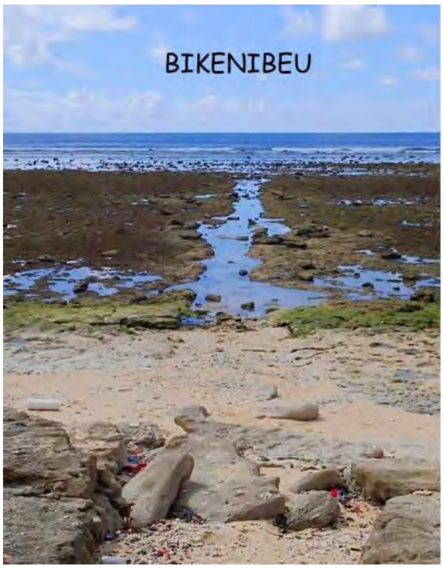
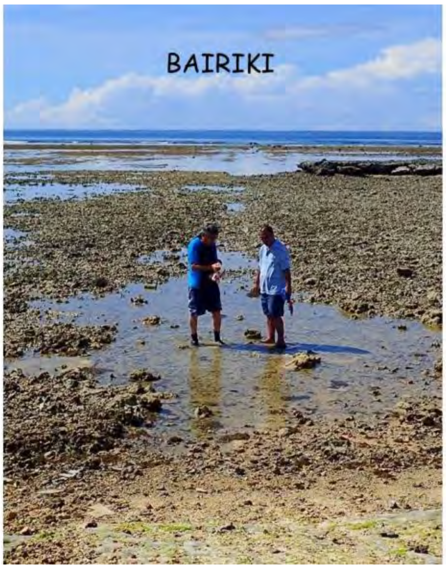
Benthic Morphology and Marine Life Assessment for the Siting of Ocean Outfalls on South Tarawa

The South Tarawa Sanitation Improvement Sector Project, Tarawa Atoll, Kiribati





Prepared for

The Kiribati Ministry of Public Works and Utilities

Prepared by

Karl Fellenius, MRM

University of Hawai'i Sea Grant College Program

and

Don Hess, MSc.

College of the Marshall Islands

GPS support and graphic documentation provided by SMEC International

March 2015

Table of Contents

Suggested citation for this report:

Fellenius, K., and D. Hess. 2015. *Benthic Morphology and Marine Life Assessment for the Siting of Ocean Outfalls on South Tarawa*. South Tarawa, Kiribati. 127p.

Acknowledgement

This paper is funded in part by a grant/cooperative agreement from the National Oceanic and Atmospheric Administration, Project No. A/AS-1, which is sponsored by the University of Hawaii Sea Grant College Program, School of Ocean and Earth Science and Technology, under Institutional Grant No. NA14OAR4170071 Office of Sea Grant, Department of Commerce. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies.

UNIHI-SEAGRANT-TT-14-06

List of Acronyms and Abbreviations

ADB	Asian Development Bank
BEIA	Basic Environmental Impact Assessment
BOM	Australian Bureau of Meteorology
CAB	Concrete Anchor Block
COT	Crown-of-Thorns Sea Star
EOP	End of the Existing Outfall Pipe
IEE	Initial Environmental Examination
LAT	Lowest Astronomical Tide
MT	Mid-point
OOE	Ocean Outfalls Expert
PPTA	Project Preparation Technical Assistance
PWU	Kiribati Ministry of Public Works and Utilities

Glossary

Acropora species: fast-growing, high rugosity stony coral with high habitat value largely known for its vulnerability to changes in water quality, coral bleaching, and Crown-of-Thorns predation

Benthic: marine ecological region on or near the bottom

Benthos: Community of marine life on the bottom

Bioerosion: erosion of hard marine substrates, notably carbonate structures built by coral reef animals and plants

Blue-green algae: containing cyanobacteria produced under oxygen-limiting conditions, particularly detrimental to coral reefs

Caulerpa species: common fleshy algae, not necessarily detrimental to coral reefs unless present in high quantities

Chainage: measured distance originating from a fixed starting point along an approximate straight line nominated as 0 chainage

Calcification: growth of calcifying organisms, build-up of carbonate structures on coral reefs

Coralline algae: hard algae deposited on the bottom from calcium and other minerals in seawater, important as the glue that bonds the rubble and debris of the coral reef together

Crustose coralline algae: pink or white variety that is favourable as a surface for regeneration of corals

Cyanobacteria algae: nitrogen-fixing bacteria found in almost every ecosystem, see blue-green algae

Eutrophication: ecosystem response to increased levels of nutrients, mainly phosphates from detergents, fertilizer, and sewage to an aquatic system, which results in the stimulation of excess plant growth

Filamentous algae: common growth form of blue-green algae

Fleshy coralline algae: red or brown variety that is unfavourable as a surface for regeneration of corals as it sloughs off its outer layer when coral gametes settle on it

Foliose: coral growth form that is leafy or sheet-like

Foreshore: area of the coast typically considered to be from where the land is exposed on a mid-tide to the storm high water mark; taken as the shoreline in this survey

Green coralline algae: common *Halimeda* sp. hard-segmented algae on coral reefs that need good water quality conditions; significant source of sand if in abundant supply

Growth form: manner in which coral grows, either massive, submassive, encrusting, branching, or foliose; indicator of healthy reefs with increasing rugosity

Halimeda species: see green-coralline algae

Intertidal: benthic area that is exposed between high and low tide

Lowest astronomical tide: the height of the water at the lowest possible theoretical tide to define chart datums. It is the lowest level which can be predicted to occur under conditions.

Macroalgae: algae that is not turf algae or other microalgae shorter than 2cm; includes filamentous blue-greens as well fleshy varieties but typically does not include green coralline algae

Mat cyanobacteria: blue-green algae shorter than 2cm that form dense micrometre-scale communities

Microalgae: typically turf algae, but can include mat varieties of blue-greens; shorter than 2cm

Morphology: shape or form; coral reef structure from reef flat to slope, see growth form and rugosity

Nutrient loading: adding nutrients, mainly phosphates and nitrates; process leading to eutrophication

Non-Acropora species: generally slow-growing, low rugosity stony coral with less habitat value than *Acropora* species; some resilience to changes in water quality, coral bleaching, and Crown-of-Thorns predation

Reef Crest: shoreward area immediately before the reef drops off on the reef slope; typically rises to an algal ridge although this is not well-developed for South Tarawa; the portion shoreward of the algal ridge is sometimes called the back reef

Reef Flat: gently sloping area seaward of the high water mark, with majority of it exposed on a low tide

Reef Slope: seaward area immediately after the reef crest, typically steeply descending to depths beyond which coral can grow; sometimes called the fore reef

Rugosity: small-scale variations in the amplitude or height of a surface; high coral reef rugosity is a measure of its coastal protection as well as habitat function and relates to coral growth form

Spur-and Groove: alternating coral or rock formations between sand, rubble, or debris channels; typically within the outer reef flat and reef crest but also found on the inner reef flat in this survey

Submassive: coral growth form that has branches or columns that fish generally cannot pass between and seek shelter

Substrate: surface or medium on which an organism may or may not grow, includes silt through to live coral

Subtidal: benthic area that is submerged at low tide

Turf algae: microalgae dominated by fleshy varieties less than 2cm in height; includes microscopic cyanobacteria but excludes mat cyanobacteria.

