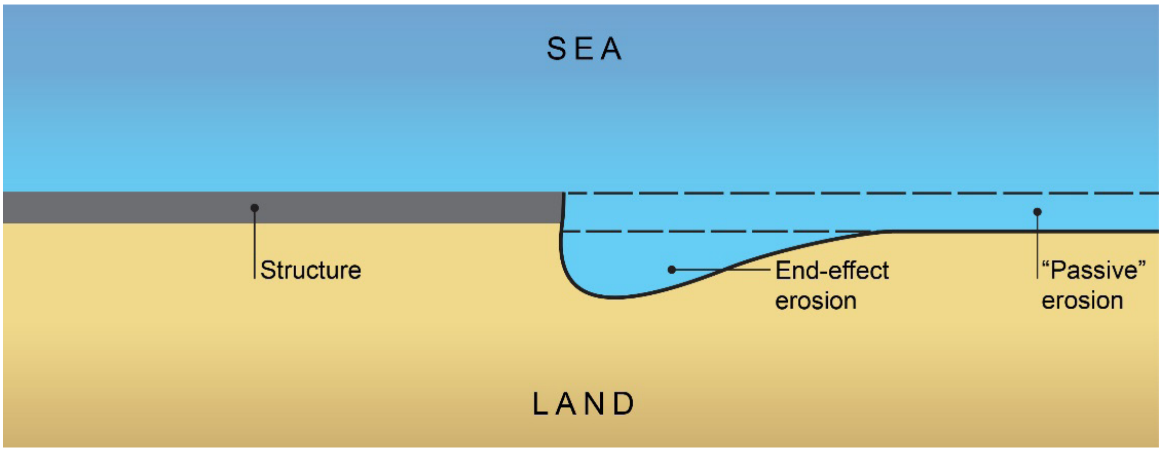
The effects on coastal processes—including potential changes to waves, currents, and sediment transport—can result in changes to the form and function of local and adjacent coastal areas. A classic example is the use of a groyne to build up a beach in front of an area with coastal erosion concerns. The groyne may build up sediment and widen the beach locally, but if it is not designed in accordance with the natural coastal processes, it may cause down-drift erosion to neighboring coastlines.

Another example involves coastal protection structures such as seawalls and rock revetments when they do not allow the natural movements of the shoreline position. On a naturally eroding coastline, for instance, there is a lowering of the beach level over time, but this effect can be accelerated by scours and wave reflections caused by the structure, eventually resulting in the loss of high-tide beach space, and possibly compromising beach access and recreation.

Other examples of effects on coastal processes include the following:

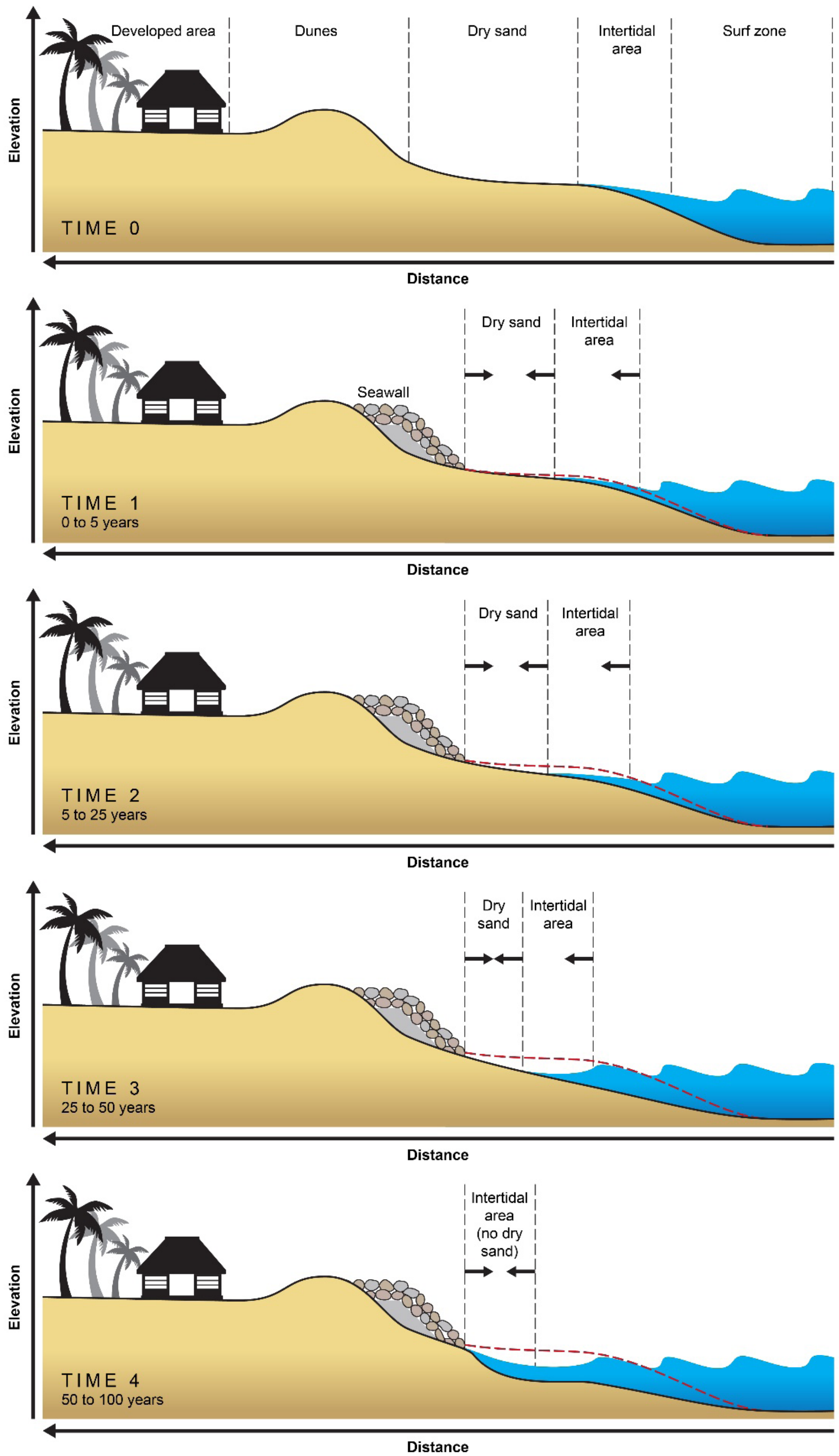
- Sediment may be locked up behind a seawall or underneath a rock revetment, and thus prevented from playing its natural role in of the dynamic coastal system.
- Flow acceleration and scours caused by a seawall or revetment can promote the erosion of an adjacent coast that has a different natural alignment to the structure.
- When sediment is redistributed from neighboring sections of the coast to a bulge behind an offshore breakwater, the result can be flank erosion on adjacent coastal sections if not properly managed by the breakwater design.
- Wave reflection off seawalls can cause resonance issues in harbors and coastal areas that may affect navigation.

Figure 17: Example of End Erosion



Note: End erosion occurs next to a structure on an eroding coast.
Source: The authors.

Figure 18: Example of Gradual Change in Beach Width on an Eroding Coast



Source: The authors.

3.5.2 Negative Effects on Ecology

Coastal structures can have adverse effects on the local ecology by occupying, removing, or influencing habitats and by interfering in the movement of species through the environment. Ecological effects can also occur during the construction and investigation phase of coastal engineering works, through such factors as how the site is accessed, how material stockpiles are managed, and how hazardous materials and waste are handled. Examples of negative ecological effects include:

- the removal of coastal vegetation, including habitat-forming trees and plants (e.g., mangroves), during the construction or occupation of engineered coastal structures;
- smothering of habitats, including bird and turtle nests on beaches and fish habitats in reef or intertidal waters, during the construction or occupation of coastal protection engineering works;
- prevention of wildlife passage due to unnavigable batteries, including fish access to streams where a seawall and culvert are being built over a natural channel;
- construction of coastal structures made from imported rock or concrete, which can have a high carbon footprint and are increasingly becoming a consideration in the optioneering phase of the design process; and
- the potential breakdown of synthetic materials such as geotextiles.

Ecological effects of coastal structures. Two examples of adverse effects of engineered coastal structures are: at left, synthetic materials released when a structure breaks down; and at right, the trapping of debris Source: The authors.

3.5.3 Negative Effects on Local Communities

Beaches and coastlines are valued natural assets in the Pacific islands. The lives of people living on a coast can be adversely impacted by structures whose design and construction do not take their needs into account. These negative effects could include:

- a reduction in access between the land and sea, caused by seawalls or revetments with no access steps or ramps;
- the sullying of what were once beautiful landscape or seascape views, thereby detracting from this natural coastal amenity;
- a reduction in beach space when a coastal protection structure reduces the availability or use of recreational areas, and reduces access along the coast;
- changes in sand flows and wave movements that, in turn, alter the mechanics of nearby surf breaks, which are regarded by some communities as valuable recreational amenities and a potential source of tourist income; and
- the interference in, or relocation of, buildings or other assets of cultural significance, including graves, social halls, community meeting places, and sacred or historic sites.

A shrinking beach. These photos show an example of the gradual change in a beach area fronting a seawall on an eroding coast. All the photos were taken at low tide.
Source: Tom Shand.

3.5.4 Positive Effects of Coastal Protection Works

In many situations, coastlines in developed communities are degraded by long-time development, and may not represent an environment with healthy habitats, recreational spaces, or social value. In these situations, a well-considered coastal-enhancement project can improve the natural and social environment, while also protecting assets from erosion or inundation.

Coastal engineering is increasingly recognizing the value of enhancing environments, rather than just protecting assets. Examples of positive effects can include the following:

- The protection of assets through the implementation of an appropriately designed coastal protection structure can improve the local property values and the well-being of coastal residents; it can also facilitate economic benefits from tourism.
- Coastal protection planning is increasingly incorporating ecological restoration into structural designs, or including an "offsetting" capacity to improve the overall habitat areas or natural processes that could be impacted. Examples include the installation of planted areas or wetlands, and use of "living seawall" designs to boost the settlement of marine species on grey infrastructure. Another option is the creation or enhancement of reef structures that provide coastal protection and habitats; these could include coral plantings or the restoration of a natural coral reef.
- In some locales, coastal structures can improve access to the sea and provide a place for the community to gather near the coast. The incorporation of community needs into the form and function of a coastal structure is important, and can be used to enhance an area.

A benefit for the community.
This structure in Suva, Fiji is an example of the positive effects that coastal protection works can have. Local residents use it as an exercise area and meeting point.
Source: The authors.

4. Asset Management of Coastal Protection Works

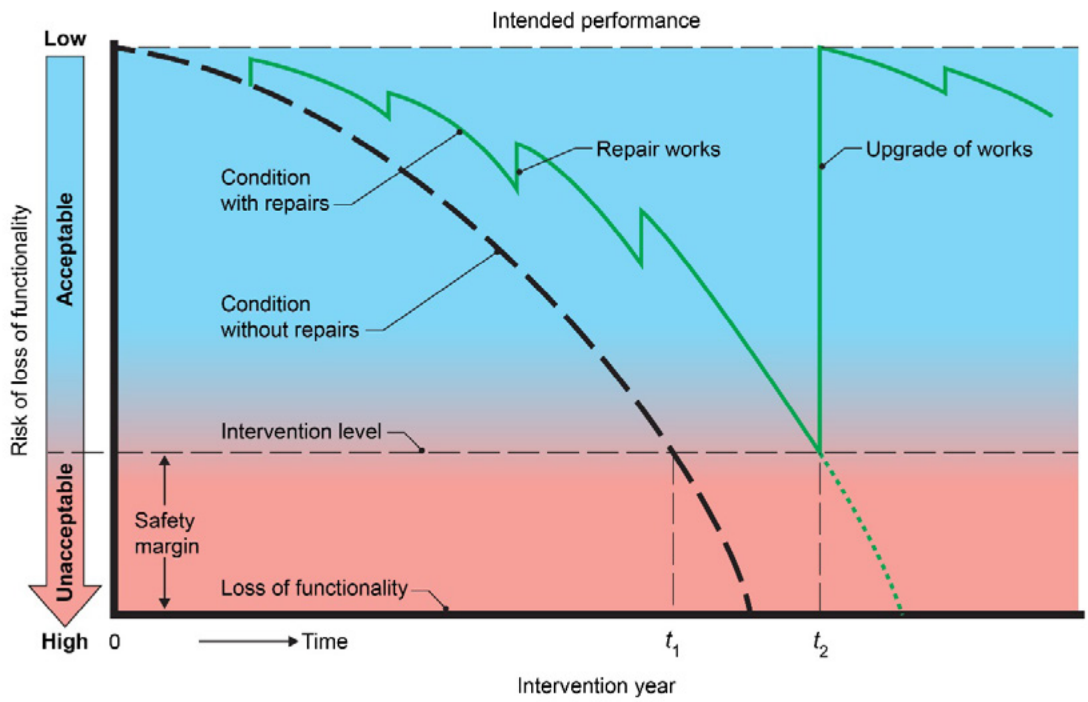
The intent of asset management is to preserve and extend the life of an asset once it has been constructed. The costs of undertaking asset management—including monitoring, maintenance, and repairs—should be treated during initial project planning and when securing funding as a critical part of the overall project budget.

Coastal protection works are built in dynamic and often high-energy environments. They are subject to frequent repeat loadings from "typical" waves and tides, and by less frequent but very high loadings from extreme storm events. Coastal structures are also exposed to variable sand levels on beaches, with scours and accumulation of sediment influencing the dynamics and functioning of these structures. Furthermore, the effects of climate change, particularly sea level rises, are changing the environmental baseline that these structures have often been designed for.

While some materials used in coastal protection works have long design lives in stable environments (e.g., rock and concrete), the structures almost always contain a combination of materials, including less resilient materials such as geotextile containers or coral blocks. It is therefore essential to continue monitoring the condition of coastal works, to ensure that changes in environmental conditions or the exposure of the less resilient parts of structures do not result in rapid degradation and possibly failure.

Figure 19 illustrates the evolution of a typical coastal protection structure that is undergoing gradual degradation, leading to decreased performance and a higher risk of functionality loss or failure. The pathway to compromised functionality can be slowed down by ongoing maintenance or timely repairs, but some form of intervention will be needed eventually—such as a rebuild, upgrade, or adaptation—if the structure is to continue providing the desired levels of service.

Figure 19: The Aging of a Structure, with and without Repair Works and Upgrades



t_1 = first year, t_2 = second year.

Source: adapted from: Construction Industry Research and Information Association (CIRIA). 2007. Monitoring, Inspection, Maintenance and Repair. In *The Rock Manual: The Use of Rock in Hydraulic Engineering.* 2nd ed. London, United Kingdom. https://www.kennisbank-waterbouw.nl/DesignCodes/rockmanual.

4.1 Existing Approaches in the Pacific Island Countries

The authors conducted a survey from 14 September to 14 October 2023 in 11 countries, many of them in the Pacific. The focus was on coastal protection works, and the respondents consisted of engineers, managers, and other practitioners with experience in the Pacific island countries (PICs). These results were used, along with the authors' own experience and knowledge of approaches to asset management in the Pacific, to derive the following points:

- A wide range of both engineered and nonengineered structures have been and continue to be used in the PICs.
- Asset-management databases for coastal protection works are not commonly used in the PICs with a combination of excel spreadsheets and in-house tools developed by consultants from developed countries.
- Inspections are undertaken at a range of intervals, often depending on the value and importance of the asset, but they occur most commonly every 6 months to 2 years or after significant storm events.
- A range of guidance materials are used for undertaking monitoring activities, including guidelines from the New Zealand Transport Agency (NZTA); repair, evaluation, maintenance, and rehabilitation (REMR) methodologies from Ports Australia; and *The Rock Manual: The Use of Rock in Hydraulic Engineering*, from the Construction Industry Research and Information Association (CIRIA 2007).
- Visual inspection meetings are most commonly used, following by photo comparisons, topographic and unmanned-aerial-vehicle (UAV) surveys, and the implementation of some proprietary systems.
- Photographic equipment is most commonly available, along with UAVs.
- Inspections almost always include the condition of the structure and, to a lesser degree, the effect of the structure on the community and environment, though it is noted that these assessments require greater resources (i.e., bigger budgets).
- Repairs carried out in the PICs were broad, given the range of coastal structures, but most often focused on the management of end effects, renourishment following storms, installation of grout bags, repair of armor units, and the replacement of displaced bags.
- Upgrades or adaptations have included adding toe berms and anti-scour protection, raising crests, and overlaying rock armor.
- Survey respondents from organizations that own and/or manage coastal protection works were roughly evenly split on whether to have a capital works program build new protection works or fund the maintenance of existing works.

Overall, the existing approaches to managing coastal protection works in the PICs vary widely. This is due to both the wide range of structure types and purposes, and to the range of countries and organizations within those countries that own and/or manage coastal works. This indicates that guidance providing consistent approaches to the monitoring and management of coastal works would be beneficial.

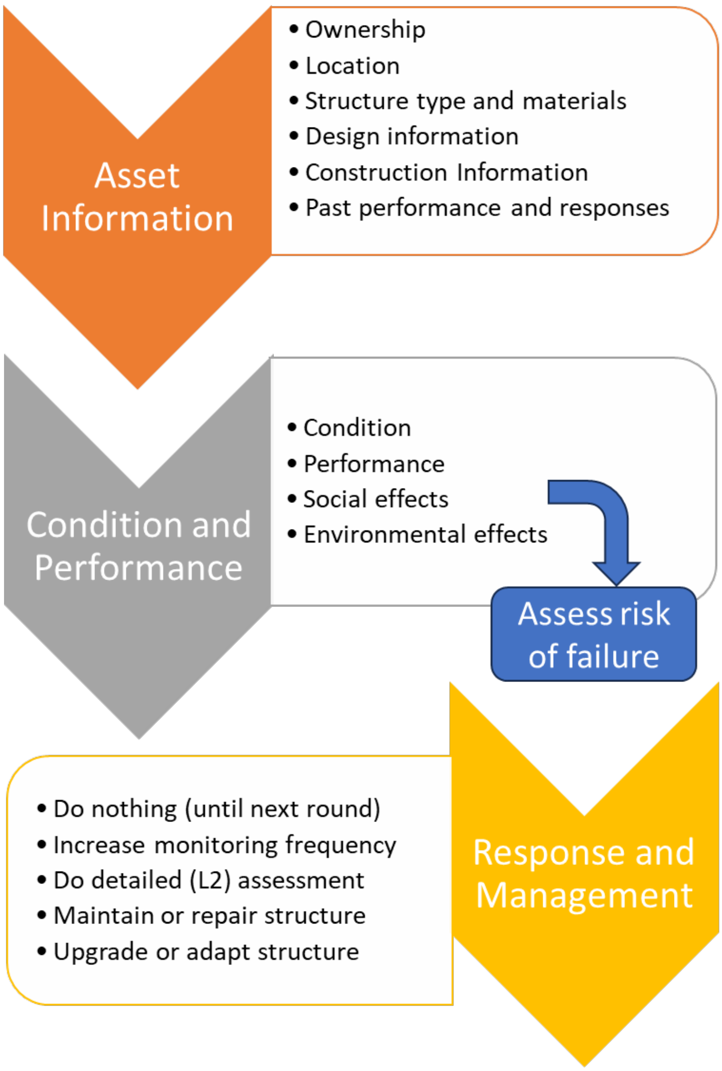
4.2 Proposed Asset Management Approach

The asset management approach presented here includes three main steps:

- **Collating asset information**, such as when the asset was built; its design intent (what it was intended to do); the structure's importance; any design information, such as the intended design event[3], level of performance, and design life; and construction information such as that found in as-built drawings and photographs. All this information provides the baseline that subsequent monitoring can be assessed against.
- **Monitoring the asset**, whereby the physical condition and performance level of a structure is assessed to determine if it is at risk of failure without intervention and whether it is performing its intended function.
- **Managing the structure**, with appropriate responses, given the identified level of risk based on the condition and performance assessment. The level of risk is a function of both the condition and performance of the structure, and of the structure's importance, with interventions for very important structures given higher priority than those for less-important structures.