Zooanthid: soft coral-like animals in the same phylum as stony and soft corals; typically grow in response to loss of coral cover due to their fast-growth rate and resilience to changes in water quality

1 Summary

This report presents the findings and recommendations from marine surveys carried out by University of Hawai'i Sea Grant and College of the Marshall Islands during January 19-25, 2015 at the existing and proposed sewer outfalls on South Tarawa in Kiribati. The purpose is to determine the optimal siting of proposed new sewage outfalls for the locations of Betio, Bairiki, and Bikenibeu via reconnaissance and a close visual inspection and marine life survey for the proposed outfalls routes. The proponent for the project is the Kiribati Ministry of Public Works and Utilities. The report will also be useful for the Kiribati environmental assessment permitting process, and provides a baseline reference for future monitoring or research (see section 3.3 p19). More directly, the report allows landowners and Government to understand the environmental value of the coral reefs along parts of South Tarawa.

A summary of chainage (distances) and depths for each outfall location is provided in appendix A and discussed within pertinent sections of the report. Observations on water temperature based on dive data are provided in appendix B.

The detailed recommendations for the close visual inspection and marine life surveys are contained within the obstructions descriptions for each outfall. The marine life transect analysis gives a detailed snapshot of degradation, which was consistent with those recommendations.

1.1 Betio Outfall

1.1.1 Ecological Concerns

Betio has heavy sedimentation, low coral, and significant rubble and debris. Even with the extension of the outfall pipe the area will take a long time to produce the conditions needed for adequate coral growth to support even a modest coral reef ecosystem.

1.1.2 Recommendations

There is significant excavation needed in the shallow reef flat where the extended trench meets the proposed route. The reason is due to there being too many obstructions along the existing route for it to be a viable option. The proposed route to the west of the existing route goes through a spur-and-groove channel. There are 25 obstructions along the proposed outfall route. All of these can be removed by a dive team, and are made of coral, rock, and debris. The vast majority are on the subtidal reef flat. The estimated underwater time needed for rectifying obstructions is 7.5 days, for a total underwater installation time of 13 days. Numerous obstructions require coral to be relocated.

Terminating the outfall within 2m south of point 7 (see fig. 4.1.1a p22) is warranted because it achieves the desired 30m depth, and keeps the diffuser and the immediate area of discharge away from the blue coral *Heliopora coerulea* that is on the upper reef slope. If the diffuser is 10m long and ends at this location, it would be 47m south of the shallower *H. coerulea*. It is expected but not confirmed via surveying, that the reef conditions on the slope are similar 25m east and west of the outfall location based on the visibility at the time.

1.2 Bairiki Outfall

1.2.1 Ecological Concerns and Recommendations

Bairiki has moderate sedimentation, low to medium coral, and medium amounts of rubble and debris. The extension of the outfall pipe will benefit the area almost immediately. By re-directing the nutrient load, some stress is removed from existing coral, especially on the reef crest where there is high coral cover. The Crown-of Thorns infestation continues, and it is likely that it is related to the shallow status quo discharge.

There is excavation needed in the shallow reef flat where the proposed route meets the existing route. There are 48 obstructions along the proposed outfall route. All of these can be removed by a dive team, and are made of coral, rock, and debris. The vast majority are on the subtidal reef flat. The estimated underwater time needed for rectifying obstructions is 11 days, for a total underwater installation time of 16.5 days. Numerous obstructions require coral to be relocated.

Note that terminating the outfall 3m south of point 23 (see fig. 4.2.1 p55) is warranted because it achieves the desired 30m depth, and keeps the diffuser and the immediate area of discharge away from the bubble coral *Plerogyra sinuosa* that is both shallower and deeper but not in the debris field in the middle. If the diffuser is 10m long and ends at this precise location, it would be 5m north of the deeper *P sinuosa*. This is not significant, but it is better than terminating it in the deeper coral patch, which would necessitate further obstruction work, damage coral from both removal of obstructions and from more concentrated effluent plume discharge, and therefore not yield the perceived benefits that a deeper outfall might suggest.

If the design allows for it, it would be even better from an environmental standpoint for the diffuser to terminate 7m north of point at 25m depth because it gives a longer buffer down to the deeper coral patch. Moreover, it would eliminate some of the deeper obstruction removal work needed.

1.3 Bikenibeu Outfall

1.3.1 Ecological Concerns and Recommendations

Bikenibeu has low to moderate sedimentation, medium to high coral, and low to medium amounts of rubble and debris. The extension of the outfall pipe will benefit the area almost immediately. By re-directing the nutrient load, some stress is removed from existing coral, especially on the reef crest, upper slope, and lower slope where there is high coral cover.

There is excavation needed in the shallow reef flat where the proposed route meets the existing route. There are 11 obstructions along the proposed outfall route. All of these can be removed by a dive team, and are made of coral, rock, and debris. The vast majority are on the subtidal reef flat. The estimated underwater time needed for rectifying obstructions is 6.5 days, for a total underwater installation time of 11 days. Numerous obstructions require coral to be relocated.

Note that terminating the outfall 2m south of point 10 (see fig. 4.3.1 p91) is warranted because it achieves a 25m depth, and keeps the diffuser and the immediate area of discharge away from the *P. sinuosa* that is both shallower and deeper but not in the debris field in the middle. If the diffuser is 10m long and ends at this precise location, it would be 10m north of the deeper *P sinuosa*. This is not significant, but it is better than terminating it in the deeper coral patch, which would necessitate further obstruction work, damage coral from both the removal of obstructions and from more concentrated effluent plume discharge, and therefore not yield the perceived benefits that a deeper outfall might suggest.

The report finds that the existing discharge of sewage at the edge of the intertidal reef flat is producing excessive sedimentation along with nutrient enrichment that is significantly contributing to the degradation of the coral reefs along South Tarawa. The report details precise routing for the proposed outfall extensions, and determines that minimal disturbance of existing coral reef habitat will ensue if obstructions removal and relocation is done by hand. This is especially obvious with the moderate to high coral cover on the reef flat at Bairiki and Bikenibeu. Further to Lovell (2000) it is noted that most of the affected corals are uncommon corals - *Heliopora coerulea* (blue coral) and *Plerogyra sinuosa* (bubble coral) – but they are relatively common in South Tarawa.

With 13 days at Betio, 16.5 days at Bairiki, and 11.5 days at Bikenibeu the total underwater time needed for rectifying obstructions and laying the new outfall pipes is estimated at 41 days.

2 Introduction

2.1 Scope

This report presents the findings and recommendations from marine surveys carried out by University of Hawai'i Sea Grant and College of the Marshall Islands during January 19-25, 2015 at the existing and proposed sewer outfalls on South Tarawa in Kiribati. The purpose is to determine the optimal siting of proposed new sewage outfalls for the locations of Betio, Bairiki, and Bikenibeu via reconnaissance and a close visual inspection and marine life survey for the proposed outfalls routes. The proponent for the project is the Kiribati Ministry of Public Works and Utilities (PWU). The report will also be useful for the Kiribati environmental assessment permitting process, and provides a baseline reference for future monitoring or research (see section 3.3 p19). More directly, the report allows landowners and Government to understand the environmental value of the coral reefs along parts of South Tarawa.

A summary of chainage (distances) and depths for each outfall location is provided in appendix A and discussed within pertinent sections of the report. Observations on water temperature based on dive data are provided in appendix B.

2.2 Site Location

Figure 2.1 is a satellite image of South Tarawa. The 1-3 numbered arrows depict the areas where the existing sewage outfalls are located. The proposed upgrades are in the same locations. Figure 2.2 is a sketch of the same area.

Fig. 2.1 Sewage Outfall Locations in South Tarawa (adapted from Google Earth)

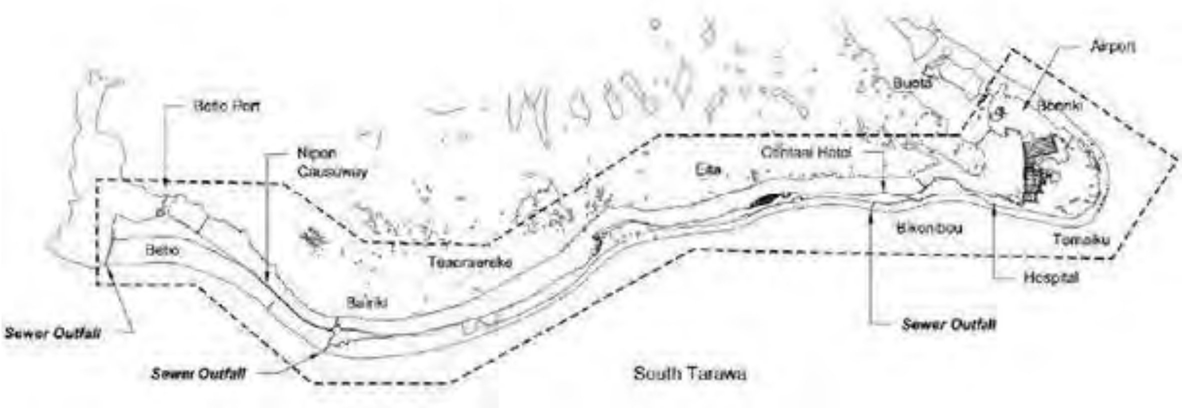


Fig. 2.2 Sewage Outfall Locations in South Tarawa (OOE 2014)

2.3 Site and Development Characteristics

The South Tarawa Sanitation Improvement Sector Project involves upgrading and renovation of sewerage and infrastructure in the townships of Betio, Bairiki, and Bikenibeu. Works include the replacement or rehabilitation of three existing sewage outfalls on the ocean side of the atoll to provide wastewater disposal for an approximate population of 39,000 people for the year 2030.

2.3.1 Betio

Figure 2.3 shows the outfall location at the town of Betio at the west end of South Tarawa. The arrow is the approximate proposed diffuser location, based on coordinates provided in the Basic Environmental Impact Assessment report (KIR PWU 2013, pA18).

Fig. 2.3 Sewage Outfall Location in Betio (adapted from Google Earth)

Figures 2.4 to 2.7 show the shoreline in all directions from the outfall location.

Fig. 2.4 From south of Betio outfall vent, looking north along the existing outfall route

Fig. 2.5 From Betio outfall location, looking South along the existing outfall route

2.3.2 Bairiki

Figure 2.8 shows the outfall location at the town of Bairiki at the west-central end of South Tarawa. The arrow is the approximate proposed diffuser location, based on coordinates provided in the Basic Environmental Impact Assessment report (KIR PWU 2013, pA22).

Fig. 2.8 Sewage Outfall Location in Bairiki (adapted from Google Earth)

Figures 2.9 to 2.12 show the shoreline in all directions from the outfall location.

Fig. 2.9 From south of Bairiki outfall vent, looking north along the existing outfall route

Fig. 2.10 From Bairiki outfall location, looking South along the existing outfall route

Fig. 2.11 From Bairiki outfall location, looking east

Fig. 2.12 From Bairiki outfall location, looking west

2.3.3 Bikenibeu

Figure 2.13 shows the outfall location at Bikenibeu town towards the east end of South Tarawa. The arrow is the approximate proposed diffuser location, based on coordinates provided in the Basic Environmental Impact Assessment report (KIR PWU 2013, pA20).

Fig. 2.13 Sewage Outfall Location in Bikenibeu (adapted from Google Earth)

Figures 2.14 to 2.17 show the shoreline in all directions from the outfall location.

Fig. 2.14 From south of Bikenibeu outfall vent, looking north along the existing outfall route

Fig. 2.15 From Bikenibeu outfall location, looking South along the existing outfall route

Fig. 2.16 From Bikenibeu outfall location, looking east

Fig. 2.17 From Bikenibeu outfall location, looking west

2.4 Benefits of Maintaining a Healthy Reef

Marine life quality on the coral reef flat, crest, and slope along the existing and proposed ocean outfall pipelines will be discussed at length in this report. This section highlights the many ecological relationships fundamental to understanding marine life quality along the ocean side stretch of South Tarawa from Betio to Bikenibeu. Coral reefs in this area are fully adjusted to the dynamic nature of the wind and swells that are the norm across Kiribati. Coral colonies are generally compact and resilient in the shallows (fig. 2.18) and more fragile and diverse with depth (fig. 2.19).

Fig. 2.18 Bairiki outer reef flat, 5m depth

Fig. 2.19 Bikenibeu reef crest vicinity, 9m depth

The most obvious direct local benefit of the reef ecosystem is the shoreline that exists today. Shores along Tarawa Atoll have been selectively weathered and eroded into sand and coral bedrock/beachrock over time. The South Tarawa ocean side shoreline is in a state of dynamic equilibrium. Great care needs to be taken in any shoreline modification effort because the effects of impacts are not easily predicted and are usually impossible to reverse. The structural integrity of the reef and reef flat protects against the daily swells and waves, and the occasional storm surge. It does this by dissipating wave energy.

If the health of the thin layer of marine life on any coral reef is compromised, there will be gradual erosion of the reef foundation and rubble fields will ensue. This rubble will cause further damage as it moves, and eventually the barrier provided by the reef will be reduced so much that high energy waves will pound the shoreline and possibly erode much more than the adjacent foreshore land area. Such features exist to some degree naturally, and are expressed through channels known as spur-and-grooves along the outer edge of the inner reef flat.

Locals obtain some of their food from the reef. Their traditional fishing activities are acceptable as long as they remain at subsistence levels and as long as the reef does not suffer from other impacts. Parrotfish and other sand makers on the reef such as green coralline algae are important sources of sand for beaches (discussed further in section 3.3). Red coralline algae act as the cement that bonds the rubble of the reef together, and precipitates from seawater on a healthy reef (fig. 2.20). The pink and white *crustose* variety is especially good at providing an excellent surface where new coral gametes settle on and grow. The presence of deep red or brownish *fleshy* varieties indicate less than ideal water quality, and slough off their outer layer when gametes attempt to settle on them. Corals with their associated photosynthetic algae are the second most important provider of oxygen for the world after rain forests (fig. 2.21). Moreover, the coral reef in all its splendour is the habitat for a myriad of animals and plants that have intrinsic value beyond direct or indirect benefits to humanity.

Fig. 2.20 *Linkia* sp. sea star on red and pink coralline algae

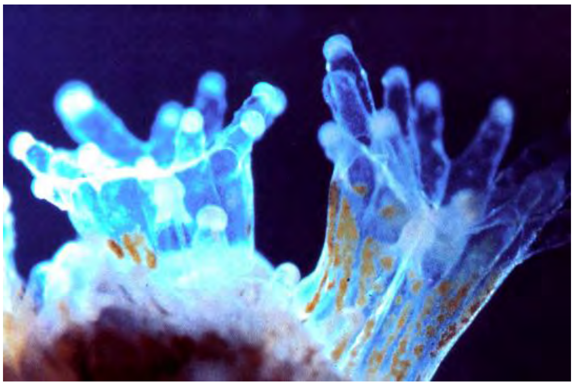


Fig. 2.21 Coral polyp with symbiotic algae

2.5 Reef Threats

There are a wide variety of threats to coral reef health. Atoll reefs are particularly vulnerable because they form and continue to depend upon a narrow range of sunlight, nutrients, temperature, and ocean chemistry variables that govern primary productivity and predator-prey relationships in the tropical ocean.