An overarching flow chart illustrating this process is presented in Figure 20. This process follows the general approach set out by PRIF (2020) for assessing an asset's condition and risk of failure, and then determining an investment strategy.

Figure 20: An Approach to Asset Management



L2 = Level 2.
Source: The authors.

3 The event which the structure is designed to withstand, e.g a 10 year return period event or a Category 3 cycle.

Specific details on the information required for each step and how it should be documented is set out in the Operations Manual (Part II). The accompanying Inspection Form (Appendix 1) includes fields for:

- **inspection details:** information about where the structure is, who owns it, and who is doing the inspection;
- **structural details:** type of structure, construction materials, asset intent, and the specifics regarding the geometry;
- **environmental setting:** the presence and details on adjacent beaches and reefs, and wave exposure;
- **elemental assessment:** the viewing of each element of the structure's design, including the toe, face, underlayers, backfill, and other key structural elements;
- **overall assessment:** determining a performance rating (is the structure preforming as intended) and a condition rating (based on the elemental assessment), and providing an evaluation of any possible failure mechanisms;
- **effects assessment:** notes on the potential adverse and positive effects within an environmental and social context; and
- **response notes:** a risk assessment method for guiding the next steps (section 7).

A basic Asset Management Database (Excel format) provided in Appendix 2 could be used to collate and store asset information and information on monitoring and proposed responses.

5. Asset Information

Information about an asset must be compiled before a monitoring regime can be implemented. This information should generally be available once a structure has been built and handed over, but in the case of older structures, this information might not be available, so it will have to be derived. However, this step is generally only required before the first inspection.

This section describes the general asset information required to effectively manage a structure. Further details regarding the required fields are set out in the Operations Manual (Part II).

5.1 General Information

General information on coastal protection works may include the **asset's owner, current manager**, or **landowner**. They may or may not be the same party, but this information is important for undertaking inspections and future management.

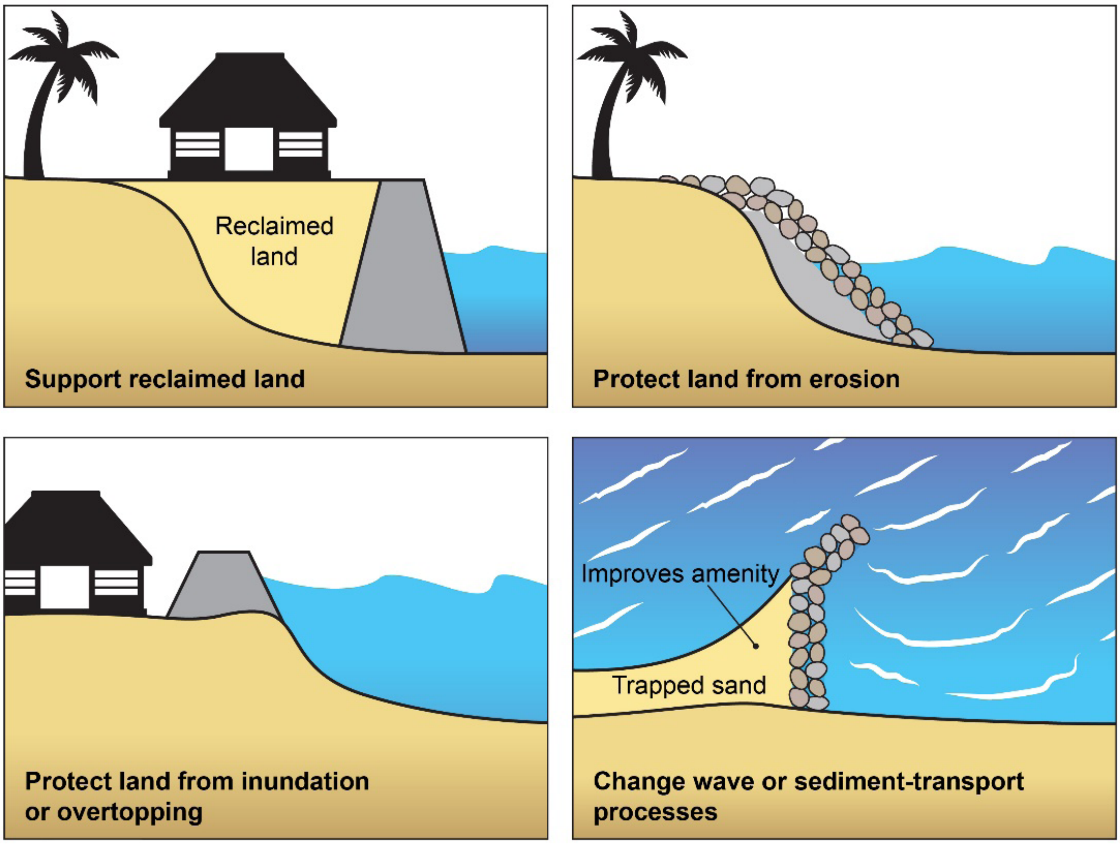
In addition, there are the asset's general characteristics, including its **location, length, structure,** and **crest height**. Also important are the **type of structure** (section 3.3), **construction materials,** and **engineering standard**.

- Engineered structures refer to structures designed and built using generally well-established and tested methods and guidance. Exceptions may include nonstandard structures, which can still be designed to an engineering standard, but will require specific testing (e.g., scale model testing in a hydraulic wave flume or basin) to confirm they can meet their design objectives.
- Non-engineered structures are not designed or built using such methods, so they are more susceptible to damage and failure (PRIF 2017b). They are also more difficult to manage, as their performance differs from that typical of engineered structures. For instance, a grouted block wall constructed without a geotextile is much more likely to fail due to the loss of fines through small cracks and gaps than an engineered structure with a geotextile and drainage, even if the same block materials are used.

Knowledge of the **purpose of the asset** is critically important for determining whether it is performing as intended. Generally, the asset will be constructed to perform a specific task (or tasks), which may include the following:

- Supporting reclaimed land, whereby the structure supports a new patch of land. Often the toe of such structures is located in relatively deep water (i.e., below the mean sea level), as the reclamation will have pushed the coastal edge beyond the existing shoreline.
- Protecting land from erosion, whereby the structure is intended to protect land from being undermined by an erosion of the coastline. Note that the structure does not protect the "beach" or any other adjacent land along the shoreline, so these areas will still be susceptible to erosion. In fact, they may be even more susceptible.
- Protecting land from wave overtopping and/or inundation, whereby the structure dissipates wave energy and limits the volume of water inundating the land behind the asset. While coastal protection works can limit static inundation when the water levels become higher than the land behind, this sort of protection is not generally sought in the PICs, as far more substantial engineering would be needed to prevent water ingress through groundwater and drainage conveyance systems.
- Modifying wave, current, or sediment-transport processes, whereby waves may be broken and currents redirected by breakwaters, and sand may be trapped by groynes. Note that when sediment is accumulated in one location, it may result in the loss of sediment in another.
- Providing amenity, whereby access to the coast is improved, amenity space is provided, the beach is nourished, and activities (fishing, diving, or surfing) are facilitated.

Figure 21: Functions Fulfilled by Coastal Protection Works



Source: The authors.

Lastly, specifying the **importance level** of the structure is critical for determining the appropriate response. While this is ultimately a decision for the asset owner and the community, examples of importance levels are shown in Table 6. It should also be noted that the importance level of a structure often influences the design event selected, with higher-importance structures often having a larger (or lower-likelihood) design event (section 5.2).

Table 6: Examples of Importance Levels of Coastal Protection Works

Importance Level	Description	Example
1 – High	Coastal protection works protect or support vital infrastructure or key community assets. Failure will lead to significant costs and even to loss of life.	 **Example of high-importance works.** This is the Nippon Causeway, Betio, in South Tarawa, Kiribati

Importance Level	Description	Example
2 – Medium	Works support or protect public roads and small areas of private land. Failure will lead to significant costs.	 **Example of medium-importance works.** This is a revetment protecting Temaiku Road, in South Tarawa, Kiribati
3 – Low	Works support or protect beaches or remote areas of public land. Failure will lead to low or moderate costs.	 **Example of low-importance works.** This structure is protecting private land in Tuvalu.

Source: James Lewis.

5.2 Design Information

Having accurate design information allows monitoring data to be compared against a baseline. Refer to PRIF (2017) for further details on the design process summarized just below:

The **design criteria** specify the expected **performance level** of the structure, i.e., if the structure is not expected to be damaged during events that are less severe than the design event, or if wave overtopping will be limited to tolerable levels during the design event.

The **design event** defines the event frequency for which a structure is designed. For example, damage to the structure may start occurring during a return period of 1 in 100 years or longer, or a beach replenishment may protect the backshore during a return period of less than 1 in 20 years. The design event may also need to consider changes in the mean sea level during the design life.

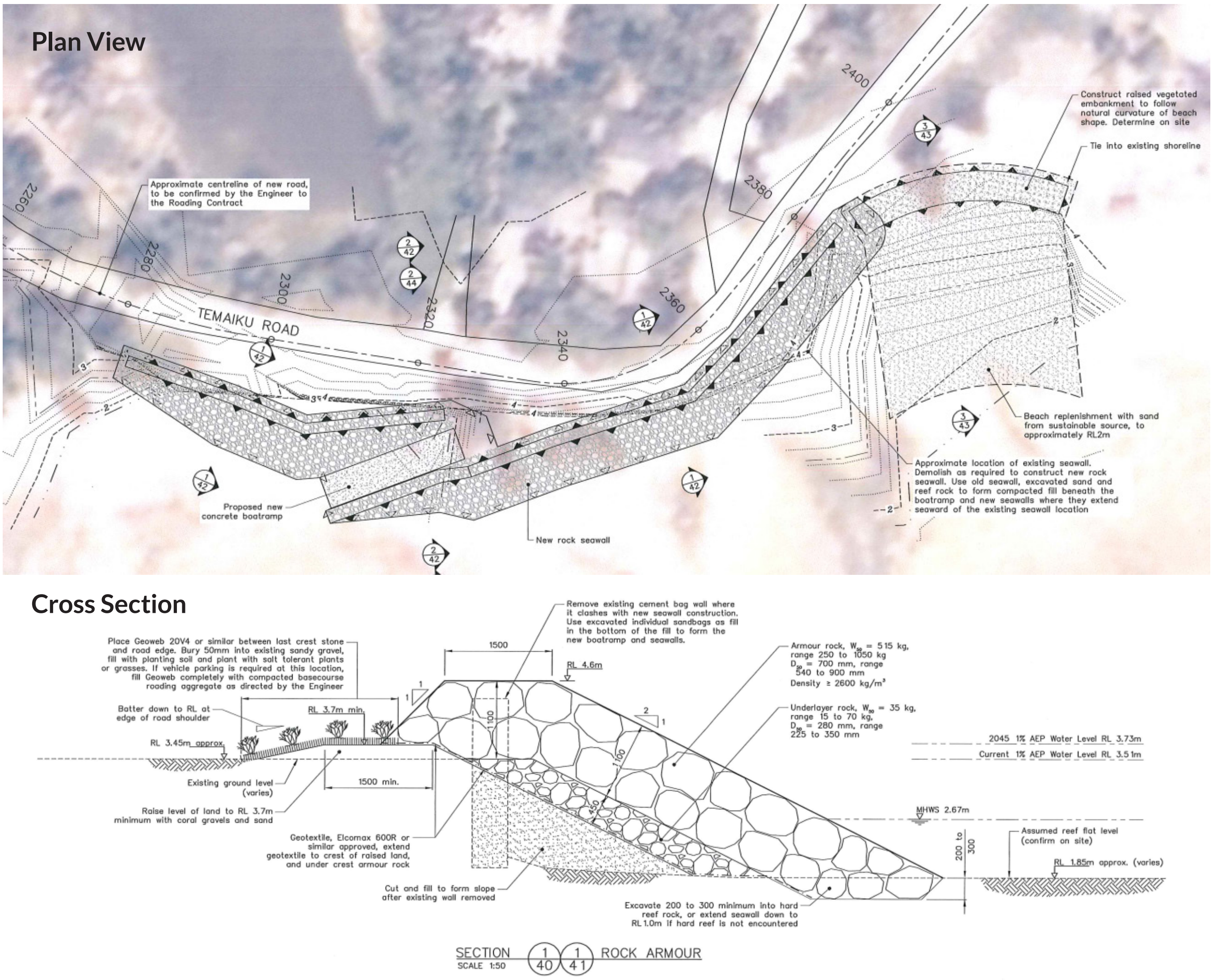
The **design life** is the intended period during which the structure is expected to meet its design objective. PRIF (2017b) discusses the generally expected design lives of various types of structures, but it is worth noting here that rock structures tend to have design lives of 50–100 years, concrete 30–50 years, and geotextiles 5–20 years.

Such information is generally provided in a design report or in a basis of design (BoD) document.

Design drawings and specifications provide a record of what was requested to be built. Drawings typically include plan views of the works from above and cross sections of the works, along with the sizes and dimensions of the various components and details regarding their locations (e.g., stormwater connections or access). Specifications include general requirements such as the hours of work, site access, environmental considerations, materials, construction and testing standards, and the methods by which the works will be measured for payment. These documents are useful for understanding the intended works.

Environmental and social impact assessments are intended to identify the likely or potential effects of the proposed works on the environment and community. By considering the potential adverse effects of the works, as well as the benefits, an informed decision can be made as to whether the works should continue and whether any mitigation of adverse effects are required. If the planners understand the potential effects identified during the design process, the effects observed during monitoring can be placed into context (e.g., whether they are expected or unforeseen).

Figure 22: Examples of Construction Drawings for Coastal Protection Works



AEP = Annual Exceedance Period, D_{50} = Average diameter of the 50th percentile sized rock, kg = kilograms, m = meters, m^3 = cubic meter, mm = millimeters, MHWS = Mean High Water Spring tide level, min. = minimum, RL = Reduced Level, W_{50} = Average weight of the 50th percentile sized rock.
Source: Kiribati Roading Rehabilitation Project, design by Tonkin + Taylor.

5.3 Information on Asset Construction

While coastal protection works generally seek to replicate their design drawings, coasts are dynamic environments, and seabed levels may fluctuate before or during construction; moreover, the ground or other aspects of a site may not be as expected. Therefore, as-built drawings are produced at the conclusion of works, based on an as-built survey to indicate exactly what has been constructed. These drawings, along with imagery taken during and immediately following construction (photos below) are important for making comparisons with the current condition of a structure and for evaluating changes.

Construction of a Revetment. These photos show various stages in the construction of a coastal revetment in Temaiku, South Tarawa, with the bottom-right photo showing the revetment after completion.
Source: The authors

5.4 Post-Construction Stage

The handing over of a coastal protection asset should include information on the monitoring regime, including the specific types of **monitoring required** and the recommended **monitoring schedule**. The monitoring could occur, for instance:

- at specified time intervals (i.e., 6 months to 5 years); or
- after specific events, such as a 10-year return period or larger storm event, or after an event during which waves washed over the top of a seawall.

The required monitoring may entail:

- a general assessment of the structure's condition and performance;
- specific aspects of the structure that are more susceptible to failure, and thus require more frequent attention, such as fixings, railings, and parts of the structure within the tidal range, which are often susceptible to corrosion and damage; and
- the condition of the surrounding environment, such as the positions and levels of adjacent beaches.

Note that the required frequency of monitoring may vary for different aspects of the structure and surrounding environment. For instance, beach surveys could be undertaken at 6-month intervals, but inspections of the structure itself could occur at 2-year intervals or following significant storm events.

Following the monitoring rounds, any **identified issues** should be captured in the asset-management database for comparison during future rounds. This is important, as it is often the rate of change that reveals a potential problem (e.g., changes in the shoreline position or in the level of the structure's toe), rather than a one-off value.

A record of **previous works** undertaken to maintain, repair, or upgrade the structure should be captured. This includes a record of the works undertaken, the reasons for the works (to inform the monitoring if the same reasons emerge again), the dates of the previous works, and any photos or drawings available.

Similarly, any **future works or adaptation** identified during the design stage should be noted, including any triggers or signals for works. Signals are used to provide an early indication that a trigger or decision point is approaching (Lawrence et al. 2020). For coastal protection works, this could take the form of a number of flooding or overtopping events, or it could involve a specific amount spent on repairs or beach replenishment.

6. Condition and Performance

Asset monitoring considers the present condition and performance of the works and the effects those works are having on the community and environment. This information is used to determine the appropriate response (section 7). The monitoring should consider whether any of the observed issues will be resolved before the next monitoring round.

This section provides an overview of the typical inspection methods, condition and performance assessment, and of how inspections can affect the community and environment.

6.1 Overview of Coastal Inspection Methods

6.1.1 Visual Inspection

A site visit is crucial for gaining an appreciation of the works, the condition of the asset, and the surrounding coastal environment. When conducting a visual inspection, it is important to first consider how the works fit into the wider coastal environment. On this scale, it is good to think about the following questions:

- What type of coastline is the structure is located on? For instance, is there a fringing reef or beach?
- What is the land used for landward of the structure? And how far is the asset from the coastal edge?
- Is the site exposed to low-, moderate-, or high-energy waves on a regular basis? Or is it exposed only during extreme events?
- Where does the structure sit with regard to the tide? For instance, is it above the tide or in an intertidal or subtidal location? Look for debris marks and water marks, as these will help provide an answer.
- If there is a beach, what types of materials are present (e.g., sand, gravel, reef origin, or terrestrial)? Also, are there signs of erosion due to scours?
- How is the structure aligned with the adjacent shoreline? Is the neighboring shoreline also protected, or is it natural and offset landward?

The visual inspection could then consider the overall works to identify whether they are generally uniform along their full length, or if discrete changes in the design or existing conditions have occurred. This can help identify how many inspection sections need to be considered in detail.

The detailed inspection can then focus in on each discrete section, the condition of discrete elements (section 6.2), and on the performance of the structure (section 6.3).

Different methods are available for a visual inspections, all of which can help provide a highly detailed understanding of the structure.

6.1.2 Physical Walk-Over Inspection

It is always advisable to walk around the site, in order to appreciate the structure as a whole, before focusing on specific details and filling out the **Inspection Form**. This can be done by going along the full length of a coastal structure, paying attention to changes in the design, and noticing the structure's general condition. At low tide, it is usually possible and beneficial to walk along the toe of a seawall or rock revetment to look at the structure's condition, its foundation, and its interaction with the environment. Viewing the structure from the crest may also be useful and accessible in some locations. Adjacent shorelines or a higher elevation nearby can also be useful vantage points from which to observe the general condition and environmental setting of the structure. During a manual walk-over inspection, you can take notes or draw sketches to better understand the structure and environment; or you can leave markers in areas of interest and then return later for a closer look when filling out the Inspection Form. And it is always worthwhile to take as many photos of the structure as possible.

Different ways to view a revetment. These photos show a revetment made of stacked geotextile containers, the top one taken during a walk-over visual inspection, the middle one taken by a drone, and the bottom one taken underwater.
Source: Tom Shand

6.1.3 Unmanned Aerial Vehicles

When on-site, it is not always possible to appreciate the full scale of a structure's features from an accessible ground location. An unnamed aerial vehicle (UAV), or drone, is a great help in visual inspections because it can serve as a qualitative visual or survey tool. UAVs can provide a clear view of how the structure fits into the surrounding environment, including other assets that are being protected. UAV images can be taken from an oblique angle, with the UAV flying over the water, facing the shoreline. It would be necessary to take care with the lighting, however, as images are best with minimal shadow on the coastal edge and with reduced sun glare. Aerial UAV photos can be taken from a distance to show the wider context, and from close up to show the details of individual armor units or sections.

6.1.4 Views of Underwater Features

Many coastal protection works are located partly underwater at all tides. In other cases, an inspection may not be possible even when the toe is visible at low tide. It is almost impossible to gain a clear view of a structure's condition by viewing it from the air through the surface of the water. In many Pacific island locations, however, water clarity provides good conditions for underwater inspections, which can be conducted in several ways:

- One can dive or snorkel along the structure, following appropriate health and safety procedures. Low-cost cameras such as the GoPro allow detailed videos and photos to be collected during a swim along the structure. In some situations, an underwater tablet (with pencil and plastic clipboard) can be used with waterproof paper to document details when swimming.
- If conditions are not appropriate for diving or snorkeling, a waterproof camera on a pole can be useful for taking photos or videos of underwater sections of a structure. Then an assessment can be made back at the office. An option for inspecting in the shallows (i.e., knee-deep water) is to use a "glass bottom box" that provides visual clarity of the underwater world to the inspector's eye.

- In some locations, gaining access by diving, snorkeling, or using a camera pole can be complicated. In these cases, a remote-control underwater vehicle that is tethered to the land can be used to collect underwater videos or photos.

6.1.5 Satellite or Aerial Images

Before heading to the site, or when compiling site notes back at the office, it is useful to review the wider environment, and to assess how it has changed over time. Historic aerial photographs may be available for some sites from tools such as Google Earth. Other aerial image providers can be used to access high-resolution planform images of most locations, with some locations having multiple images that show environmental change. These can be a valuable tools for understanding changes in the coastline at or near the structure. Tools like Google Earth can also be used to take simple measurements, such as the length of a structure, width of the reef, and proximity of assets to the coast.

Figure 23: Example of How Satellite Images Can Show Gradual Changes in the Wider Environment

Source: Google Earth. *Landsat/coppurnicus* Sources: Landsat/Copernicus (photo from 2003, 2014), CNES/Airbus (2017, 2024).

6.1.6 Topographic Surveys

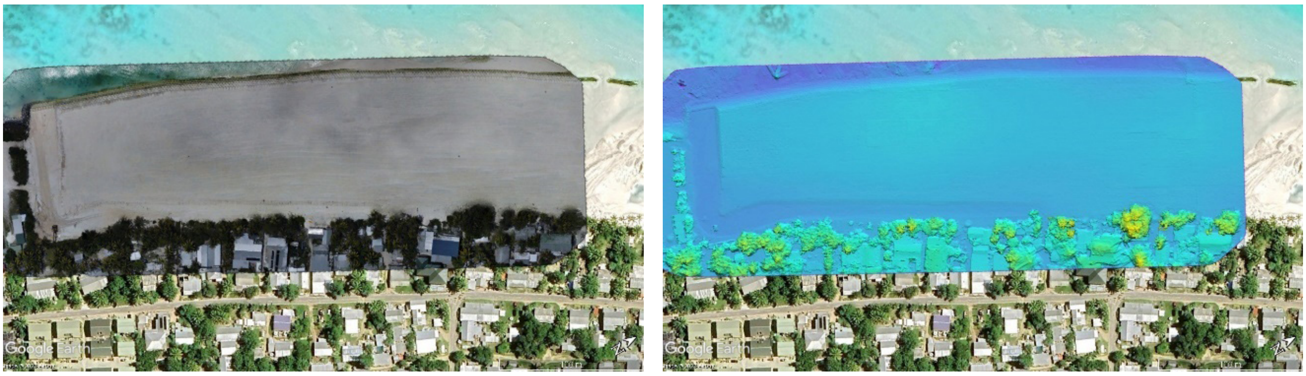
Topographic surveys provide quantitative information on the spatial characteristics of coastal works. Important features such as crest level, toe level, and slope are important to capture when undertaking a topographic survey of a coastal structure. A simple topographic survey can be undertaken with some basic training, but a professional survey from a qualified surveyor is generally required for obtaining engineering-design-level information. Many survey methods are available and the technology is improving rapidly, so it is possible to conduct high-quality surveys that are detailed and relatively cost-effective. These can be manual ground surveys, such as laser leveling or surveys done with a real-time kinematic (RTK) global positioning system (GPS), or mostly autonomous surveys such as UAV photogrammetry or laser-scanning light detection and ranging (LiDAR).

For all survey methods, it is critical to have known data that can be related to previous surveys and construction drawings. It is important to capture sufficient detail to describe the crest elevation; toe elevation; slope of the seaward-facing edge; structure outline (width and length); and any features that cross the structure, such as culverts, drains, steps, ramps, and trees; and the proximity of other assets.

Commonly used methods are described below:

- **Laser leveling**. Laser leveling is a survey method in which one person operates a total station on a tripod and a second person uses a staff and prism to collect topographic points. When undertaken with appropriate training in equipment setup and reference to benchmarks, the laser level method can provide highly accurate point measurements of elevation. This method provides accurate ground measurements, but can be limited with regard to spatial density due to the manual requirements. However, a benefit of manual surveys is that the surveyor can visually assess the structure at the same time. The laser leveling method can also provide ground points for submerged areas, by having someone with a staff walk in waist-deep water.
- **Real-time kinematic survey.** An RTK GPS utilizes a specialized global navigation satellite system (GNSS) to collect topography data using a rover and or base station. The rover can collect point data with suitable vertical and horizontal accuracy to reconstruct the topography of a structure. An RTK survey can be undertaken by a single operator or by multiple operators, but the manual collection of each point can limit the spatial coverage. A disadvantage of using a GPS is that vegetation coverage can limit where points can be collected. An RTK survey can also collect topography points in submerged areas by having someone with a staff walk in waist-deep water.
- **Photogrammetry.** The advent of relatively low-cost UAVs with built-in GPS has resulted in the widespread use of photogrammetry for topographic surveys. High-quality topographic information can be obtained from a standard off-the-shelf UAV, with a very high point density and detailed topographic data. The photogrammetric method reconstructs topography by using GPS-tagged oblique aerial photos that overlap each other; for a small site it can produce an elevation grid with a spatial resolution of <0.1 m. Post-processing methods are necessary, as they can produce an orthomosaic for visualizing the site, a gridded elevation surface, and a three-dimensional point cloud. The detailed imagery enabled by this high resolution can be used in structure assessments to measure rock sizes, assess slopes, and count quantities of materials. A limitation of standard UAV photogrammetry is that the reconstructed terrain does not accurately capture areas underwater or in the wave wash zone. Another limitation is that the standard post-processing methods will only accurately reconstruct a digital surface model, which will include objects such as cars, park benches, and vegetation, as well as people. In areas of thick vegetation, it can be difficult to estimate the underlaying ground level (digital terrain model) using the additional post-processing required. An engineering assessment usually needs to filter out these "nonground" points to be able to reconstruct the underlying terrain. However, this can be a complicated process for nonprofessional surveyors.

Figure 24: Example of an Output Orthomosaic and of a Digital Surface Model



Note: The output orthomosaic (left) and digital surface model (right) were developed based on a coastal survey of a site in Funafuti, Tuvalu, using a low-cost, off-the-shelf drone and post-processing software.
Source: James Lewis.

- **Light detection and ranging**. LiDAR surveys provide accurate measurements of topography using high-resolution laser scanners. They can be undertaken at the national scale by using airborne LiDAR methods (e.g., 1 m resolution) or at specific sites by using UAV LiDAR, a tripod, or car-mounted terrestrial laser scanner (e.g., 1 cm resolution). The collection and post-processing of LiDAR data should only be undertaken by a qualified professional surveyor. The resulting data provide a three-dimensional point cloud of coded elevation features and terrain surface for assessing the wider terrain levels and structure details. A special class of marine LiDAR sensors can be used in aerial surveys to measure underwater terrain (bathymetry). This can be ideal in the Pacific islands, where the water is clear, allowing coverage to depths of over 20 m below the surface.
- **Echosounder.** All land-based survey methods are limited to dry areas or very shallow water (<1 m deep). An echosounder uses a combination of GPS and sonar to measure the elevation of the seabed, and the equipment can be mounted on a survey ship, small boat, kayak, or jet ski. Collecting bathymetric data can be important in locations where the coastal structure is submerged at low tide, thus making surveying impossible. Using automated pinging, a vessel can travel at a slow speed, equivalent to "mowing the lawn," to reconstruct the coastal bathymetry.

6.1.7 Subsurface Measurement

Intrusive measurement may be required if a visual inspection or topographic survey cannot be used to determine the subsurface conditions or components of the structure. This is most likely to occur when design information on the structure is not available, resulting in a lack of knowledge of the structure composition.

Excavation, or digging a **test pit** through a structure manually, removes the outer layers to reveal the underlayer materials and subsurface conditions (photo below). This is particularly useful when determining if a geotextile has been placed beneath the underlayer rock or if, based on the soil conditions below the structure, there has been geotechnical failure.

Often the depth of the toe beneath the beach or seabed surface is unknown, particularly in the case of aged structures that may have been subject to ongoing slumping and topping up. **Scala Penetrometers** or **jet lancing** (blowing compressed air to sink a steel lance) are methods for determining the depth to a hard material such as rock through a granular material. Other nonintrusive methods of gauging subsurface conditions, such as **ground-penetrating radar,** may be used in some situations, particularly higher up on the structure.

Example of a test pit. This pit in Nelson, New Zealand, was dug through a revetment to determine subsurface and underlayer conditions (photo by the Nelson City Council).

6.2 Assessing a Structure's Condition

The condition of a structure provides an indication of how closely that structure reflects the as-built structure (i.e., the structure when it was new). As a structure ages, its condition degrades. Some parts or elements of the structure are likely to degrade more quickly than others; for example, fixings and access typically have shorter design lives and degrade more quickly than the main seawall or revetment structures. Therefore, it is useful to assess the individual elements before defining an overall condition rating.

Table 7: Asset Condition Ratings

Condition Rating	Description
A – Excellent	Asset is in as-new condition, with no wear, damage, deformation, defects, or deterioration evident in the overall structure or in the individual elements.
B – Good	Asset is in "like new" condition, with minor wear, but no damage, defects, deformation, or deterioration in the overall structure or individual elements.
C – Fair	Overall structure and/or individual elements show minor wear, deformation, damage, defects, or deterioration. The elements can generally be repaired at a reasonable cost.
D – Poor	Overall structure and/or individual elements show major deformation, degradation, deterioration, damage, or defects. Major repairs will likely be required to restore the structure, and may not be economically feasible.
E – Very poor	Overall structure and/or individual elements show major degradation, deterioration, damage, or defects. It will probably not be possible or economically feasible to restore the structure through repair.

Source: Pacific Region Infrastructure Facility (PRIF). 2020. *Methodology for Condition Assessment of Public Sector Infrastructure Assets in Pacific Island Countries*. Sydney. https://www.theprif.org/sites/default/files/documents/AssetConditionManual2020_web2_0.pdf.

6.2.1 Assessment Levels

An assessment of a structure's condition can be undertaken at two levels: Basic (Level 1) or Detailed (Level 2). The levels differ from each other as described here:

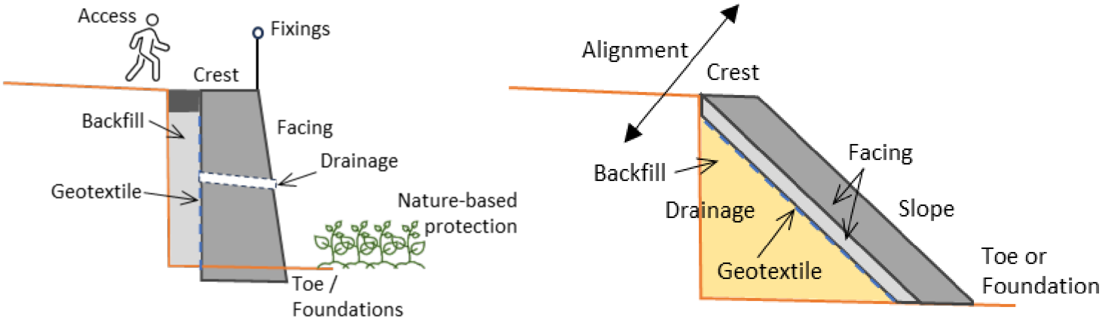
- A Level 1 assessment is generally undertaken for the entire structure using basic visual observation methods, and may be undertaken by a nonspecialist, though with training in asset inspection.
- A Level 2 assessment is generally undertaken by a specialist, and may be undertaken for specific elements of a structure or for the entire structure. The assessment may include topographic or intrusive methods, as well as visual.

A Level 1 assessment will generally be undertaken before a Level 2 assessment is requested. However, Level 2 assessments may be done routinely for high-value or high-importance assets, though less frequently than Level 1 assessments. For instance, Level 1 assessments could occur once a year and after storm events, while Level 2 assessments could occur once every 5 years and as requested following a Level 1.

Condition of Elements

It is often useful to assess the condition of the structure's individual elements. The specific elements, and the considerations regarding each element, will depend on the type of structure and the construction materials used, with the specific considerations listed in the **Operation Manual** (Part II) and **Inspection Form** (Appendix 1). The typical elements of a coastal structure are shown in Figure 25, and the main considerations for each element are summarized in Table 8.

Figure 25: Typical Elements of a Coastal Protection Structure

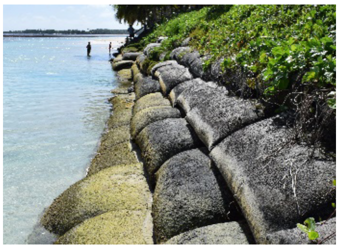
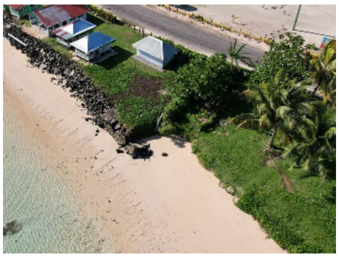


Source: The authors.

Table 8: The Main Considerations regarding the Key Elements of Structures

Element	Main Considerations	Example
Toe or foundation	Is the toe stable and is it well supported by the ground below? While rigid structures may show a gap below the toe, flexible structures tend to adjust if undermined, so an assessment of stability and/or support may be based on the slope above or on the position of units at the toe.	
Structure facing	(i) Are there displaced or damaged units (for revetments)? (ii) Does the outer face show evidence of cracking, deterioration, wear, or damage (for seawalls)?	
Filter layers or geotextile	(i) Is an underlayer or secondary armor is visible (for revetments)? (ii) Is the geotextile visible, intact, and of sufficient thickness or quality? It can be difficult to assess this element visually, as underlayers and geotextiles are generally covered with outer layers.	
Backfill	Are there are signs of migration of fill through the structure? Evidence of migration include holes or lower land immediately behind the structure, where the ground has settled as materials below have been lost.	
Crest	(i) What is the condition of the structure's crest (e.g., displaced rocks, cracked concrete cap or wall)? (ii) What is the condition of the land immediately behind the structure? (iii) Is there any evidence of overtopping or damage.	

Table 8: The Main Considerations regarding the Key Elements of Structures (continued)

Element	Main Considerations	Example
Drainage	Is the structure allowing drainage of the land behind it? Or is it causing ponding or affecting flow paths?	
Slope	The main consideration for this element concerns the profile geometry of the structure: Does it appear to be slumping, deformed, or leaning forward or backward?	
Alignment	The main consideration for this element concerns the alongshore alignment of the structure: (i) Is the alignment locally deformed? (ii) Are there are signs of increased erosion at either end of the structure?	
Fixings	The main considerations for this element concern the fixings or accessory components of a structure (if present), such as mooring points and bollards, stormwater pipes, footpaths, furniture, or lighting: (i) Are they properly connected to the structure? (ii) Are they in good working order?	
Access	(i) Is there safe public access both over and along the structure? (ii) Is there is a safe way to access and maintain the structure?	
Nature-based components	The main consideration here is the condition of any nature-based components, such as plantings or the adjacent beach (e.g., if the beach needs replenishment).	

Source: The authors.

6.2.3 Assessing Potential Failure Mechanisms

Assessing the individual elements of a structure helps determine the overall condition, but does not necessarily define the specific failure mechanisms, something that must be done to determine and enact an appropriate repair or upgrade response. Observations can, however, be useful in diagnosing potential failure mechanisms, which are set out in Table 5. Some may require a Level 2 assessment, with a more detailed inspection by an experienced engineer.

6.3 Assessing Performance

Assessing performance means gauging the ability of a structure to fulfill its intended function, or "desired service levels". This is not necessarily the same thing as a structure's condition, which is discussed below. A structure may be in poor condition, but still perform well and fulfill its function. An example of performance ratings is set out in Table 9, but these ratings may vary for specific structures and functions.

As noted above, a performance assessment can be carried out two levels: Basic (Level 1) or Detailed (Level 2). Level 1 is based on a retrospective method—asking, for instance, if the structure has been performing. Level 2 is carried out in greater detail and is based on a predictive method. Detailed assessments would generally be undertaken if required after a Basic assessment has already been done (section 7). The inspection methods presented in this guidance are aimed at the Basic method, but the Detailed method will also be described.

Table 9: Asset Performance Ratings

Performance Rating	Description	Examples
A – Excellent	Structure is performing as well or better than intended.	Structure prevents overtopping during a design event, and is expected to perform equally well in the coming years.
B – Good	Structure is performing almost as well as intended, but minor upgrades should be considered in future.	Extreme events are causing minor overtopping and damage to the backshore, and this is expected to increase as the sea level rises.
C – Fair	Structure performs well under typical conditions, but not under extreme conditions. Minor repairs or upgrades are required.	Structure is preventing overtopping during typical events, but more severe events cause overtopping and erosion.
D – Poor	Structure is not performing well under typical conditions. Major repairs or upgrades are required.	Waves are overtopping the structure during high spring tides and moderate storm events.
E – Very poor	Structure is not performing its function on a daily basis. Repairs and upgrades are likely impossible, and a complete replacement is probably required.	Waves are eroding the backshore during each high tide.

Source: The authors.