2.5.1 Global Reef Stressors

Few people purposely damage coral reefs. Most issues arise from the assumption that reefs can handle a variety of excesses. By far the two greatest threats to reef health today are global; coral bleaching and ocean acidification stemming from increased carbon dioxide and other greenhouse gas levels in the atmosphere. Reef-building colonial corals are found in both tropical and subtropical areas across the globe (fig. 2.22). Coral bleaching is a term referring to the loss of symbiotic algae living within the coral polyp in response to thermal stress (fig. 2.23). Acidification refers to the stunting effect on coral skeletal growth with changing ocean chemistry and increasing acidity of surface waters.

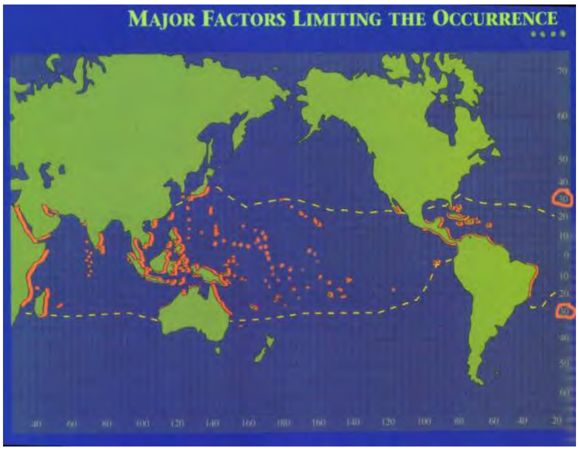


Fig. 2.22 Reef-building coral distribution

Fig. 2.23 Bleached table coral

Despite a few examples of coral mortality from bleaching, most of the coral along the existing ocean outfalls in South Tarawa at the time of this survey did not display significant thermal stress. However, the Western Gilbert Islands have been on a bleaching alert level 2 since December 2014 with the outlook for 2015 for continued elevated sea surface temperatures (fig. 2.24, NOAA Coral Watch 2014). The overriding point is that even pristine reefs cannot escape these global killers. Practically it means that even the outwardly intact reefs in Kiribati are already under threat and therefore survive somewhat precariously. Seemingly benign impacts can have serious consequences because the reef immune system is already under stress. Moreover, reefs already under threat from local impacts are less capable of embracing the adaptation needed to dampen the effects of global climate change.

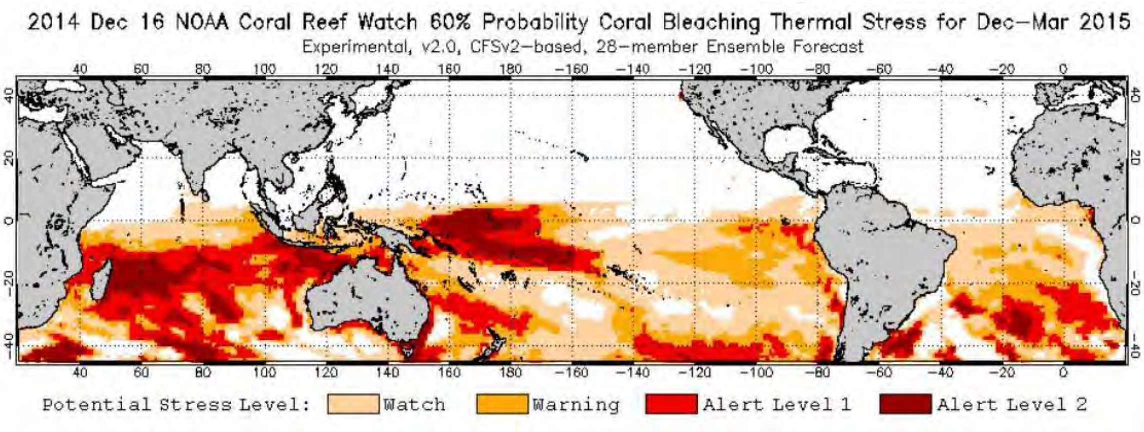


Fig. 2.24 Coral Bleaching Alert Levels 1 and 2 for Micronesia
(from NOAA Coral Watch)

2.5.2 Local Reef Stressors

Local threats to reef health are typically related to surface run-off such as from the current deteriorated road works in South Tarawa. Few stressors affect corals adversely as much as sedimentation. A coral polyp obtains part of its food from the derivatives of photosynthesis. But a significant portion of its nutrition comes from filtering plankton and other organic detritus. Sedimentation reduces the amount of sunlight getting through for photosynthesis as well as smothering the tentacles that it uses for filter feeding. It effectively starves and suffocates the coral. The stress response may be similar to coral bleaching, but usually polyp death sets in whether the coral symbionts have been ejected or not. Typically within days there appears on the colony a thin layer of anaerobic algae called cyanobacteria. If not controlled by algae eaters such as surgeonfish and sea urchins and other herbivores, this layer will grow into a thick mat or stringy assemblage of blue, brown, or black filamentous algae (fig. 2.25). Having up to 5% of the reef covered in such blue-green algae is considered to be the lower limit of a healthy reef. One excavator working on one section of the shoreline in South Tarawa can conceivably produce enough sediment over a short time period to damage an area of reef much larger than the section itself. Usually it depends on the rate at which the material enters the system. Nature is used to dealing with large volumes of sediment. It only becomes a problem when it enters the system rapidly.

Beyond the physical impact of sedimentation in run-off is the nutrient nature of the material. Ground coral rock contains phosphates and nitrates that act as liquid fertilizer in the marine environment. While nutrients in the marine environment are normal, the excessive rates at which they enter South Tarawa's waters from excavated shorelines, road works, sewage leakage, open defecation on reef flats, and animal husbandry areas in particular cause eutrophication. Coral reefs are gradually being replaced by algae.

Fig. 2.25 Stringy Black Cyanobacteria

Fig. 2.26 COTs on table corals

South Tarawa, and especially Bairiki, continues to have infestations of the Crown-of-Thorns (COTs) sea star *Acanthaster planci* beyond the 2009 outbreak (KIR PWU 2013, items 42-91). It is a growing problem all over the world. Numerous animals and feeding scars were seen on this survey (discussed further in section 3.3). COTs eat stony coral (fig. 2.26). Much research has been done in this area and the consensus is that COTs thrive in polluted, nutrient-rich areas. There are also outbreaks in pristine areas so there is some indication that COTs control fast-growing coral from taking over a reef. Nonetheless, they are considered to be pests and the best management practice is to remove them from the water and to avoid the high nutrient water quality conditions in South Tarawa that attract them in the first place.

3 Methodology

The methodology used for this assessment is *in situ* observation of the substrate and benthos along the existing and proposed outfall routes to gather information about reef morphology and marine life. Techniques employed include intertidal walks, subtidal surveying using transects and photo quadrats along the proposed outfall route and vicinity to a depth of 35m, and video transects along the entire existing and proposed routes. Data is interpreted in the context of existing outfall pipeline condition, underwater features, obstructions, and the importance of marine biodiversity and the complexity of relationships among reef inhabitants.

3.1 Reconnaissance Survey

An initial reconnaissance survey was carried out to assess the general condition of the existing pipelines, features and obstructions, and marine life at each outfall location. This is necessary to determine the relative extent of survey work needed across the three sites.

3.1.1 Shoreline and Foreshore

Photo and GPS documentation of the vent and associated shoreline features at low to mid tide provided the reference starting point for chainage along the existing and proposed outfalls routes.