6.3.1 Basic (Level 1) Assessments

A Level 1 assessment evaluates the performance of the structure in the recent past, and then uses this information to predict performance in the near future. The method generally works as follows:

- Gather information based on:
  - reports of damage or closure (e.g., road maintenance reports),
  - anecdotal information from those living near the structure or working on or around it (e.g., stories of waves overtopping the structure once last year and twice the year before), and
  - observations of the site (e.g., evidence of damage behind a structure crest, which is indicative of overtopping).
- Consider the environmental aspects: For instance, have particularly large storm events occurred recently, or have water levels risen during the current El Niño Southern Oscillation (ENSO) phase. These environmental aspects may indicate whether recent performance was typical or atypical.
- Using this information, the likely performance in coming years may be inferred. For instance, if conditions have been relatively benign in recent years, but damage has been occurring, it is likely that performance may be compromised in the coming years.
- Rate the structure from A (excellent) to E (very poor), based on the performance ratings set out in Table 9 or on another, similar rating system.

This method is suitable for qualitative assessments, but cannot provide quantitative information or probabilities; and it is not useful for predicting performance well into the future (including with regard to sea level rises).

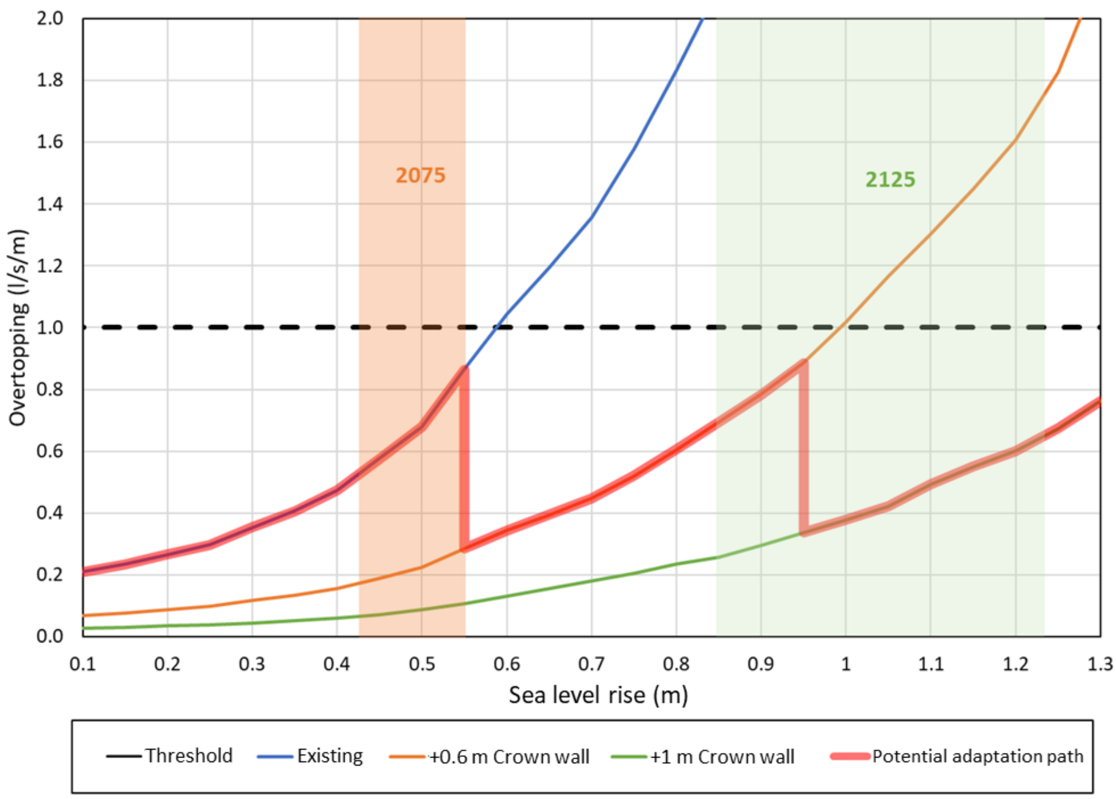
6.3.2 Detailed (Level 2) Assessments

A Level 2 assessment considers the current performance of the structure in a quantitative manner. For instance, it would gauge the probability of the structure not performing as intended. However, it would also consider how that structure will perform going forward, and whether there is a particular time frame during which performance may drop below the design criteria or below an acceptable level as determined by the asset owner. The general approach for a Level 2 assessment is as follows:

- Assess the structure characteristics (e.g., sizing, height).
- Assess the past environmental conditions (e.g., tides, waves). Numerical or empirical modeling may be required to determine environmental conditions at the structure.
- Assess current performance; for instance, how often has structure overtopping occurred per year since construction.
- Validate with reports and observation, if possible.
- Forecast future performance by including the effects of climate change (including sea level rises).
- Determine when performance will drop below design criteria.

An example of such an assessment as presented in Figure 26, which shows the change in wave overtopping during a design event with a sea level rise, together with an indication of when overtopping may exceed the highest tolerable level. Options for adaptation can be considered using this approach (section 7.2).

Figure 26: Example of a Change in Wave Overtopping during a Design Event, as a Function of Sea Level Rise



l/s/m = liters per second per meter of structure length.

Notes:

1. This figure also includes a prediction of when tolerable limits of overtopping may be exceeded, and presents a potential adaptation that would avoid exceedance.
2. The sea level rise data are from 2010.

Source: The Te Ara Tupua project, New Zealand Transport Agency.

6.4 Assessing Effects

The effects of the works should be considered compared with what was expected, but also in the context of what is tolerable for the community and environment versus what is intolerable. For example, exposed steel in or around access to the structure or coast would be generally deemed intolerable for a community due to the potential for harm. In another example, the loss of access along the foreshore may be deemed tolerable, as it was presented to the community during the design or construction phase, based on the argument that the protection of the land behind is more important. It should also be noted that the effects of coastal protection works on the community and environment may be both positive and negative.

6.4.1 Effects on the Community

Table 10 lists some considerations when assessing the effects of coastal protection works on the community.

Table 10: Potential Effects of Coastal Protection Works on the Community

Consideration Type	Positive Effects	Negative Effects
Health and safety	Is the structure protecting the community from wave overtopping or erosion?	Is there exposed or corroded steel or wire?
	Is the structure making access to the coast and into the sea safer?	Is there unstable rock, large holes in the structure, or slippery or uneven surfaces?
		Is the structure increasing wave overtopping?
Access and amenity	Is public access improved?	Has access been lost across the structure to the foreshore or along the foreshore?
	Is the structure providing a new location for meeting and socializing?	Is the structure causing flooding and water ponding?
	Has the structure improved fishing and fossicking opportunities, including vessel access?	Is the structure adversely affecting recreational amenities, including areas for walking, sunbathing, diving, and surfing?
	Has the structure resulted in improved recreational amenities, including areas for walking, sunbathing, diving, and surfing?	Is the structure causing adverse outcomes for any particular group?
Visual impact	Does the structure improve the aesthetic appeal of the coastal edge?	Does the structure reduce the visual amenity value of that part of the coastline?
		Is the structure being used as a garbage dumping site?

Source: The authors.


Downsides of coastal protection works. Possible negative effects of structures include an exposed wire (left) and large holes at the crest (right). Both pose dangers to public health and safety).
Source: Tom Shand

6.4.2 Effects on the Environment

Table 11 lists some considerations when assessing the effects of coastal protection works on the environment.

Table 11: Potential Effects of Coastal Protection Works on the Environment

Consideration Type	Positive Effects	Negative Effects
Ecology	Does the structure improve the local habitats for flora or fauna?	Does the structure adversely affect habitats or connectivity?
Environment	Does the structure improve the water quality?	Does the structure block flow paths?
	Does the structure reduce the amount of rubbish and debris?	Does the structure trap debris and waste?
		Is the structure breaking down and releasing synthetic materials?
Coastal processes	Does the structure provide training for a creek or inlet?	Has the building of a structure led to erosion at the structure's front (e.g., a lowered beach)?
		Has the building of a structure led to erosion at the structure's sides (e.g., end effects or downdrift erosion)?
		Does the structure affect lagoon currents or stream flow processes?
		Does the structure affect wave processes (e.g., increased reflection)?

Source: The authors.

Structural breakdowns. When coastal structures break down, they can release synthetic materials onto beaches (left) or trap debris there (right), thus harming the environment.
Source: The authors

7. Management of Coastal Protection Works

Once the condition, performance, and effects of a structure have been determined, an appropriate response must be developed. The level of response should be proportionate to the risk posed by failure of the structure.

7.1 Assessing Risk

Risk is a function of both the likelihood of an event occurring and the consequence if that event does occur. In this context, the likelihood comprises the condition and performance ratings of the structure, as they indicate how likely the structure is to fail. The consequence is the importance level of the structure (Table 12).

The combination of the condition and performance ratings and the importance level of the structure can be used to determine the level of risk posed to the structure, or to the assets being protected by the structure. A high-importance structure should be in good condition; otherwise, the risk posed by its failure becomes high. By contrast, a low-importance structure can be in poor condition without the risk immediately becoming high.

The effects of the structure on the community or environment are harder to quantify and, therefore, no risk level has been assigned to them. Rather, the effects must be assessed as tolerable or intolerable to stakeholders such as the community or asset owners.

Table 12: Risk Matrix for Coastal Protection Works

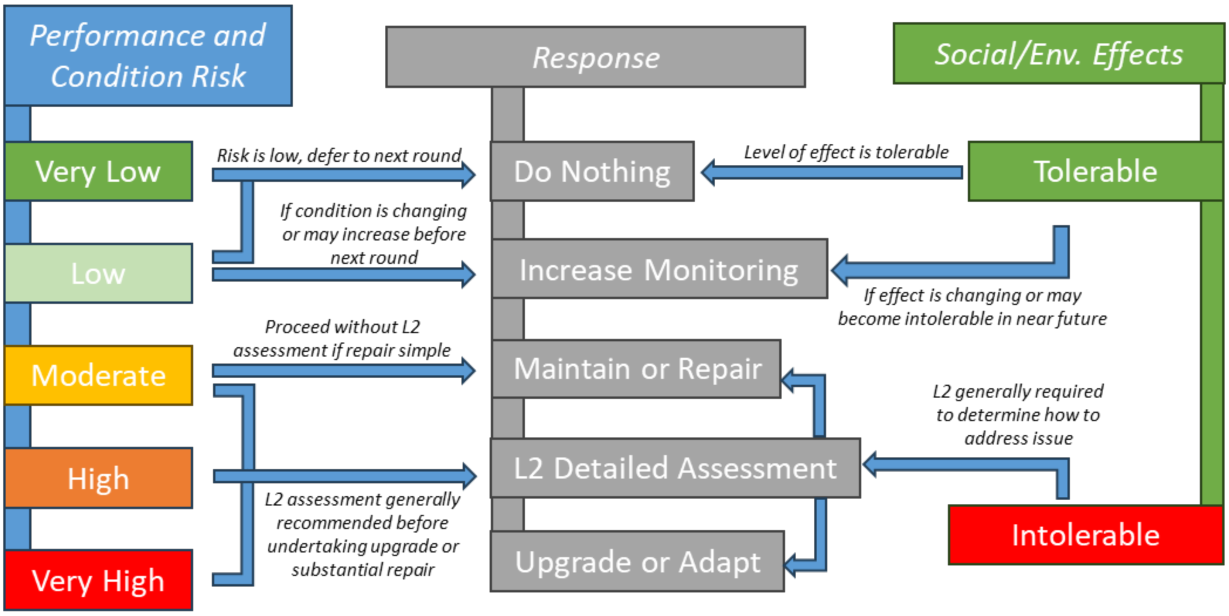
		Importance of Structure		
		3: Low	2: Medium	1: High
Condition/ Performance	A – Excellent	Very Low	Very Low	Low
	B – Good	Very Low	Low	Low
	C – Fair	Low	Moderate	Moderate
	D – Poor	Moderate	Moderate	High
	E – Very Poor	Moderate	High	Very High

Source: The authors.

7.2 Response Options

A range of potential response options are available, depending on the level of risk. General response options are described below, with Figure 27 presenting a flow chart relating a structure's performance and condition risks to the possible responses and consequences. In general, lower risk (i.e., better condition and/or lower importance) results in lower levels of intervention (i.e., do nothing or increase monitoring), while higher risk (i.e., poorer condition and/or higher importance) results in higher levels of intervention, although these will generally require a more detailed assessment before progressing until the response can be limited to a relatively simple maintenance job or repair.

Figure 27: Response Options for Managing Coastal Protection Works



Env. = environmental, L2 = Level 2.
Source: The authors.

7.2.1 Do Nothing

This option defers any response until the next monitoring round, and is generally selected if the works are in good condition and performing well, with a low overall risk and no intolerable effects noted. This should be the most common response for works that are well engineered and constructed and in the early part of their design life.

7.2.2 Increase Monitoring Frequency

A decision to increase the frequency of monitoring may be made if changes are occurring in the structure or there is concern that the structure's condition or performance may change before the next scheduled monitoring round.

Increasing the monitoring frequency may include undertaking full assessments or may be limited to certain aspects. For example, if low beach levels fronting coastal works are a concern, then the monitoring frequency of that aspect may be increased, either using beach profile surveys or imagery (photo below).

Beach monitoring. This is a "CoastSnap" station on the coast of Queensland, Australia, used to monitor beach levels (photo by Gladstone Regional Council).

7.2.3 Undertake a More Detailed (Level 2) Assessment

A more detailed assessment of the condition and/or performance of coastal protection works may be required if:

- the structure is at moderate-to-high risk, having either a high-importance level or a poor condition or performance index;
- the structure is likely to require significant or large-scale repair that may involve additional design;
- the structure is likely to require upgrade or adaptation; and/or
- the failure mechanism cannot be easily identified, and thus requires further investigation.

Detailed assessments are likely to be undertaken by specialist coastal engineers, though they could involve other specialists, such as geotechnical or structural engineers, ecologists, or geomorphologists, depending on the intent of the assessment. The conduct of a detailed assessment may include the use of specialist tools or the targeting of a certain part of the structure (e.g., intrusive measurements at the toe to determine depth), or it may include a more detailed analysis of past and likely future performance (section 6.3.2).

7.2.4 Undertake Maintenance

Maintenance activities are planned and undertaken to prevent damage or degradation of the works or of particular elements. They may be regular or reactive, but are generally identified during the initial design phase, and do not require further design work to carry out.

Examples of maintenance works include:

- clearing drains to prevent water ponding behind the structure and to improve the drainage element;
- clearing weep holes to prevent the buildup of groundwater within and behind the structure;
- moving sand along the coast to maintain beach levels in front of the structure, and to improve the toe and foundation elements or the performance of beach nourishment works; and
- removing debris from plantings, thereby improving the condition of the nature-based components.

7.2.5 Do Repairs

Repairs are done in response to damage to one or more elements of the works, to prevent further loss of function or failure. Repairs may bring a structure back to its original condition or to a point where it is still at a lesser condition, but one good enough to prevent or lessen further damage.

Simple repairs can generally be undertaken immediately, but larger-scale repairs may require a more detailed assessment and/or design.

Examples of repairs include:

- repacking armor stones that have been displaced from a revetment face,
- repairing the degraded face of a seawall, and
- repairing damaged geotextile containers.

Structural repairs. The photo at left shows the face of a seawall being fixed, and the photo at right shows the patching of a damaged geotextile container.
Source: Photo on left: R. Craven, New Zealand High Commission to Kiribati; Photo on right: Tom Shand

7.2.6 Undertake Upgrades

Upgrades are done to improve the performance of a structure when the works fail to provide the required level of service (design life or design criteria), or when the design criteria themselves need to be improved. An upgrade usually retains the original intent of the works; and the existing form or type of structure remains largely unchanged.

When upgrades are done, additional design will likely be required, although the upgrades may have already been identified during the initial design phase (i.e., as an adaptive design to be implemented if needed).

Examples of upgrades include:

- augmenting the toe of a structure to accommodate greater scours,
- adding a geotextile behind a structure to prevent loss of fines, and
- adding a crown wall to a structure's crest to reduce overtopping during a design event.

A crown wall. These photos show a crown wall being added to a structure to reduce overtopping. The goal was to complete this upgrade before a subsequent failure occurs.

Care should be taken that the right failure mechanism or performance issue is being addressed, and that the solution does not end up adding weight to other parts of the structure.

7.2.7 Adapt the Works

Adaptation will be needed when the requirements of the works (the intent or performance) or the environmental conditions have changed, or are expected to change, to an extent that the existing structure may not be able to provide the required level of service.

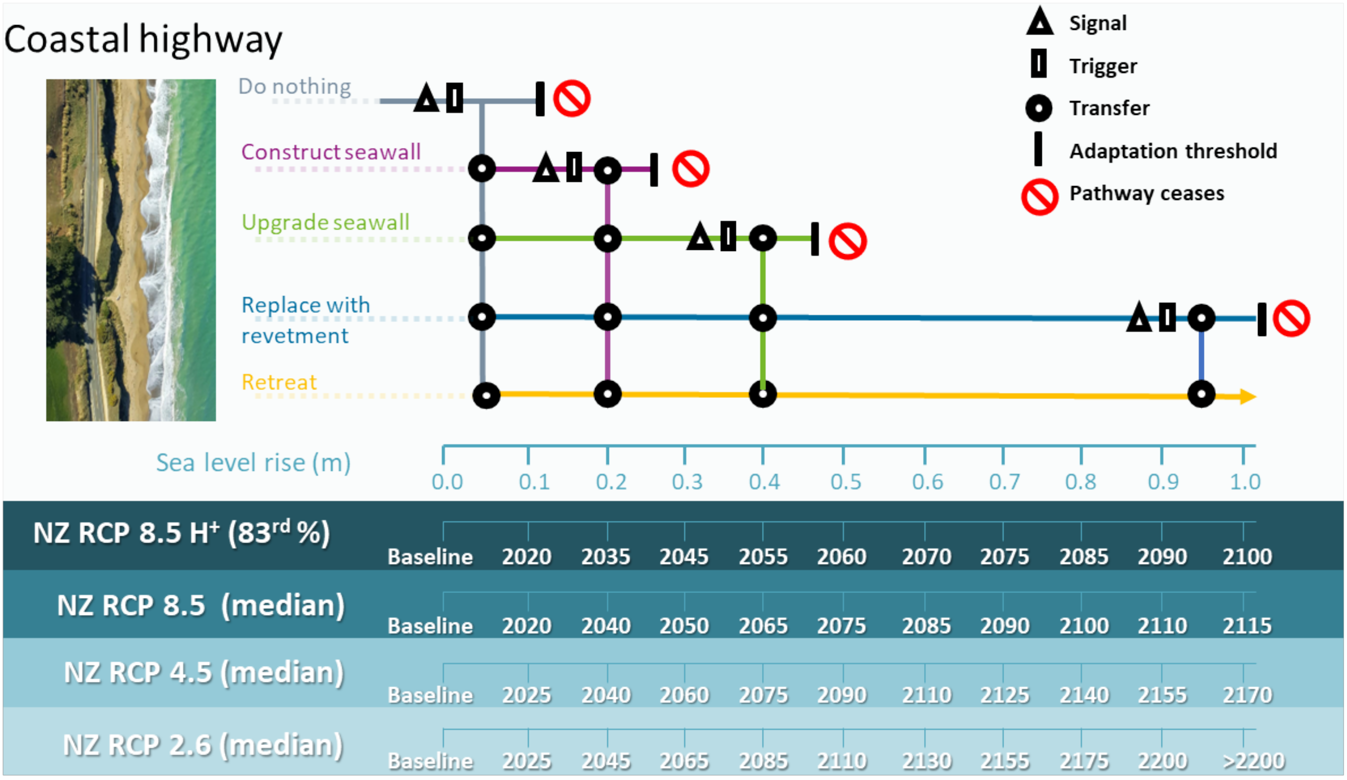
Before adaptation works are implemented, there would have to be an option assessment, with design criteria reestablished and consideration given to engineering (including an upgrade of the existing structure) and nonengineering (retreat or accommodation) options.

Examples of adaptations include:

- replacing a structure with a more effective structure (e.g., one that can tolerate larger waves or reduces overtopping more effectively);
- adding an offshore breakwater in front of a structure to reduce the wave climate during sea level rises;
- adding vegetation behind the crest of a structure to reduce wave overtopping to tolerable levels; and
- removing a structure, with the assets it protects realigned inland.

Future adaptation options may have been identified during the initial design phase. These options, together with signals and triggers to indicate when those options may be needed (Lawrence et al. 2020), can be developed into dynamic adaptation pathways (Figure 28) that will indicate to the asset managers what actions may have to be taken in the future.

Figure 28: Example of an Adaptation Pathway



H+ = High end sea level rise scenario (83% exceedance of model runs), m = meters, PCTL = percentile, RCP = Representative Concentration Pathways.
Note: This figure shows an adaptation pathway developed at the start of a project to indicate when particular options may be viable. Signals and triggers are included to indicate when a change in option may be required.
Source: The authors.

7.3 Examples of Responses

Two examples of response development based on a structure's condition and performance risks are set out below. The first is an actual example of seawall failure, with the implemented response. The second is a hypothetical response developed for an existing seawall inspected during the development of these guidelines.

Table 13: Example 1—Seawall with a Failed Section

Works description

A seawall protects a landfill on the lagoon coastline of an atoll island. The lagoon coastline is exposed to local wind waves and infrequent long-period swells that penetrate through a reef pass. The wall is constructed from grout-filled bags, and a massive concrete crown wall has been retrofitted onto the crest to reduce overtopping. There has been frequent maintenance and repair due to the degradation of the materials, and a section at the most seaward end has recently failed.

Importance level

The seawall protects a landfill. Failure would potentially release small volumes of landfill materials into the environment. While these materials may be moderately hazardous to people and the environment, fatalities or serious injury are unlikely, and the works are not protecting lifeline infrastructure. The importance level of this structure has therefore been rated as **2 (medium)**.

Assessed performance

A section of the seawall has failed and is no longer retaining the landfill materials behind it. The crown wall has also been knocked over in places, resulting in wave overtopping during extreme conditions.

The performance of the structure is rated as **D (poor)**.

This rating has been selected rather than E because most of the structure is still performing its intended function, and a rebuild of this section may be possible.

Assessed condition

The **facing** along the entire length of the structure has been subjected to deterioration, wear, and damage. Large holes through the structure are evident in places where there is apparently **no geotextile or filter layer**. There are gaps at the toe in some locations, and displacement of the crown wall along the structure **crest** has occurred.

Along the failed section of the seawall, the degradation of these elements has caused the complete collapse of the structure.

The condition of the structure has been rated as D (poor) along most of the wall and **E (very poor)** in the failed section.

Likely failure mechanism

While several potential failure mechanisms were likely developing, including **toe erosion** undermining the foundation, as well as **structural degradation**, and **crest damage**, the mechanism that led to the failure of one section was the **loss of internal materials**, to which the additional mass of the retrofitted crown wall was potentially contributing.

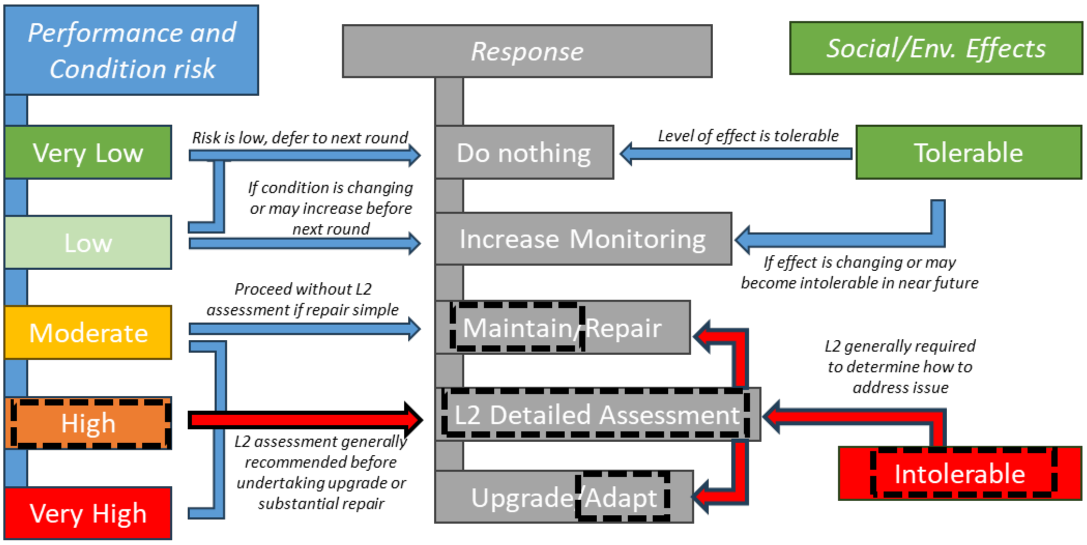
Assessed risk

Based on the assessed **medium level** of importance, **D (poor)** performance, and **E (very poor)** condition (the overall condition rating being the lower of the two), the risk is rated as **1 (high)**.

		Importance of structure		
		3: Low	2: Medium	1: High
Condition / Performance	A – Excellent	Very Low	Very Low	Low
	B – Good	Very Low	Low	Low
	C – Fair	Low	Moderate	Moderate
	D – Poor	Moderate	Moderate	High
	E – Very Poor	Moderate	High	Very High

Table 13: Example 1—Seawall with a Failed Section (continued)

Assessed effects	The failure of a section of the seawall has led to the release of waste material from the landfill behind. While this landfill had been exposed to the lagoon prior to the seawall's construction, the release of waste into the lagoon, with its potential effects on the community and environment, is **deemed intolerable**.
Selected response	Due to the **risk rating of "high**" and the **effect rating of "intolerable,"** a more detailed assessment will be required to gain a better understanding of the failure mechanism; the likely future performance of the remainder of the wall; and the options for repair, upgrade, or adaptation. This assessment finds that, while it may be possible to rebuild this section using similar materials, another failure is likely to happen in this or another section of the seawall. A combined maintenance and adaptation option is therefore selected: The facing along the remainder of the seawall will be more proactively monitored and maintained to decrease the likelihood of large holes developing, which would cause the release of internal materials and increase the risk of failure. Where failure has occurred, the seawall will be rebuilt using an improved variation of the existing grout-filled bags. Concrete blocks will be precast and grouted together over a geotextile, forming a more effective facing and filter. This repair will be done by local labor using local construction techniques. The crown wall will be replaced, but on top of a more robust seawall foundation.



Source: The authors.

Table 14: Example 2—Damaged Seawall

Works description

A seawall supports a reclamation site inside a fringing reef on a high volcanic island. The seawall is a combination of grouted rock on its lower portion and a mass concrete crown wall on top. Drainage weep holes extend through the seawall, with larger stormwater pipes at intervals draining the land behind. The seawall toe is generally located at or below low tide, so it is almost always covered by water. The age of the wall and its history of maintenance or repairs are unknown.

Importance level

The seawall protects a public reserve and walkway. A failure of the wall would limit access, but would not result in significant costs, loss of life, or the loss of lifeline infrastructure. The importance level is therefore rated as **3 (low)**.

Assessed performance

The structure is generally performing its intended function of retaining land. Some voids are apparent immediately behind the crown wall where land has subsided. Wave overtopping is not reported as being problematic at present.

The performance of the structure is rated as **B (good)**.

Assessed condition

The overall **slope** and **alignment** of the structure appear uniform; however, erosion has occurred at the **exposed end of the structure**, where it transitions into the rock revetment. The lower **structure facing** is exhibiting loss of grout, particularly in sections away from the wall ends, as access for maintenance and repair is more difficult. **Geotextile** or **filter layers** are not apparent behind the wall at the exposed end. Drainage appears to be sufficient and overtopping negligible; however, there are voids immediately behind the structure, indicating loss of backfill material.

The condition of the seawall overall is rated as **D (poor)**.

Likely failure mechanism

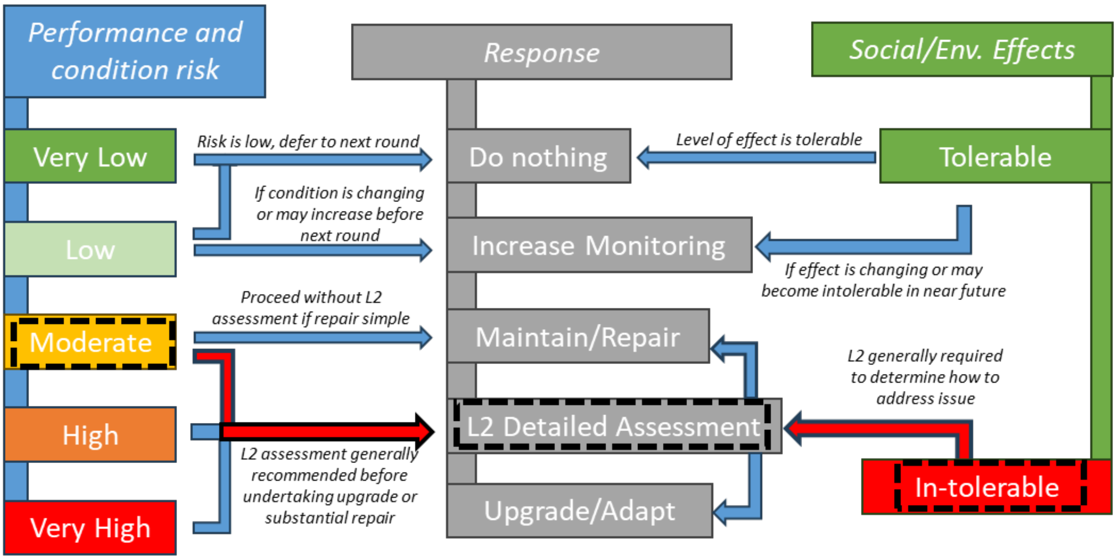
The voids behind the seawall indicate a **loss of internal materials**. However, it is uncertain whether this is primarily due to **structural degradation** (loss of grout between the rocks) in the lower part of the wall or to an **undermining of the toe**, as the toe is not viable. The lack of geotextile means that the condition of the face is very important in preventing the loss of material through the structure.

Assessed risk

Based on the assessed low level of importance, **B (good)** performance, and **D (poor)** condition, the risk is rated as **moderate**.

		Importance of structure		
		3: Low	2: Medium	1: High
Condition / Performance	A – Excellent	Very Low	Very Low	Low
	B – Good	Very Low	Low	Low
	C – Fair	Low	Moderate	Moderate
	D – Poor	Moderate	Moderate	High
	E – Very Poor	Moderate	High	Very High

Table 14: Example 2—Damaged Seawall (continued)

Assessed effects	The structure provides support to a well-used amenity area and is used as a community meeting place. Voids behind the seawall pose some risk to public safety if someone were to step into them, particularly in the dark, or if they accumulate rubbish. At the end of the seawall where outflanking has occurred, some of the steel reinforcing steel is exposed, posing a hazard. These problems are deemed intolerable, and thus require a response. 
Selected response	Maintenance of the front face of the grouted-rock seawalls is typical, and is particularly important where a geotextile or filter layer is not present behind the structure. However, voids are already evident, indicating that backfill is currently being lost, but it is not known whether the cause is loss of grout from the seawall face or an undermining of the toe. A more detailed L2 assessment should therefore be undertaken to determine the pathway through which material is leaking out, and to develop an appropriate repair strategy. Similarly, an appropriate extension or termination at the end of the seawall should be designed to prevent further damage due to outflanking. To limit the risks to public safety, two actions should be undertaken immediately: the exposed steel reinforcements should be removed and markers should be placed around the voids. 

Source: The authors.

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Pacific Region Infrastructure Facility

Guidance for Managing Coastal Protection Works in Pacific Island Countries

Part II: Operations Manual

Part II: Operations Manual – Contents

Tables

Figures

Abbreviations

AMD	Asset Management Database
GIS	Geographic information system
GPS	Global positioning system
JSA	Job Safety Analysis
L1	Level 1 (Basic)
L2	Level 2 (Detailed)
PIC	Pacific island country
PPE	Personal protective equipment
PRIF	Pacific Region Infrastructure Facility
QGIS	Quantum Global Positioning System
SWMS	Safe Work Method Statement
UAV	Unmanned aerial vehicle (or “drone”)
UTM	Universal Transverse Mercator

1. Purpose

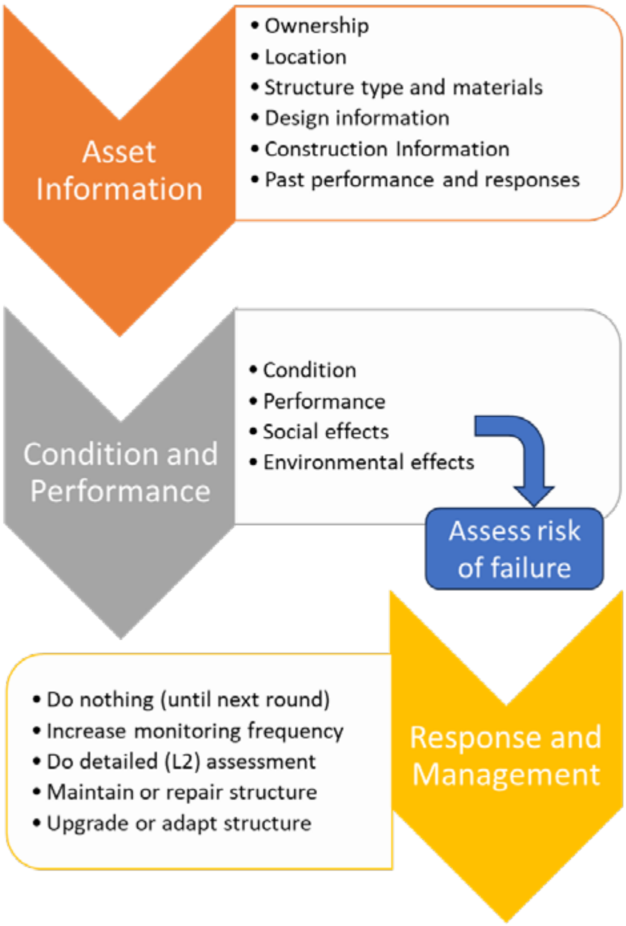
This **Operations Manual** provides guidance for using **inspection forms** when undertaking a Basic (Level 1) assessment of coastal protection works in the Pacific island countries (PICs). Information and instructions are provided for completing the forms with respect to:

- inspection details,
- structural details,
- condition assessment,
- performance assessment,
- effects assessment, and
- response to the assessment.

Guidance is also provided on setting up a simple asset management database (AMD) to be used for tracking asset information, specifically on condition and performance.

A flow chart illustrating the overall asset management approach is provided in Figure 1. It follows the general approach developed by the Pacific Region Infrastructure Facility (PRIF) to assessing condition and risk of failure and to determining an investment strategy.[1]

Figure 1: An Approach to Asset Management



Sources: The authors; Pacific Region Infrastructure Facility (PRIF). 2020. *Methodology for Condition Assessment of Public Sector Infrastructure Assets in Pacific Island Countries*. Sydney. https://www.theprif.org/sites/default/files/documents/AssetConditionManual2020_web2_0.pdf.

1 Pacific Region Infrastructure Facility (PRIF). 2020. *Methodology for Condition Assessment of Public Sector Infrastructure Assets in Pacific Island Countries. Sydney.* https://www.theprif.org/sites/default/files/documents/AssetConditionManual2020_web2_0.pdf.

1.1 Before going to the site

Conducting an effective Level 1 (L1) assessment is key to ensuring that the required information is gathered on-site.

1.1.1 Health and safety

Given the environmental hazards and remoteness of some locations of coastal protection works in the PICs, an understanding of the site and potential safety risks is essential. For this reason, every site has to be assessed before the field work begins. A Safe Work Method Statement (SWMS), Job Safety Analysis (JSA), or similar document should always be prepared and recorded prior to entering any site. These can be as simple as noting the personal protective equipment (PPE) required for the site, assessing any hazards that may exist, understanding emergency-response procedures and protocols, and notifying other members of your team of the plans and estimated return time.

Prior to any site visit, it is essential that any approvals required for access to the site and structure be obtained before the inspection. It is recommended that neighboring landowners and local community groups be informed about the inspection, including the fact that you will be accessing the structure and adjacent areas.

1.1.2 Know what you are going to look at

Having a clear understanding of the structure prior to the site visit will make the time spent in the field more effective. Gather as much information as possible beforehand about the structure to be assessed. This could include:

- any design information that may exist, such as construction drawings or previous inspection reports;
- ownership and management details;
- anecdotal information from local residents who have observed the performance of the structure (e.g., a seawall); and
- aerial imagery, historical photos, and any other visual information about the structure, especially about its performance and condition.

1.1.3 Check the weather and tides

Check upcoming weather and tidal conditions prior to your site visit. It is generally recommended that inspections of coastal protection works be undertaken during a low tide (though observing performance during a high tide and with wave action may also be useful). Planning the inspection around the monthly spring low tide will ensure that a larger proportion of the subaerial structure can be assessed. If undertaking inspections via a vessel, ensure that your safety assessment (SWMS and JSA) includes a forecast of wind and wave conditions. Also take note of previous rainfall or large erosive events that may make site access difficult. Ensure that you have sufficient time to return from the site if it is tidally restricted. If undertaking an inspection using an unmanned aerial vehicle (UAV), also known as a "drone," it is advisable to plan your flights on days with minimal (or evenly distributed) cloud cover and low wind speed. It is also recommended that you not undertake the survey around midday, when the sun is at its highest point.

1.1.4 Equipment requirements

The equipment requirements for an L1 assessment are quite simple, but they should (at a minimum) include the following:

- **Visual inspection forms.** Be sure to print out the attached inspection forms or get a digital version that can be edited in the field via a tablet or laptop. It is also advisable to have a printed or digital version of this operations manual for reference.
- **Personal protection equipment.** This will depend on the site and the conditions on the inspection day.
- **Camera.** A smartphone or digital camera will suffice, but the camera should preferably be enabled by a global positing system (GPS). Refer to the settings on your smartphone or camera to see how to enable the GPS. This information is usually stored in the metadata of each photo, and can be accessed via the properties or details settings on your computer. Later on, this information will provide a record on where the photos were taken.
- **Tape measure.** This will be needed to measure rock or armor unit sizes, concrete or timber elements, etc.