3.1.2 Intertidal Reef Flat to End of Existing Pipe

Photo and GPS documentation of the intertidal reef flat at low tide was done approximately every 15m to record chainage and identify general features, obstructions, and marine life quality. Some sections of the reef flat are recorded every 30m with one interval of 130m at Bikenibeu.

3.1.3 Subtidal Reef Flat beyond End of Existing Pipe

Photo documentation of the subtidal reef flat at mid to high tide was done as needed to identify general features, obstructions, and marine life quality. This is straightforward for Bairiki and Bikenibeu where the broken outfall pipe portion remains in place beyond the end of existing pipe. For Betio, significant reconnaissance to determine appropriate new outfall routing was needed.

3.1.4 Reef Crest and Slope

Photo documentation of the subtidal reef flat irrespective of the tide was done as needed to identify general features, obstructions, and marine life quality.

3.2 Close Visual Inspection

A close visual survey was carried out to assess the detailed condition of the existing outfall pipe, chainage, features, and obstructions at each outfall location. This is necessary to determine the proposed outfall route required for each of the three locations. All depths were corrected with respect to 0 chart datum, which is the lowest astronomical tide (LAT) in the 2015 Australian Bureau of Meteorology (BOM) tide tables.

3.2.1 Intertidal Reef Flat to End of Existing Pipe

Photo documentation of the intertidal reef flat at low tide was done approximately every 15m to identify detailed features and obstructions. Some longer sections at Betio were sampled every 30m.

3.2.2 Subtidal Reef Flat beyond End of Existing Pipe

Photo and GPS documentation of the subtidal reef flat at mid to high tide was done to record chainage, and identify detailed features and obstructions. Positions were noted by attaching a numbered marker buoy on a line to each feature or obstruction, which was subsequently, recorded topside. In current conditions, a snorkeler held the buoy line vertical to avoid bias. Survey coverage does not exceed 3m on each side of the proposed routing, and no deeper than 5m below the depth of the new outfall. Widths of channels and heights of features and obstructions were recorded using a tape measure as needed. Maximum effort was placed on utilizing existing crevices within the naturally-occurring spur-and-groove formation throughout the subtidal reef flat.

3.2.3 Reef Crest and Slope

Photo and GPS documentation of the reef crest and slope irrespective of the tide was done to identify detailed features and obstructions. The methodology is outlined above in section 3.2.2. SMEC's Ocean Outfall Expert (OOE) indicated that the original construction of the outfalls involved blasting of the 'spur' between the 'grooves' in the reef beyond the outfall to allow for effective discharge (OOE 2014, p2). These basins were the focus of the morphology survey because they are the likely optimal route for the extensions of the end of existing pipes.

3.3 Marine Life Survey

Biodiversity is a measure of species richness and evenness. It is applied in this survey as a relative measure to inform the discussion of observed indicators of reef degradation. Species richness is the *variety* or number of species within an area. For example, South Tarawa has many kinds of coral species including the common *Porites rus* and the more unique *Acropora echinata*. Species evenness is the *relative abundance* or number of individuals of a species compared with another species within the same area. For example, a site may have an abundance of the habitat-poor *P. rus* but very few colonies of the IUCN red-listed and therefore vulnerable *A. echinata*.

Scientists measure richness and evenness for many target species and taken together, they indicate high or low biodiversity. Complexity of ecological relationships among species and their habitats do not always mean that high biodiversity is preferred in all environments. But high biodiversity is always preferred on coral reefs, such as in South Tarawa. More specifically, abundance within keystone species indicates a healthy environment. Measuring relative biodiversity on the coral reef can be done without conducting a complete species inventory. It does require a certain amount of representative sampling across areas and depths, but it is also about observing ecological relationships among reef inhabitants that indicate whether the reef is functioning as it should Biodiversity information on an already impacted reef should ideally be compared to some sort of pre-impact baseline at the same location. A marine survey report on Tarawa Atoll by Lovell (2000) is used to inform that baseline. Whether a control site or pre-impact baseline reference is used, observing reef function requires both quantitative and qualitative measurement.

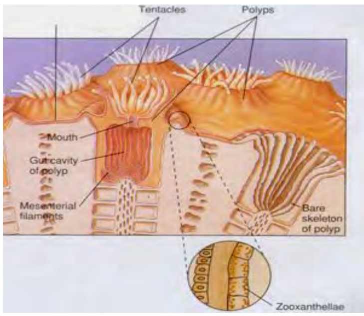


Fig. 3.1 Coral Polyp x-section

Understanding the general relationships among producers, consumers, decomposers, and sand makers is necessary for assessing relative biodiversity and overall coral reef health. The entire reef depends on the producers, the plants and special animals that turn sunlight and carbon dioxide into food and release oxygen as a byproduct. In addition to plants and algae, an important producer is the coral itself. The brown colour of many kinds of coral comes from countless tiny, microscopic single-celled algae called *zooxanthellae* that live inside the coral animal, the polyp (fig. 3.1). Other rich colours result from a pigment mix of the algae and the often 'faded' colour of the polyp itself. Without the algae, the polyp would not have the strength to make its hard skeleton, and the coral rock of the reef would not form.

Algae both produce and feed off nutrients in the water. There are *good* algae, and *bad* algae, and even good algae can disturb the delicate coral reef balance if there is too much of it. As animals on the reef die to make room for new life, their tissues and skeletons provide yet more nutrients and solid material for the next generation. Algae grow everywhere, and the most edible types are so small that they are easily overlooked. They grow on dead coral rock, and are scraped up by schools of herbivorous fish.

All animals produce waste, which act as fertilizer for producers. A healthy coral reef takes care of its wastes through decomposition. Decomposers are bacteria who turn dead animals and animal waste into nutrients. In the coral world, there is another special category of creatures, the sand makers. Sand is the home for many worms that are eaten by fish and it is where sea cucumbers find their food. Some sand comes from the dead remains of green-segmented coralline algae (fig. 3.2). Other sand comes from microscopic shells of small pink animals called *forams*. Much of it is excreted from parrotfish after feeding on corals (fig. 3.3). Parrotfish are herbivores, as they only target coral to get at the filamentous green algae inside the polyp skeleton. A large adult parrotfish can produce upwards of a tonne of sand per year.

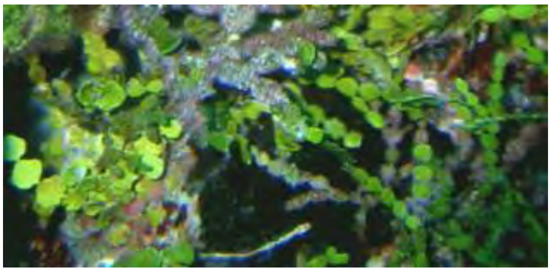


Fig. 3.2 *Halimeda sp.*

Fig. 3.3 Parrotfish - *Scarus sp.*

A detailed marine life survey was carried out to assess the ecological condition at each outfall location in South Tarawa. This is necessary to determine if the replacement or rehabilitation of the outfalls requires an Environmental Impact Assessment, or if this survey combined with the Basic Environmental Impact Assessment (BEIA) report (KIR PWU 2013) conducted in 2013 is deemed sufficient (OOE 2015). The BEIA report was a follow-up to the 2011 Initial Environmental Evaluation (IEE) report (ADB 2011) that lacked information on current, water quality, and bottom conditions in the discharge zones of the three outfalls (KIR PWU 2013, p1).

3.3.1 Intertidal Reef Flat to End of Existing Pipe

Photo documentation of the intertidal reef flat at low tide was done approximately every 15m to identify detailed marine life quality. Some longer sections at Betio were sampled every 30m. Emphasis was placed on representative photo quadrats to gauge changes in substrate and algae cover across the intertidal reef flat with observations for coral cover expected with proximity to the end of existing pipe.

3.3.2 Subtidal Reef Flat beyond End of Existing Pipe

Photo documentation of the subtidal reef flat at mid to high tide was done to identify detailed marine life quality. Emphasis was placed on continuous spot checks along the subtidal reef flat with observations recorded of substrate, algae cover, coral growth form and cover, coral genus and species where possible, and invertebrates. There were several marine plants and animals that could not be accurately identified *in situ*, and others where positive identification to the species level was made. Fish and larger marine life were not focused on in this survey except as needed to highlight an ecosystem function.

Characteristics of the underwater environment were adapted from the methodology developed by the Australian Institute of Marine Science. Such surveys are often conducted using underwater tape measures, quadrats, and photography equipment (figs. 3.4 & 3.5). The supplemental TOR and its focus on multiple transects and quadrats for the reef crest and slope (see section 3.3.3) limited the time available to carry out the close visual inspection and marine life survey on the subtidal reef flat. Therefore, due to time constraints it was decided not to utilize full transects and photo quadrats for the subtidal reef flat except for observations at the 5m depth (part of depth transect 3).

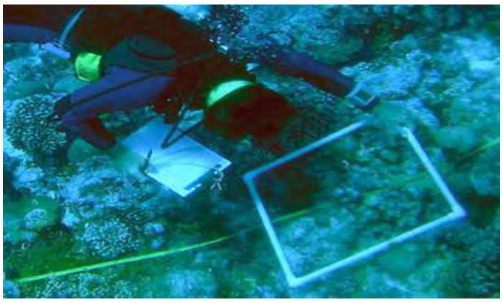


Fig. 3.4 Diver with Survey Quadrat

Fig. 3.5 Camera Housing

The continuous spot check methodology involved both simple and robust observations every 0.5m along three 5m transects. It is likely that there would be little variation in diversity across the highly impacted subtidal reef flats in the vicinity of the sewage outfalls in South Tarawa. Some entries were basic, such as sand. Other types of substrate were divided into further categories. Solid rock can be with or without surface cover of crustose or fleshy coralline algae. Rubble is either partly consolidated with coralline algae (on its way to becoming rock) or unconsolidated (loose). Coral is alive or dead. Dead coral can also be recently killed. Live coral is stony or soft, and can also be bleached. Stony coral has a number of growth forms ranging from massive to branching, and both stony and soft coral can often be identified to the level of genus. Because there are 10 data points in 5m, it is straightforward to present the data as frequency percentages. At a minimum this yields the amount of coral cover on the reef. By itself, coral cover is only a general indicator of reef health. But taken with select information from other substrate details, along with explanatory photos, an understanding of the reef bottom emerges.

Figure 3.6 is the substrate and benthic recording framework that was applied by the PPTA (Project Preparation Technical Assistance) dive team in 2011 and generally reported on in the Basic Environmental Impact Assessment report (KIR PWU 2013). The continuous spot check methodology used for the subtidal reef flat beyond end of existing pipe is complemented by reporting pertinent findings in this context.

Substrate		Stony Corals		Other Marine Life		
Category	Abbreviation	Category	Abbreviation	Category	Abbreviation	Definitions
sand	SSA	branching	CBR	sponge	OSP	SRU - non-consolidated rock fragments under 15cm in size
mud/silt	SMS	massive	CMA	anemone	OAN	SDE - non-consolidated rock fragments over 15cm in size
rubble	SRU	submassive	CSU	ascidian	OAS	SRO - consolidated substrate with no visible corallites
debris	SDE	encrusting	CEN	zoanthid	OZO	SCF - consolidated substrate with visible corallites
rock	SRO	digitate	CDI	soft coral	OSC	SCD - non-consolidated coral fragments with visible corallites
dead coral formation	SCF	table	CTA	gorgonian	OGW	CDI - only primary branching present,
dead coral debris	SCD	foliose	CFL	filamentous algae	OFA	branches appear to stem from a central point
		mushroom	CMU	coralline algae	OCA	CSU - vertical wedges or columns
		fire	CFC	other algae	OAO	OAN - all species
				sea grass	OSG	OAS - all species

Fig. 3.6 Substrate and Benthic Categories
(adapted from OOA 2014, appendix 1)

3.3.3 Reef Crest and Slope

Photo documentation of the reef crest and slope irrespective of the tide was done to identify detailed marine life quality. Prior to the receipt of the supplemental TOR from SMEC's International Environmental Expert on January 16, 2015 just before the commencement of the survey, the reef crest and slope were to be surveyed using spot check and photo quadrat techniques. The required transect and quadrat methodology from the supplemental TOR was used instead and is described below (fig. 3.7). All tables are provided in the findings section 4.

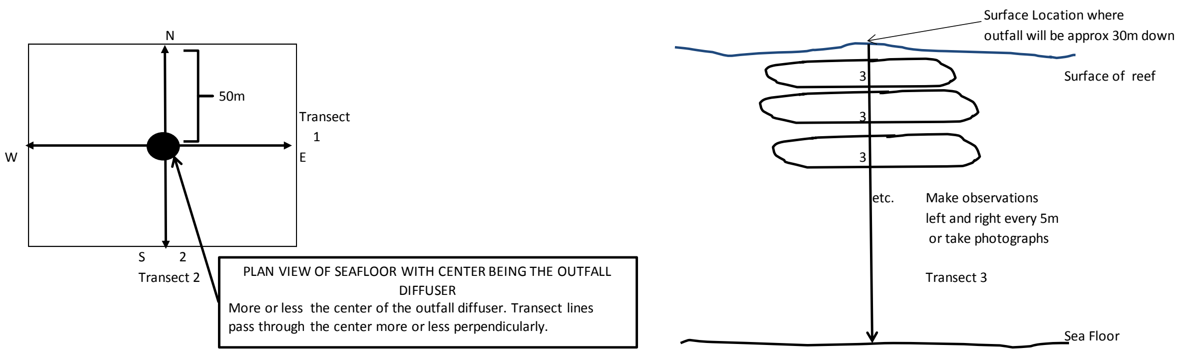


Fig. 3.6 Marine Life Survey Transects (from SMEC International Environmental Expert, Geza Teleki)

The methodology calls for using the depth of the mid-point of the diffuser as the reference point for observations. Due to diving safety limits it was agreed with SMEC's Ocean Outfall Expert (OOE) that this depth be 25m instead of 30m. It should be noted that had the supplemental TOR been provided earlier the survey would have been spread out over 14 days of diving instead of 7, with 30m used as the midpoint diffuser depth. Also note that even at 25m, the two transects from deep to shallow (distance transect 2 and depth transect 3) had to be integrated in order to carry out within the time allotted and to avoid exceeding dive safety limits. This was done via careful attention to distances and depths from south to north.

3.3.3.1 Transect 1 West-East by Distance

Ten (10) photo quadrats were recorded along a 100m west-east transect with the mid-point at 50m on the proposed outfall route at a depth of 25m. Each quadrat covered $1m^2$ of substrate at 10m distance intervals. Each photo quadrat was analysed for a number of marine life and substrate variables on a degradation scale of 1-5.

3.3.3.2 Transect 2 South-North by distance

Eight (8) photo quadrats were recorded along a 70m south-north transect with the "mid-point" at 25m on the proposed outfall route at a depth of 25m. Each quadrat covered $1m^2$ of substrate at 10m distance intervals. Each photo quadrat was analysed for a number of marine life and substrate variables on a degradation scale of 1-5.