Additional items that may be useful for the inspection, depending on the structure type, including:

- **Unmanned aerial vehicle** (i.e., a drone). This will assist you with overhead imagery, and help you take photos of hard-to-access or over-water areas of the structure.
- **Global positioning system unit.** A GPS unit can be used to track and/or measure structure alignment, shoreline position, and any other items of interest that may require geolocation.
- **Depth plomb**. This may be useful for submerged or semi-submerged structures to determine the structure height below the surface. Notes on measurement times and levels should be precise and always referenced to the local tide gauge recordings.

Check that your phone, camera, GPS unit, and any other electronic devices are sufficiently charged.

1.2 On-site inspection

Once you are on-site, and all the approvals for the visit have been obtained, it is a common courtesy to follow the initial inspection request with a verbal introduction and request to the landowners and community members present when you arrive. Other factors to consider when on-site include the following:

- Ensure that all the team members visiting the site visit have read and understood the health and safety documents, including emergency procedures and protocols.
- Make sure that another team member (not in the field) knows your whereabouts, is contactable, and knows your estimated time of return.
- Confirm that you are wearing the correct PPE, and have sufficient water and sunscreen.
- Be aware of slippery and uneven surfaces, also loose rocks, and ensure that you always have three points of contact when climbing over rocks or steep embankments.

Complete all the sections of the inspection forms, providing as much information as possible in each section. Be sure that your writing is legible, so it can be easily transferred to the digital asset management database (AMD). It is worthwhile taking along a ledger, book, or something else with a hard backing, so that you can complete the forms in the field.

1.3 Following the inspection

Upon your return from the field, the next step of the inspection process is to transfer the field data to the AMD. It is recommended that this process be undertaken as soon as possible, while the details of the structure inspection are fresh in your mind. If you are using a physical (printed out) inspection form, this will be a simple data-entry exercise. The AMD has more information fields than the inspection forms, and section 3 of this manual provides further instructions on how to populate the AMD.

The purpose of the **AMD** and **inspection form** is to determine the current condition and performance ratings of the coastal protection works, and to formulate an appropriate maintenance and/or upgrade response, if required. After you have completed the AMD and updated it with the recent inspection details, the formulated response needs to be planned or implemented. Actions will vary, depending on the recommended response, but they may include:

- informing the asset owner, the asset manager, or landowner of the recommended response;
- including the planned works in the operational (for maintenance or minor repair) or capital (for major repair, upgrade, or adaptation) works program;
- engaging a suitably qualified coastal engineer to undertake a Detailed (Level 2) assessment; and
- setting a calendar reminder for future inspections.

2. Completing the Inspection Forms

The following sections provide guidance on completing the inspection form while in the field.
The form has three (3) pages, each with its own distinct subsections:

- **Page 1** and its subsections provide an overview of the structure, surrounding environment, and details of the inspection.
- **Page 2** is dedicated to the "elemental assessment," which includes a detailed analysis of each component of the structure.
- **Page 3** provides for an overall assessment of performance and condition, risk and response.

Guidance for completing each subsection is provided below.

2.1 Inspection details

Most of the inspection details section required by the inspection form can be completed prior to entering the field. These details are listed and described in Table 1. It is recommended that the users familiarize themselves with the inspection form prior to going on-site, so that as much information as possible is gathered prior to the site visit.

Table 1: Inspection details required by the inspection form

Field	Description	Example
Asset name	If there is a local name for the structure, please provide this. Otherwise, name the structure based on its location and type.	FDB Foreshore concrete seawall, in Suva, Fiji
Asset owner	Provide details on the person (or party) who owns the structure. This is usually a government department or ministry, or a private individual or company.	Fiji Roads Authority
Asset manager	This is the person (or party) responsible for the management of the structure (i.e., maintenance, renewal, upgrade). This is usually a government department or ministry, or a private individual, or company. Note that the asset owner and manager may be the same party or different parties.	Fiji Roads Authority
Landowner	If known, provide details on who owns the land on which the structure stands. This is usually the government or a local landowner. Please check local legislation on offshore structures below the high water mark, as the land may be subject to eminent domain, with the national government or local community having the right to seize it.	Government of Fiji
Site's cultural and environmental significance	If the structure is located on a site of cultural or environmental significance, this may be an important consideration when undertaking inspections or determining appropriate management responses.	A reclamation, with the site having no identified cultural or environmental significance
Location (address or GIS coordinate)	Provide a physical street address for the coastal protection works, especially if the structure spans several properties. If possible, provide the geographical location of the center of the structure. Google Earth or a similar platform. could be used at the office prior to the site visit, Otherwise, you can use your smartphone or GPS when on-site. Provide the latitude and longitude coordinates in decimal format. If you can, also provide the location under the UTM (or local) coordinate system.	Victoria Parade, Suva, Fiji -18.145706°S, 178.422282°E, 650460mE, 7993109mS (UTM 60K).

Field	Description	Example
Previous inspections	List the previous inspections of the site, noting what type of inspections they were and what recommendations were made as a result.	4 July 2023, routine biannual condition assessment
Date	Date of your inspection, along with the time of day (in local time).	7 November 2023, 10:00 a.m. to 11:30 a.m.
Inspected by	Who is undertaking the inspection?	Tom Shand
Section	If you are inspecting the entire structure, this section can be left blank, or *"whole"* can be written in the response. If you wish to inspect a certain section or length of the structure, this needs to be specified in the form via a description, GPS, or chainage of the structure.	Chainage 0-150 (S-N) Vertical wall directly seaward of the site foreshore 650455mE, 7993143mS to 650456mE, 7993101mS
Monitoring	Specify the level of inspection being undertaken: L1 (Basic) or L2 (Detailed). The inspections are to be undertaken by a qualified coastal engineer. See section 6.2.1 of the Guidance Manual for more detail.	L1
Monitoring type	Specify the reason for the inspection, also noting whether this is a scheduled, unscheduled, or post-event inspection.	Scheduled yearly inspection
Previous actions	List any previous repairs (if known), upgrades, or rebuilds that were undertaken at the structure.	Cracks in the capping beams were repaired 12 months ago at ~CH50. Grout was applied to a small crack on the surface (<20 mm wide, 500 mm long).
Notable events	Specify any notable weather events that have occurred since construction, the last inspection, or the most recent repair.	Two overtopping events have occurred since the last inspection: king tide 23 February 2023 (no waves) and wave overtopping during Tropical Cyclone Kevin (Category 4), on 5 March 2023.

~ = approximately, < = less than, GIS = geographic information system, L1 = Level 1, L2 = Level 2, mm = millimeter, UTM = Universal Transverse Mercator

Source: The authors

2.2 Structural details

Table 2 shows the information required by the inspection form covering the basic structural and material components of coastal protection works. These details are key element required for the AMD.

Table 2: Structural details required by the inspection form

Field	Description	Example
Structure type	This term refers to the general type of coastal protection structure. Circle the most appropriate response from the list provided on the **inspection form**. The various types of coastal protection works are defined in section 3.3 of the **Guidance Manual**. If you are unable to determine the category of the structure, if the structure falls into a number of structural categories, or if the structural type is not listed, circle more than one or specify the correct type(s) in the last box (labeled "Other - Specify").	Seawall

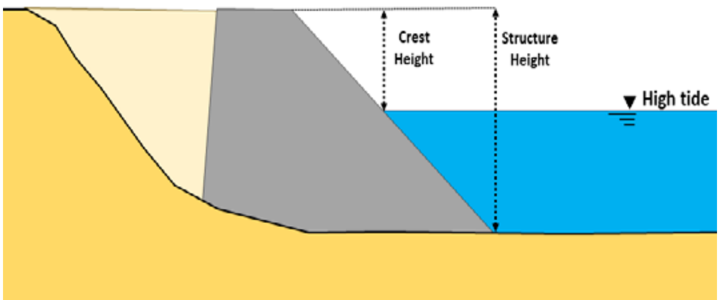
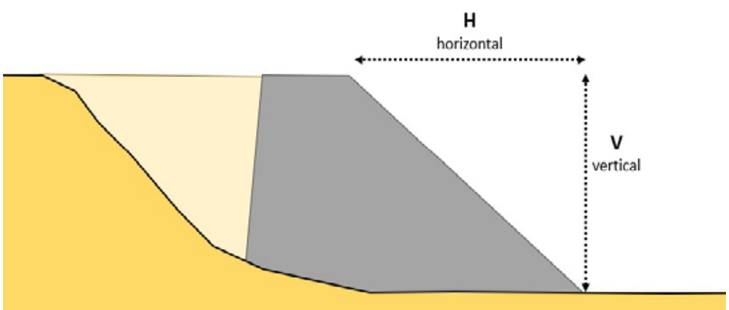
Structure Details			
Structure Type (circle - more than one if reaquired)	Seawall	Revetment	Breakwater / Offshore Breakwater
	Groyne	Nature Based - Specify:	Other - Specify:

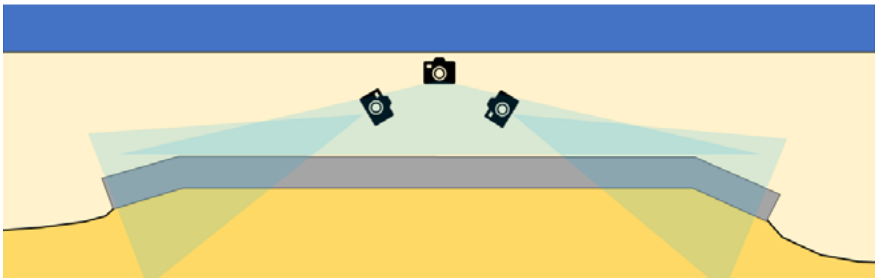
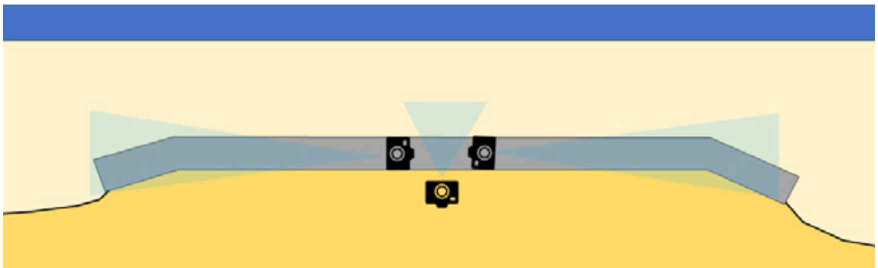
Field	Description	Example
Construction materials	This term refers to the materials that the structure is made from. You may be unsure what materials the structure contains. In this case, circle more than one possibility, as seen in the example below, where the user was unsure if the concrete used in the seawall was reinforced or mass formed. The **inspection form** also provides space to elaborate on nature-based solutions, hybrid solutions (using both nature-based solutions and engineered structures), and on the use of waste materials. Please provide as much information as you can in these sections.	Grouted rock, reinforced concrete, and crown wall

Construction Material (circle -more than one if required)	Rock armour	Timber	Mass concrete
	Reinforced concrete	Grouted rock	Grouted sand bags
	Stacked sand bags	Stacked coral boulder	ACB/grouted mattress
	Masonry blocks/bricks	Gabion	Beach nourishment
	Concrete armour unit	Sand-filled geotextile container	Imported fill
	Concrete/sand-filled fuel drum	Set cement bag	Gravel/rubble berm
	Seabees	Shot-crete	Sheet piles Steel / FRC /PVC
	Waste material - Specify:	Hybrid - Specify:	Nature based Solution - Specify:

Field	Description	Example
Material specifi-cations	Describe the materials that are contained in the structure. That would include, for instance, rock armor size, armor unit dimensions and how the units are joined to each other, capping beam size and materials, access across or along the structure, and footpath widths and connections.	Grouted 100–200 mm rock (likely basalt) in the lower portion of the wall, with a crown wall (likely reinforced concrete) sitting on top
Purpose of asset	For what purpose was the structure built? You may be unsure of the original intent, or there may be more than one reason. In either case, you can circle more than one option, as seen in the example below. If you think that the structure has a design intent that is not listed, please specify the actual intent in the last box (labeled "Other-Specify").	

Asset Intent / reason (circle)	Support reclaimed land	Protect land from erosion	Protect land from inundation or wave overtopping
	Change waves or sediment transport processes	Improve amenity	Other - Specify:

Field	Description	Example
Engineering standard	This section defines the standard to which the structure was built. Select either "Engineered" or "Non-Engineered." Generally, engineered structures have been planned and designed to a known design standard, with drawings produced, and have been built using professional methods. Non-engineered structures are usually of an more ad-hoc nature and are built in response to some sort of trigger. See section 5.1 of the **Guidance Manual** for further detail.	Unknown, lower portion likely non-engineered, as drawings have not been found and some components (such as geotextiles) are missing.
Asset importance rating	The importance rating is a scale from 1 to 3, defined as follows: **1 – High**: These are works that protect or support vital infrastructure or key community assets. The failure of these works will lead to significant costs or to loss of life. **2 – Medium**: These works protect or support a small area of private land or of a public road. Failure will lead to significant costs. **3 – Low**: These works protect or support a remote area of public land or beach. Failure will lead to low or moderate costs. See section 5.1 of the **Guidance Manual** for further detail.	3 – Low Public reserve and walkway protected by a seawall, the failure of which would limit access, but not result in significant costs or loss of life or lifeline infrastructure.
Length of structure (m)	Define the length of the structure (or section) being inspected along the coastline. This can be done on-site with a tape measure, stepped out physically, or calculated later using a GIS program like Google Earth or QGIS.	150 m
Crest height (m)	This is defined as the freeboard of the structure, i.e., the height of the crest above high tide. It can be determined by measuring during a high tide using a plomb, by using a tape measure, or by viewing the tide line on the seaward face of the structure (look for dark surfaces or reduced algae growth). See the diagram below.	2.5 m
Typical height of structure (m)	This refers to the height of the front face of the structure from toe to crest. It is best to use a plomb or length of rope for this measurement but note that the toe may be buried beneath the beach or sea floor at the time of inspection. See the diagram below. 	4 m
Structure face slope	The slope is defined as the ratio of the H:V displacement of the seaward face of the structure. A 45° face would be defined as a slope of 1H:1V. Common rock revetments have a slope of 1.5H:1V to 3H:1V. A vertical slope is 0H:1V. 	0H:1V (vertical)

Field	Description	Example
Photo of structure	Be sure to take as many photos as possible, making note of the photo number (or time of photo), angle, location, and subject. Be sure to take a range of photos. As a minimum, this should include: • A frontal photo taken from the toe of the seaward side of the structure, looking inland: including the front, front left, and front right (see the diagram just below);  • An oblique photo taken from the crest (or just behind), looking down the structure's seaward side: including along the crest and downward from the crest;  • a photo of either end of the structure, wide enough to capture any end effects that may be present, including End 1 or End 2;  • a photo of the toe, capturing the embedment depth and any gaps; • a photo of the crest, showing any differences in crest level, loss of material, or evidence of overtopping; • photos of any notable defects in the structure facing, such as cracks, broken armor units, or displaced armor rock; and • photos of any notable defects in the structure facing, such as cracks, broken armor units, or displaced armor rock; and • photos of any environmental effects, including the disruption of flow paths, altering of sediment transport or hydrodynamics, scours, wave reflections, or the accumulation of debris or rubbish.	
Photo numbers	If possible, record the photo name or the time that each photo was taken, for use in cataloguing.	Front 10:15-DSC_0239 Front L 10:17-DSC_0240 Front R 10:18-DSC_0241 End 1 10:22-DSC_0242 End 2 10:27-DSC_0243 Crest 10:32-DSC_0244 Crest L 10:34-DSC_0245 Crest R 10:35-DSC_0246

DSC_XXXX=photo file of the name, GIS=geographic information system, H:V=horizontal to vertical, L=left, m=meters, mm=millimeters, QGIS=Quantum Geographic Information System, R=right

2.3 Environmental setting

This section describes the coastal setting in which the structure s located. An understanding of the surrounding environment will provide insights into the coastal hazards the structure is exposed to.

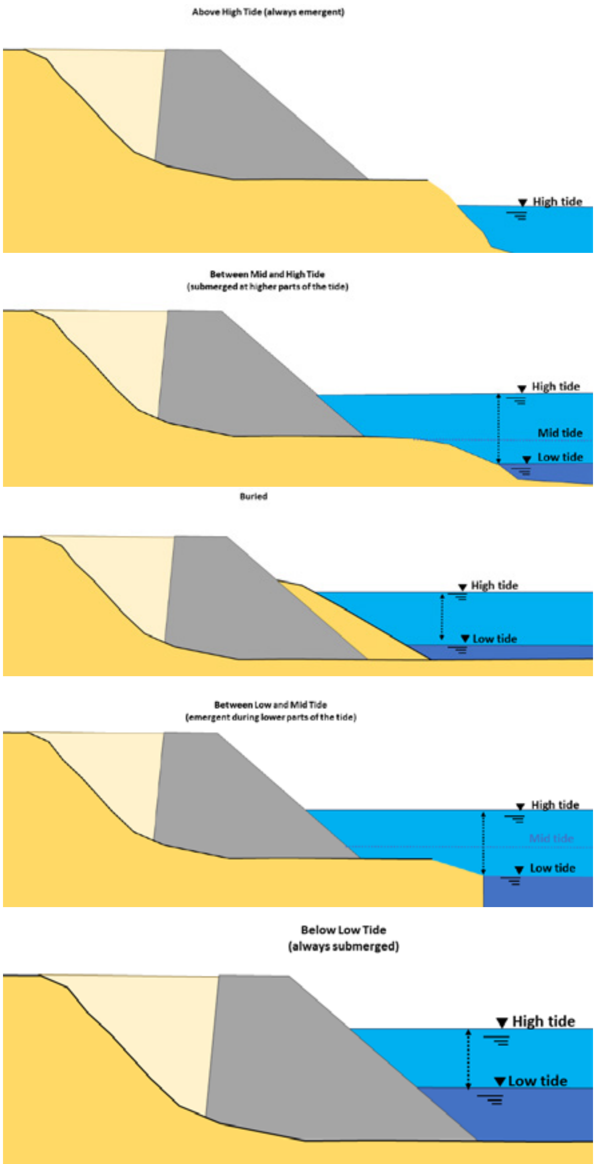
Table 3: Environmental setting of the structure

Field	Description
Coastal environmental setting	This refers to the coastal setting in which the structure is located, i.e., the physical environment. Circle the most appropriate response from the list provided on the **inspection form**. The setting is considered to be to the coastal environment directly offshore.

Coastal Environmental Setting (circle)	Lagoon (<5km fetch)	Lagoon (>5km fetch)	Open sandy coast
	Open coast (reef platform <300m width)	Open coast (reef platform >300m width)	Other - Specify:

Field	Description
Position of the toe on the beach or foreshore	State the position of the structure's toe on the beach in relation to the natural tidal range.

Structure Toe Position on Beach/Foreshore (circle)	Above high tide (always emergent)	Between mid and high tide (submerged at higher parts of the tide)	Buried
	Between low and mid tide (emergent during lower parts of the tide)	Below low tide (always submerged)	Other:



Source: The authors

2.4 Elemental and condition assessments

The **elemental assessment** section breaks down the structure into its individual elements to assess the current condition and performance of each element against the design intent. The inspection form includes a series of questions and prompts to assist with the assessment of the elements. Some questions may apply to other structures, and are not general in their application. **These questions should not be answered directly**; they are simply a means to stimulate thought about what might be affecting the condition of each element of the structure question. In the space provided on the form, provide as much detail as you can regarding what you see. Be sure to take pictures and note the photo numbers and/or the time the photos were taken.