3.3.3.3 Transect 3 South-North by Depth

Seven (7) photo quadrats were recorded for each outfall location, one every 5m depth from 35m to 5m alternating left and right along the proposed outfall route. Each quadrat covered $1m^2$ of substrate. Each photo quadrat was analysed for a number of marine life and substrate variables on a degradation scale of 1-5. The four deepest quadrats were along the reef slope, two middle ones on the reef crest, and the shallowest one at the seaward end of the subtidal reef flat.

4 Results and Discussion

In contrast with the methodology section, the results from the reconnaissance survey, close visual inspection, and marine life survey are presented and discussed in an integrated manner for each outfall location. Depths recorded on the survey were corrected for 0 tide datum (for example, a 35m depth observation taken at high tide is listed as 33m).

Video transects of all existing outfall pipe routes and proposed extensions are provided along with this report. They are discussed in the appropriate sections and titled as follows:

- Betio 1 existing route N to S vid 1m [first 5min on route, rest disregard]
- Betio 2 existing route N to S vid 1m outer RF to EOP
- Betio 5 new route S to N vid 3m (pt17) to 0m
- Betio 6 new route N to S vid 3m (pt17) to 11m (pt14)
- Betio 7 new route N to S 11m (pt14) to 35m (pt6)
- Betio 8 new route S to N vid 35m (pt6) to 11m (pt14)
- Bairiki N to S vid 1m to 35m (pt 24)
- Bikenibeu 1 - N to S vid 4m (6m N of Pt14) to 36m (pt9)
- Bikenibeu 2 - S to N vid 33m (approx pt9) to 1m [disregard first 3min]
- Bikenibeu 3 - 5m 360 deg EOP broken (pt14)

The video transects of the initial reconnaissance at Betio for the proposed extension deeper than the end of existing pipe is also provided, although not discussed in this report. This option was discarded in favour of a new route.

- Betio 3 existing route N to S vid 4m to 35m
- Betio 4 existing route N to S vid EOP to 4m bend [disregard after 2min]

4.1 Betio Outfall

Each section begins with a description of the chainage with photos referenced accordingly. Figure 4.1.1a shows the distribution of GPS positions taken along the existing and proposed outfall route.

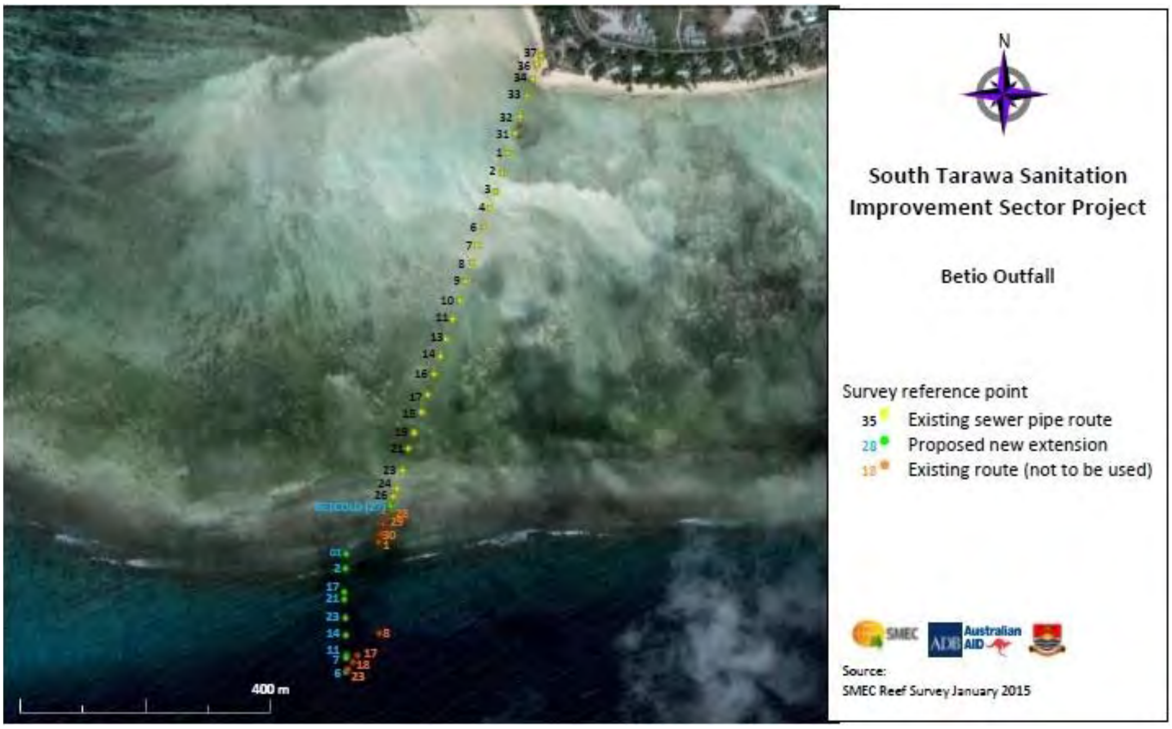


Fig. 4.1.1a Location of Existing and Proposed Betio Outfall Route

Figure 4.1.1b shows the pipeline route that was derived from the GPS points.

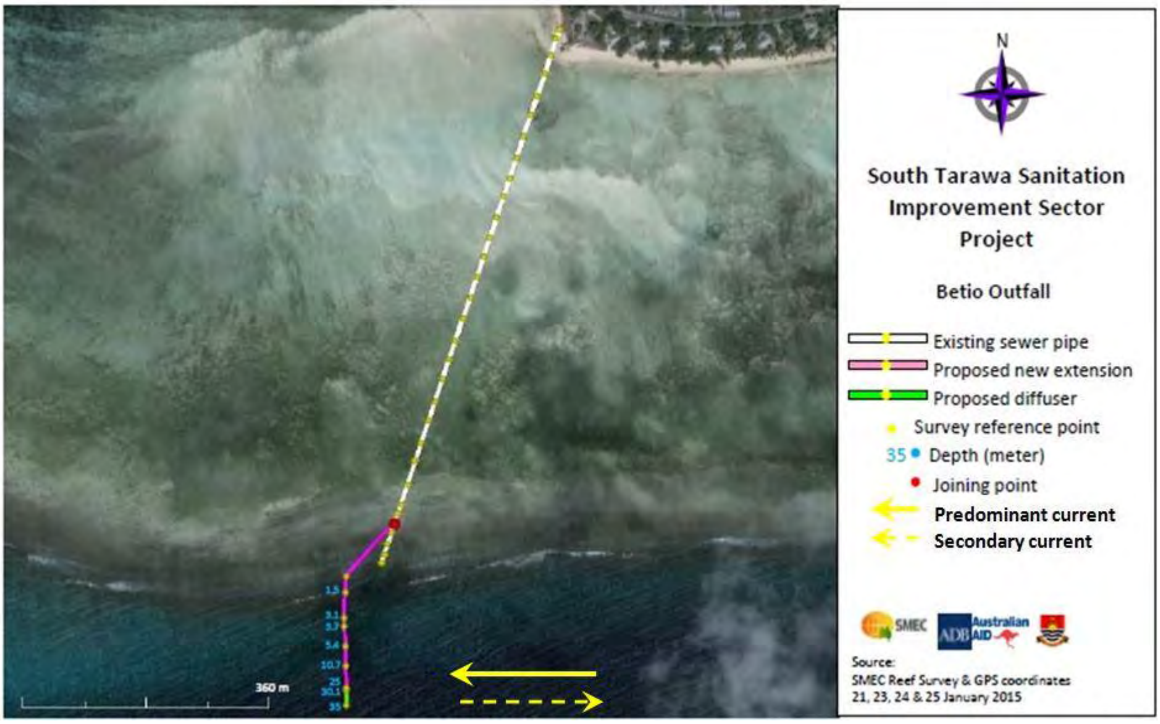


Fig. 4.1.1b Existing Outfall Pipe and Proposed Extension at Betio
(note: reference depths not corrected for 0 datum)

Figure 4.1.2 is the depth profile for the existing outfall pipe and proposed extension from point 37 at the vent on the shoreline to point 6 at 34m depth on the reef slope. The total distance is 1000m. Note that GPS points on the intertidal reef flat to end of existing pipe are all displayed as 0m.