Table 4: Elemental and condition assessments required by the inspection form

Field	Description	Example
Toe or foundation	Check for stability and if the structure is supported by hard ground below. Hard structures may show a gap below the toe. Rock structures will adjust and fill the hole, so the overall slope may change.	Toe appears mostly buried, but there may be some gaps at the structure's corners and beneath stormwater outlets at ~CH55 and CH150. **Photos:** 10:43–10:45 -DSC_0247-51
	 **Examples of toe problems.** The photo on the left shows a buried toe and the photo on the right shows a seawall with a gap between the toe and ground surface	
Structure facing	Check for cracks, holes, deterioration, or inconsistencies in the outside facing of the structure. Look for cracks, chips, or large voids in armor units or in revetment rocks.	The lower portion of the structure has lost grout between some rocks. A crack <5 mm wide is evident across the crown wall at ~CH55 above a stormwater pipe. **Photos**: 10:46–10:47 -DSC_0252-55
	 **Examples of facing problems.** On the left is the deteriorated face of a seawall, and on the right is a concrete crown with a crack above its stormwater pipe and a void in the backshore	

Field	Description	Example
Filter layers or geotextiles	Look for the presence of a geotextile underlayer, as the excess will usually be hanging out from the toe or the crest. Check flexible structures for a smaller armor layer behind the primary rock armor or units.	When an exposed end was examined, there was no indication of a geotextile layer behind the seawall. **Photos:** 10:49 - DSC_0256
	No support. There is an evident lack of geotextile behind this structure	
Backfill	Look for backfill coming through any holes in the structure. The land behind the crest will become lower if backfill is being lost. 	There are multiple depressions immediately behind the structure's crown wall, including above the stormwater outfall locations (Ch~55) and in corners (Ch. 150). **Photos:** 10:52–10:56 -DSC_0256-61.
	Loss of land. Voids are immediately apparent behind this crown wall where land has subsided	
Crest	Check the general condition of the crest and capping beam, if present, and look for displaced rock or cracked concrete. See if there are signs of overtopping and damage, vegetation dieback, or a lowered back level.	The crest of the structure appears to be in generally good condition, except for local cracking, with overtopping reported by the local residents only during extreme events.
	 **Damaged seawall crest.** The concrete here is showing signs of deterioration, and a repaired section is clearly seen.	
Drainage	Look for ponding behind the structure or for evidence of "springs" flowing through the structure or around the structure toe at low tide.	There is no evidence of impeded flow paths. There are several drainage pipes through the structure, at 15 m intervals along the footpath. **Photos:** 11:02–11:04 - DSC_0262-64.

Field	Description	Example
	 **Water through a seawall.** Springs flow under and through this seawall, and flow paths are evident on the section of beach in front of the structure.	
Slope	See if rigid structures are leaning forward or backward, if flexible structures are sloping more than the design intent allowed for, or if adjacent sections have differing slopes.	There is no evidence of the seawall leaning, as the wall appears vertical along its entire length. **Crest L:** 10:34 - DSC_0262 **Crest R:** 10:35 - DSC_0263
	 **Sloping seawalls.** Standing at toe level and looking along the structure is a good way to spot any changes in slope in different sections.	
Alignment	As you take in the view along the structure from the toe or crest, look for changes in the structure's layout, e.g., if the toe is farther seaward anywhere, or if there is increased erosion at either end of the structure. For beach nourishment, check if the sand has been spread or if it is maintaining its design shape and orientation.	Erosion has occurred at the southern end of the seawall, with part of the seawall having collapsed where supporting land has been lost. **Front L:** 10:17 - DSC_0264 **Front R:** 10:18 - DSC_0265
	Seawall collapse. This photo shows the effect of erosion at the end of a seawall.	
Fixings	Check if the nonstructural components attached to the structure are in good condition (e.g., mooring points, bollards, ladders, lights, handrails, and walkways).	There are no fixings or accessories on the structure. Light poles are separate from the structure, located landward of the footpath, and they are in working order.

Field	Description	Example
Access	Check for access around and over the structure. Is the access safe for the public? Is access available for disabled people? How will machines get in to work on the structure.	There is no access over the structure due to the verticality of the wall. Machines will have to work over the top of the crest, drive onto the beach in front at low tide, or work via vessel if upgrade or maintenance is required.
	 **Limited access.** This is a long stretch of seawall where access for pedestrians and maintenance equipment is restricted.	
Nature-based components	Check the condition of any nature-based components, such as plantings or beach replenishment: For instance, ask: • Is the vegetation planted as part of a nature-based solution in good condition? • Is there evidence of dieback or sparsity in the vegetation? • Is the vegetation securely rooted in the bed? • Are other nature-based components in good condition?	The vegetation is in generally good condition, though some damage is evident in plants along the seaward edge.
	 **Example of a nature-based solution.** This photo shows a planting in front of the toe of a seawall. It is intended to dissipate wave energy and accumulate sediment	

Ch = Chainage along structure in meters, DSC_XXXX = photo file name, mm = millimeter.
Source: The authors.

2.5 Structure rating

The structure rating section brings together the findings from the elemental assessment and the rest of the visual inspection to make an informed evaluation of the current condition and performance of the structure. It also asks the Inspector to use the results of the inspection to suggest possible failure mechanisms that may occur if the structure is not maintained or upgraded. Refer to section 6.2.3 of the Guidance Manual for additional information.

Table 5: How Structure Ratings Work

Field	Description	Example
Potential failure mechanism	Using the elemental analysis, list any of these failure mechanisms (or add others) that may occur to the structure if not maintained or upgraded prior to the next inspection: **Toe erosion:** when the level of the beach in front the structure drops below its footing, causing the wall to subside into a hole. **Structural degradation:** occurring in the face or elements, including corrosion, abrasion, cracking, or spalling, which may lead to loss of strength and eventual collapse or loss of internal material. **Armor damage:** affecting individual units, rocks, or bags in a revetment, which may lead to loss of strength and eventual collapse or loss of internal material. **Armor displacement:** displacement or loss of individual units within a revetment, which may lead to loss of strength and eventual collapse or loss of internal material. **Geotechnical failures:** movement of the ground below the structure, due to settlement (sinking into the ground), outward rotation (when the crest rotates out), or slip circle failures (when the toe rotates out). **Loss of internal materials:** occurring within or behind the structure due to piping and/or failure of the geotextile, causing the structure to slump or crack. **Crest damage:** affecting the structure and backshore, generally caused by wave overtopping, resulting in scours and potential collapse of the crest. **Outflanking and end erosion:** occurring adjacent to the structure, causing loss of support behind the structure and eventual collapse. See section 3.4 of the **Guidance Manual** for further detail.	The voids behind the seawall indicate a loss of **internal materials**. However, it is uncertain whether this is primarily due to **structural degradation** (loss of grout between the rocks) in the lower part of the wall or to an **undermining of the toe**, as the toe is not viable. The lack of geotextile means that the condition of the face is very important in preventing the loss of material throughout the structure.
Performance rating	Rate the performance of the structure from **1** (poor) to **5** (excellent), based on the criteria listed below. Performance is the ability of the structure to achieve its intended function, or "desired service levels." A structure may be poor condition but still perform well in achieving its function. **A – Excellent:** Structure is performing as well or better than intended. **B – Good:** Structure is performing almost as well as intended, but minor upgrades should be considered in the future. C – Fair: Structure performs well under typical conditions, but not under extreme conditions. Minor repairs or upgrades are required. **D – Poor:** Structure is not performing well under typical conditions. Major repairs or upgrades are required. **E – Very Poor:** Structure is not performing its function on a daily basis. Repairs and upgrades are likely impossible, and a complete replacement is probably required. See section 6.3 of the **Guidance Manual** for further detail.	**B – Good** The structure is generally performing its intended function of retaining land. Some voids are apparent immediately behind the crown wall where land has subsided. Wave overtopping is not reported as problematic at present.

Field	Description	Example
Condition rating	Rate the condition of the structure from **1** (poor) to **5** (excellent), based on the following criteria: **A – Excellent:** Asset is in as-new condition, with no wear, damage, deformation, defects, or deterioration evident in the overall structure or in the individual elements. **B – Good:** Asset is in "like new" condition, with minor wear, but no damage, defects, deformation or deterioration in the overall structure or individual elements. **C – Fair:** Overall structure and/or individuals elements shows minor wear, deformation, damage, defects, or deterioration. Elements can generally be repaired at a reasonable cost. **D – Poor:** Overall structure and/or individual elements show major deformation, degradation, deterioration, damage, or defects. Major repairs will likely be required to restore the structure, and may not be economically feasible. **E – Very Poor:** Overall structure and/or individual elements show major degradation, deterioration, damage, or defects. It will probably not be possible or economically feasible to restore the structure condition through repair. See section 6.2 of the **Guidance Manual** for further detail.	**D – Poor** The overall **slope** and **alignment** of the structure appear uniform; but erosion has occurred at the **end of the structure**, where it transitions into the rock revetment. The lower **structure facing** is exhibiting loss of grout, particularly away from the wall ends, as access for maintenance and repair is more difficult. **Geotextile** or **filter layers** are not apparent behind the wall at the exposed end. Drainage appears to be sufficient and overtopping negligible; however, there are voids immediately behind the structure, indicating loss of **backfill** material.

Source: The authors

2.6 Effects assessment

This section requires the inspector to look beyond the performance and condition of the structure and its individual components to the possible social and environmental effects they may be having. Speaking to and observing stakeholders including members of the community who live close to or interact with the structure regularly, may inform this section of the **inspection form**.

Table 6: The structure's effects on the community and the environment

Field	Description	Example
Effects on the community	Typical positive and negative effects of coastal protection works on the community are listed in the **inspection form**. Select any effects that you may have seen or been informed about. Add any additional positive or negative effects that may have occurred, and elaborate where you can. See section 3.5 of the **Guidance Manual** for further detail.	The structure provides support to a well-used amenity area and is used as a community meeting place. Voids behind the seawall pose some risk to public safety if someone were to step into them, particularly in the dark, or if they accumulate rubbish. At the end of the seawall where outflanking has occurred, some steel reinforcement is exposed posing a hazard.

	Positive		Negative		Other -Specify:
Effects on community	Improved coastal access	☐	Exposed steel/wire	☒	*Uneven land behind structure posing safety risk*
	Provision of new meeting/social location	☒	Unstable rocks	☐	
	Improved fishing/fossicking	☐	Loss of access to or along beach	☐	
	Improved recreational amenity; walking, sunbaking, diving, surfing, etc	☒	Flooding caused by seawall blocking return flow	☐	
	Reduction in wave overtopping/inundation	☐	Is the structure having adverse outcomes for any particular group	☐	
			Use as a refuse point	☐	

Field	Description	Example
Effects on the Environment	Typical positive and negative effects of coastal protection works on the environment are listed in the **inspection form**. Select any effects that you may have seen or been informed about. Add any additional positive or negative effects that may have occurred, and elaborate where you can. See section 3.5 of the **Guidance Manual** for further detail.	

	Positive		Negative		Other - Specify:
Effects on the Environment	Improved water quality	☐	Increased erosion in front of the asset (i.e. beach is lowering)	☒	
	Improved flora or fauna habitat	☐	Increased erosion next to asset (i.e. end effects or downdrift erosion)	☒	
	Reduced rubbish/debris	☐	Affecting lagoon currents or stream flow processes	☐	
	Training of creek/inlet	☐	Affecting wave processes (i.e. increased reflection)	☒	
			Affecting ecology (specify)	☐	
			Blocking flow path	☐	
			Trapping debris/waste	☐	

Source: The authors

2.7 Response to an assessment

In order to formulate an appropriate response to the findings of the inspection, you have to assess not only the structure's condition and performance, but also its risk levels. Using the Risk Matrix for Coastal Protection Works (Table 7-1 in the **Guidance Manual**), which is included in the **inspection form**, you should assess the risks based on the importance of the structure, as shown in Table 7.

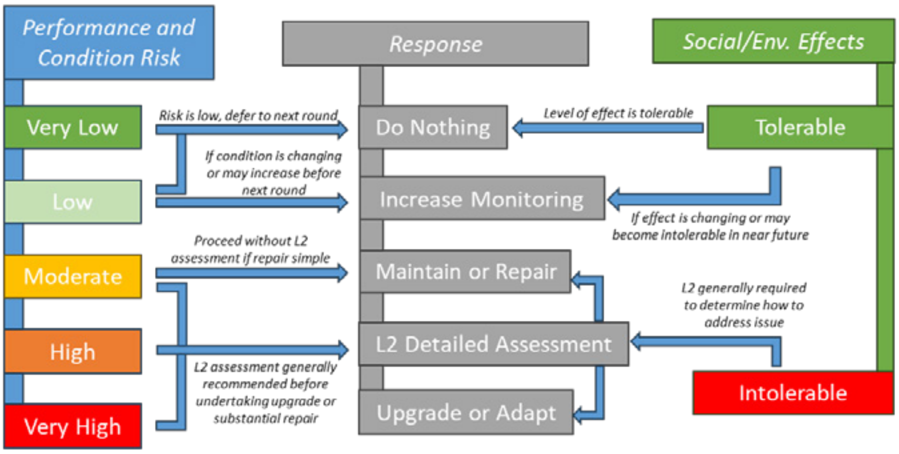
Table 7: Determining the structure's risk levels and formulating an assessment response

Field	Description
Risk levels	First determine the structure's importance rating, which can be low (3), medium (2), or high (1). Next, you must rate the **performance risk level** and condition risk level, which range from "very low" to "very high," based on the Risk Matrix for Coastal Protection Works (see below).

	Performance Risk Level	Condition Risk Level
Risk Level	Performance vs importance (circle) VERY LOW LOW MODERATE HIGH VERY HIGH	Condition vs Importance (circle) VERY LOW LOW MODERATE HIGH VERY HIGH

		Importance of structure		
		3: Low	2: Medium	1: High
Condition / Performance	A – Excellent	Very Low	Very Low	Low
	B – Good	Very Low	Low	Low
	C – Fair	Low	Moderate	Moderate
	D – Poor	Moderate	Moderate	High
	E – Very Poor	Moderate	High	Very High

Field	Description
Intolerable effects	Determine if the structure is having any social or environmental effects that are deemed intolerable by the community, the asset owners, or other stakeholders. An intolerable effect is one that requires immediate attention. It may involve: • health and safety; • access and amenity value, • visual and aesthetic considerations, • the environment and ecology, and/or • coastal processes.
Potential or recommended response	Select an appropriate response based on the findings of the inspection. Use the monitoring response flowchart below to inform your decision.



Section 7.2 of the **Guidance Manual** provides further details and information.

Potential / Recommended Response (refer to Operations Manual for appropriate response)	Do nothing (defer to next monitoring round)	☐	**Notes:** Structure to be further assessed by a coastal engineer to determine the extent of damage and likelihood of failure. This should be done prior to the upcoming wet season to minimise further damage
	Increase monitoring frequency	☐	
	Undertake L2 (detailed) assessment	☒	
	Undertake maintenance or repair works	☐	
	Upgrade or adapt structure	☐	
	Replace or remove structure	☐	

Env.=environmental, L2=Level 2.
Source. The authors

2.8 Updating the Asset Management Database

A simple asset management database (AMD) is provided as part of the Guidance and Operations Manual package in digital (Microsoft Excel) format. This database is not exhaustive, and it is understood that many organizations will have their own systems, which should be used in preference if they serve the purpose. However, the AMD spreadsheet provides a good starting point, should the user not have an asset management system in place, as it provides all the information required for effective asset management and is fully editable, should the user which to add more fields or store additional asset information.

The following section provides an overview of the AMD, as well as instructions on how to transfer the information gathered in the field to the **inspection form** into the AMD.

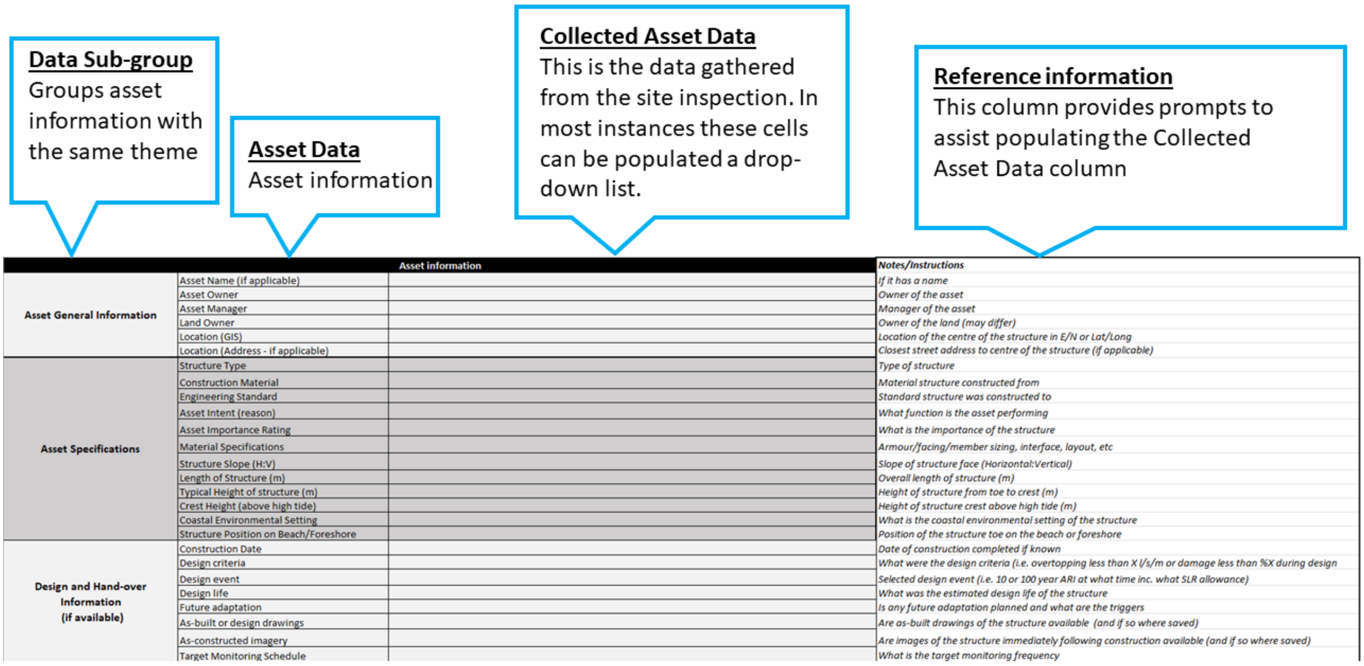
2.9 The layout

Each coastal protection work has its own AMD spreadsheet, which should be named, saved, and stored in a format that can easily be located in the future, especially when it is time for a routine assessment and update. Each AMD spreadsheet is made up of three key tabs as seen below:

Details on each of these tabs and how to complete them is provided in the subsections that follow.

2.10 Asset specification

This tab contains the information that defines the structure: ownership, type, location, etc. It will remain constant throughout the life of the asset, and only needs to be completed once. This tab is to be completed first. The tab is divided into four columns as shown below:

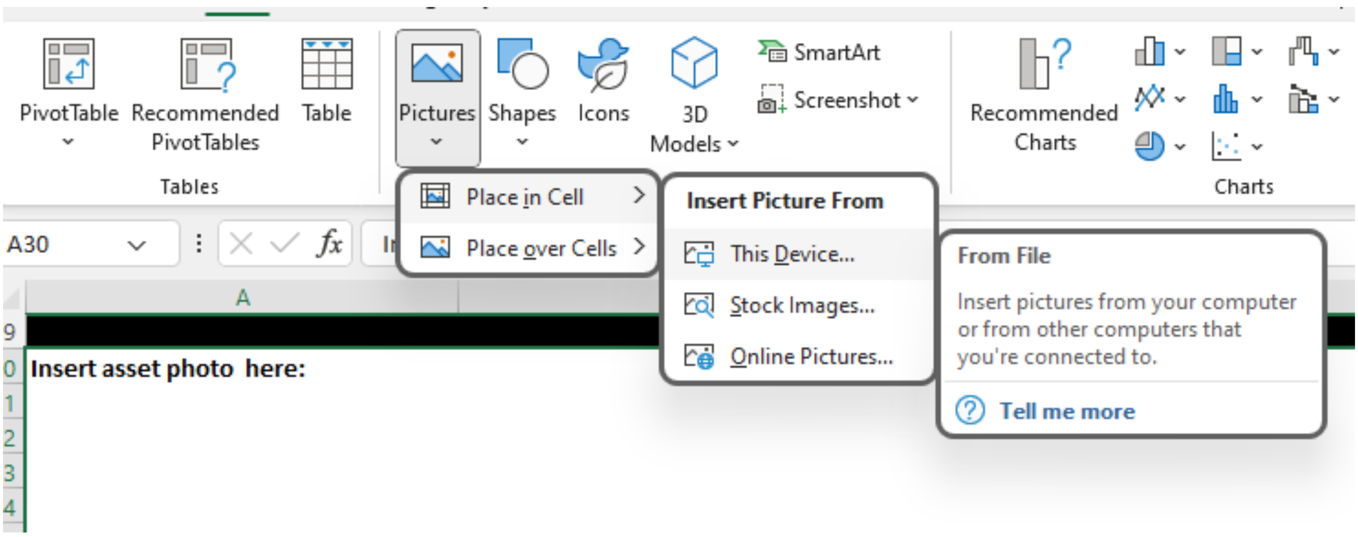


Asset information			Notes/Instructions
Asset General Information	Asset Name (if applicable)		*If it has a name*
	Asset Owner		*Owner of the asset*
	Asset Manager		*Manager of the asset*
	Land Owner		*Owner of the land (may differ)*
	Location (GIS)		*Location of the centre of the structure in E/N or Lat/Long*
	Location (Address - if applicable)		*Closest street address to centre of the structure (if applicable)*
Asset Specifications	Structure Type		*Type of structure*
	Construction Material		*Material structure constructed from*
	Engineering Standard		*Standard structure was constructed to*
	Asset Intent (reason)		*What function is the asset performing*
	Asset Importance Rating		*What is the importance of the structure*
	Material Specifications		*Armour/facing/member sizing, interface, layout, etc*
	Structure Slope (H:V)		*Slope of structure face (Horizontal:Vertical)*
	Length of Structure (m)		*Overall length of structure (m)*
	Typical Height of structure (m)		*Height of structure from toe to crest (m)*
	Crest Height (above high tide)		*Height of structure crest above high tide (m)*
	Coastal Environmental Setting		*What is the coastal environmental setting of the structure*
	Structure Position on Beach/Foreshore		*Position of the structure toe on the beach or foreshore*
Design and Hand-over Information (if available)	Construction Date		*Date of construction completed if known*
	Design criteria		*What were the design criteria (i.e. overtopping less than X l/s/m or damage less than %X during design*
	Design event		*Selected design event (i.e. 10 or 100 year ARI at what time inc. what SLR allowance)*
	Design life		*What was the estimated design life of the structure*
	Future adaptation		*Is any future adaptation planned and what are the triggers*
	As-built or design drawings		*Are as-built drawings of the structure available (and if so where saved)*
	As-constructed imagery		*Are images of the structure immediately following construction available (and if so where saved)*
	Target Monitoring Schedule		*What is the target monitoring frequency*

At the very bottom of this tab, there is space provided in which to insert images of the structure. The left cell is for a general photo of the asset, and it is recommended that the photo encompass a wide view of the structure, preferably from the toe to the crest looking landward from the beach or foreshore. The right cell provides space for an aerial view or a geographic information system (GIS) map of the structure. This can be taken from a drone or by using a GIS platform with satellite imagery such as Google Earth or QGIS. If using GIS software, all maps should have at least a scale bar and a north arrow included in the image for reference.

Images can be inserted into the cells by clicking:

Insert > Pictures > Place in Cell > This Device



2.11 Asset Inspection

The **Asset Inspection** tab must be completed following each asset inspection in the field. A new tab should be created each time a new inspection is undertaken. This can be done as follows:

- right-click over the tab name at the bottom of the spreadsheet;
- select **Move or Copy**;
- **to book**, select the same workbook you are working in;
- **before sheet**, select (**move to end**);
- check the **Create a Copy** checkbox; and
- rename the **yyyymmdd** portion of the new tab to match the date of inspection (e.g., "Asset Inspection-20231107)".

Completing the **Asset Inspection** tab is simply an exercise in data entry. It is recommended that the tab be filled out by the same person who undertook the inspection. The tab is set up with the same four columns as shown for the **Asset Specification** tab, above. As in that case, most of the cells have drop-down lists to auto-populate. If your response is not in the cell, you can enter it manually. If you would like to add this response to the drop-down list for future entry, this can be done in the **Response Lists** tab described below.

The elemental assessment provides room for photos of each element to be entered into the cell adjacent to the condition response cell. Photos can be entered into the cell as described above. Additional cells for photos are provided on the bottom of the tab.

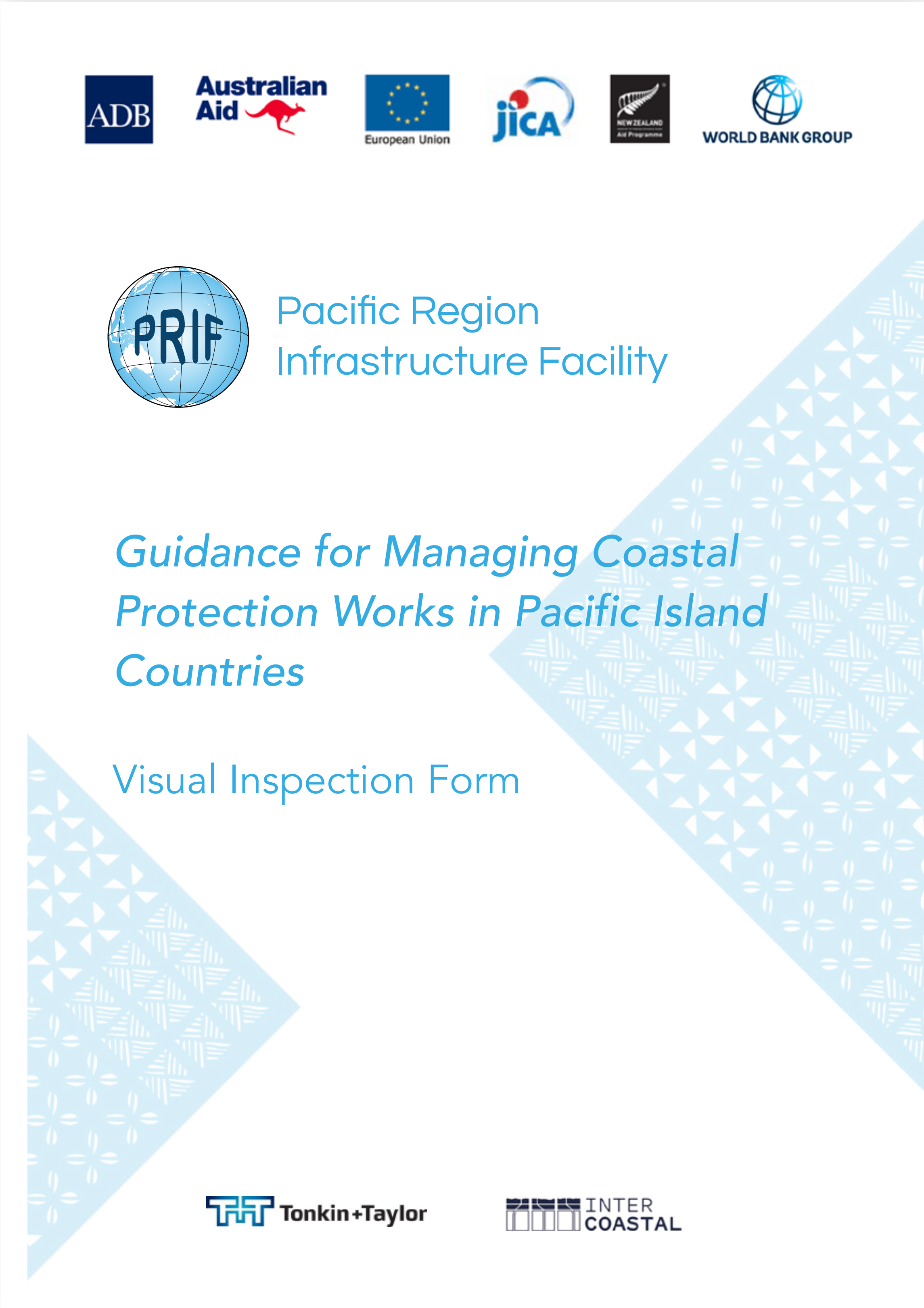
2.12 Response lists

This tab is used to populate information that feeds drop-down lists throughout each of the other working tabs in the spreadsheet. Only edit this tab if you wish to add another option to a drop-down list.

Appendices

Appendix 1: Visual Inspection Form

CLICK HERE to download Appendix 1


ADB
Australian Aid
European Union
JICA
New Zealand Aid Programme
WORLD BANK GROUP

PRIF Pacific Region Infrastructure Facility

Guidance for Managing Coastal Protection Works in Pacific Island Countries

Visual Inspection Form

Tonkin+Taylor
INTER COASTAL

Coastal Protection Works - Visual Inspection Form (page 1)

Inspection details

Asset name *(if applicable)*		**Date**	
Asset owner/manger *(if known)*		**Inspected by**	
Land owner *(if known)*		**Section** *(if applicable)*	
Site cultural/env significance *(if known)*		**Monitoring level** *L1 - Basic, L2 - Detailed*	
Location, address or GIS		**Monitoring type** *Scheduled, un-scheduled, post-event (specify)*	
Previous inspections *(specify if known)*		**Previous actions** *(specify previous repairs if known)*	
Notable events *(specify any notable weather events that may have occurred since construction or last inspection)*			

Structure details

Structure type *(select more than one if required)*	☐ Seawall	☐ Revetment	☐ Breakwater / offshore breakwater
	☐ Groyne	☐ Nature based - specify:	☐ Other - specify:
Construction material *(select more than one if required)*	☐ Rock armour	☐ Timber	☐ Mass concrete
	☐ Reinforced concrete	☐ Grouted rock	☐ Grouted sand bags
	☐ Stacked sand bags	☐ Stacked coral boulder	☐ ACB / grouted mattress
	☐ Masonry blocks / bricks	☐ Gabion	☐ Beach nourishment
	☐ Concrete armour unit	☐ Sand-filled geotextile container	☐ Imported fill
	☐ Concrete / sand-filled fuel drum	☐ Set cement bag	☐ Gravel / rubble berm
	☐ Seabees	☐ Shot-crete	☐ Sheet piles (Steel / FRC / PVC)
	☐ Waste material - specify:	☐ Hybrid - specify:	☐ Nature based solution - specify:
Material specifications *Armour/facing/member sizing, interface, layout, access (stairs, ramps, etc)*			

Coastal Protection Works - Visual Inspection Form (page 2)

Structure details

Asset intent / reason	☐ Support reclaimed land ☐ Change waves or sediment transport processes	☐ Protect land from erosion ☐ Improve amenity	☐ Protect land from inundation or wave overtopping ☐ Other - specify:
Engineering standard *Engineered / non-engineered*		**Asset importance rating**	☐ 1 High ☐ 2 Med ☐ 3 Low
Length of structure (m)		**Typical height of structure (m)** *(toe to crest)*	
Crest height (m) *(above high tide)*		**Structure slope (H:V)**	
Photos of structure	☐ Front left ☐ Front right	☐ End 1 ☐ End 2	☐ Crest along ☐ Crest down
Photo number/s *(if applicable)*			

Environmental setting

Coastal environmental setting	☐ Lagoon (<3km fetch) ☐ Open coast (reef platform <300m width)	☐ Lagoon (>3km fetch) ☐ Open coast (reef platform >300m width)	☐ Open sandy coast ☐ Other - specify:
Structure toe position on beach/foreshore	☐ Above high tide (always emergent) ☐ Between low and mid tide (emergent during lower parts of the tide)	☐ Between mid and high tide (submerged at higher parts of the tide) ☐ Below low tide (always submerged)	☐ Buried ☐ Other:

Coastal Protection Works - Visual Inspection Form (page 3)

Elemental assessment	Considerations depending on type of work	Notes on element (take photos of each element where possible)
Toe / Foundation	Y, N, N/A ☐ Is the toe founded on hard strata? ☐ Is the surrounding ground higher than the toe? ☐ Are there signs of scour? ☐ Is the toe buried? ☐ Is there a gap between the bottom of the structure and the ground? ☐ Is there evidence of bed lowering since construction?	
Structure facing	☐ Are there displaced armour rocks/units? ☐ Are there gaps in the armour/outer layer? ☐ Is there visible cracks in the façade? ☐ Is there exposed reinforcing? ☐ Is there exposed reinforcing? ☐ Is there signs of deterioration (cracked concrete, rust, ALWC, splitting/worn timber)? ☐ Are there discontinuities in the outer surface? ☐ Are there visible splits in geotextile containers? ☐ Is the geotextile partially empty, flapping?	
Filter layers / geotextile	☐ Can you see a geotextile underlayer? ☐ Is the geotextile underlayer intact? ☐ Is the geotextile of sufficient thickness/high quality? ☐ Is there more than one layer of armour rock/units?	
Backfill	☐ Are there signs of migration of fill through the structure? ☐ Is there holes or slumping behind the structure? ☐ Is the land lower immediately behind the structure?	
Crest	☐ Is there evidence of overtopping, vegetation die-back / salt burn? ☐ Is there signs of submergence on higher tides; algae, darker colour elements? ☐ Are units at the crest of the structure displaced? ☐ Is the capping beam cracked / deteriorated?	

Appendix 1: Visual Inspection Form

Pacific Region Infrastructure Facility

Coastal Protection Works - Visual Inspection Form (page 4)

Elemental assessment	Considerations depending on type of work	Notes on element (take photos of each element where possible)
Drainage	**Y, N, N/A** ☐ Is ponding present behind the crest? ☐ Are there weep holes in the face of the structure? ☐ Is the structure blocking creek/inlet or landward flow path? ☐ Is there evidence of flow through/under the structure at low tides?	
Slope	☐ Does the structure appear to be slumping/ becoming flatter? ☐ Does the structure appear to be leaning forward or back? ☐ Are any geotextile containers emptying or moving?	
Alignment	☐ Are sections of the structure out of alignment with the rest? ☐ Does there appear to be wash-throughs / or blow-outs along the structure? ☐ Are there signs of increased erosion at either end of the structure? ☐ Is beach nourishment maintaining its design shape/planform?	
Fixings	☐ Does the structure have fixings; mooring points/bollards, stormwater pipes, a footpath or furniture/lighting connected to the structure? ☐ Are the fixings in good working order?	
Access	☐ Is there safe access to and from the coast both over and along the structure? ☐ Is access available for disabled people? ☐ Is there safe access to maintain the structure? ☐ Is the structure safe for the community to interact with, sit/walk on?	
Nature-based	☐ Is vegetation planted as part of a NbS in good condition? ☐ Is there evidence of dieback or sparsity in vegetation? ☐ Is the planting securely founded/rooted on the bed? ☐ Are other NbS components in good condition	

Coastal Protection Works - Visual Inspection Form (page 5)

Structure rating

Potential failure mechanism	From the elemental assessment, are you able to determine a possible future failure mechanism that may occur before next inspection? i.e: - Toe erosion - Structural degradation - Geotechnical failure - Armour damage or displacement - Loss of internal materials - Crest Damage - Outflanking and end erosion Refer to Operations Manual and Guidance Document for Defects-Failure linkages	**Notes on potential failure:**

Performance rating: ☐ A – Excellent ☐ D - Poor ☐ B – Good ☐ E - Very poor/failed ☐ C - Fair	**Notes on performance** (based on results of elemental assessment):
Condition rating: ☐ A – Excellent ☐ D - Poor ☐ B – Good ☐ E - Very poor/failed ☐ C – Fair	**Notes on condition** (based on results of elemental assessment):

Effects assessment

Effects on community	**Positive** ☐ Improved coastal access ☐ Provision of new meeting/social location ☐ Improved fishing/fossicking ☐ Improved recreational amenity; walking, sunbaking, diving, surfing, etc ☐ Reduction in wave overtopping/inundation	**Negative** ☐ Exposed steel/wire ☐ Unstable rocks ☐ Loss of access to or along beach ☐ Flooding caused by seawall blocking return flow ☐ Is the structure having adverse outcomes for any particular group	**Other - specify:**
Effects on the Environment	**Positive** ☐ Improved water quality ☐ Improved flora or fauna habitat ☐ Training of creek/inlet	**Negative** ☐ Increased erosion in front of the asset (i.e. beach is lowering) ☐ Increased erosion next to asset (i.e. end effects or downdrift erosion) ☐ Affecting lagoon currents or stream flow processes ☐ Affecting wave processes (i.e. increased reflection) ☐ Affecting ecology (specify) ☐ Blocking flow path ☐ Trapping debris/waste	**Other - specify:**

Coastal Protection Works - Visual Inspection Form (page 6)

Response notes

Risk level

Performance risk level
Performance vs importance:

- ☐ VERY LOW
- ☐ LOW
- ☐ MODERATE
- ☐ HIGH
- ☐ VERY HIGH

Condition risk level
Condition vs importance:

- ☐ VERY LOW
- ☐ LOW
- ☐ MODERATE
- ☐ HIGH
- ☐ VERY HIGH

Intolerable effects
Environmental / social (specify):

		Importance of structure		
		3: Low	2: Medium	1: High
Condition / Performance	A – Excellent	Very Low	Very Low	Low
	B – Good	Very Low	Low	Low
	C – Fair	Low	Moderate	Moderate
	D – Poor	Moderate	Moderate	High
	E – Very Poor	Moderate	High	Very High

Potential / recommended response
(refer to Operations Manual for description of response options)

- ☐ Do nothing (defer to next monitoring round)
- ☐ Increase monitoring frequency
- ☐ Undertake L2 (detailed) assessment
- ☐ Undertake maintenance or repair works
- ☐ Upgrade or adapt structure

Notes:

Appendix 2:
Basic Asset Management Database

CLICK HERE to download Appendix 2

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