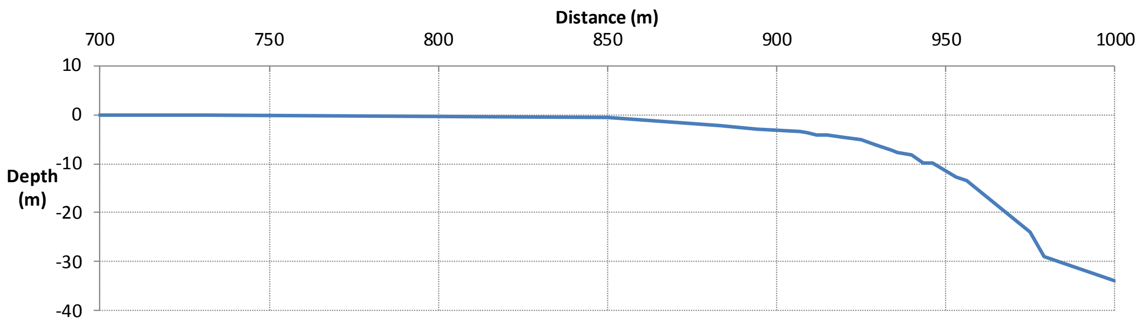


Fig. 4.1.2 Reef Depth Profile along the Existing Betio Outfall Route and Proposed Extension

4.1.1 Shoreline and Foreshore

Figures 4.1.3 and 4.1.4 of the vent location on the shoreline show point 37 as the 0m chainage point.

Fig. 4.1.3 Betio vent looking North

Fig. 4.1.4 Betio vent looking South

4.1.2 Intertidal Reef Flat to End of Existing Pipe

The total distance from the vent to the end of the existing outfall pipe is 790m (figure 4.1.5). The end of existing pipe (EOP) is at a height of 0.77m above 0 tide datum (LAT, BOM).

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)
Betio	vent	37	0.0	0.0
Betio	reef flat	36	13.6	13.6
Betio	reef flat	34	26.9	40.5
Betio	reef flat	33	27.1	67.6
Betio	reef flat	32	35.1	102.7
Betio	reef flat	31	26.3	129.0
Betio	reef flat	1	30.0	159.0
Betio	reef flat	2	32.3	191.3
Betio	reef flat	3	32.0	223.3
Betio	reef flat	4	30.2	253.5
Betio	reef flat	6	28.7	282.2
Betio	reef flat	7	28.4	310.6
Betio	reef flat	8	28.7	339.3
Betio	reef flat	9	29.0	368.3
Betio	reef flat	10	31.3	399.6
Betio	reef flat	11	29.4	429.0
Betio	reef flat	13	31.5	460.5
Betio	reef flat	14	30.0	490.5
Betio	reef flat	16	29.4	519.9
Betio	reef flat	17	31.5	551.4
Betio	reef flat	18	29.0	580.4
Betio	reef flat	19	31.4	611.8
Betio	reef flat	21	26.4	638.2
Betio	reef flat	23	35.0	673.2
Betio	reef flat	24	29.0	702.2
Betio	reef flat	26	13.2	715.4
Betio	reef flat	27	16.0	731.4
Betio	reef flat	28	13.7	745.1
Betio	reef flat	29	16.6	761.7
Betio	reef flat, near EOP	30	15.7	777.4
Betio	reef flat, EOP	1	12.8	790.2

Fig. 4.1.5 Intertidal Reef Flat Chainage

Figures 4.1.6 to 4.1.79 show the location and representative substrate and algae characteristics of the intertidal reef flat to the end of existing pipe, including a proposed extension to the southwest from point 27 (existing pipe from points 27 to 1 is not to be used). Quadrat photos are taken to the left and right of the transect line. Refer to reef flat videos: *Betio 1 existing route N to S vid 1m [first 5min on route, rest disregard]* and *Betio 2 existing route N to S vid 1m outer RF to EOP.*

Approximately the first 600m of the inner intertidal reef flat is sand with progressively greater proportions of rubble, with the exception of almost complete cover of the odoriferous and fast-growing red macroalgae, *Hypnea* sp. along the shoreline. It is not an alien algae, but exhibits invasive characteristics as it proliferates under nutrient-loading conditions resulting from the existing outfall discharge. It generally attaches to rocky substrate and other macroalgae as epiphytes, and occurs in significant quantities as windrows on the shoreline and as both attached and unattached mats (IUCN 2006). For that reason it is omnipresent when exposed or caught in pools at low tide, but partly washes away when the tide rises.

Fig. 4.1.6 Betio inner intertidal reef flat

Fig. 4.1.7 Betio point 36 looking South

Fig. 4.1.8 Betio reef flat between points 37 & 36

Fig. 4.1.9 Betio reef flat between points 37 & 36

From about 350m to 600m from shore (points 9 through 19) the substrate in the south-looking photos appear to have more macroalgae present than in the subsequent detailed quadrat photos. This is because the latter were taken on a slightly higher low tide.

Fig. 4.1.10 Betio inner intertidal reef flat

Fig. 4.1.11 Betio point 33 looking South

Fig. 4.1.12 Betio reef flat at point 33

Fig. 4.1.13 Betio reef flat at point 33

Note: Figures 4.1.14 through 4.1.29 have been removed for brevity in the report. Existing ones were deemed sufficiently representative of the observed changes in substrate and algae with chainage.

Fig. 4.1.30 Betio inner intertidal reef flat

Fig. 4.1.31 Betio reef flat at point 9 looking South

Fig. 4.1.32 Betio reef flat at point 9

Fig. 4.1.33 Betio reef flat at point 9

Note: Figures 4.1.34 through 4.1.45 have been removed for brevity in the report. Existing ones were deemed sufficiently representative of the observed changes in substrate and algae with chainage.

Fig. 4.1.46 Betio outer intertidal reef flat

Fig. 4.1.47 Betio reef flat at point 19 looking South

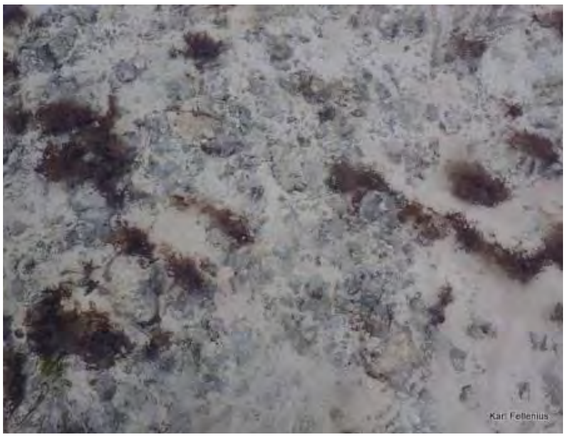


Fig. 4.1.48 Betio reef flat at point 19

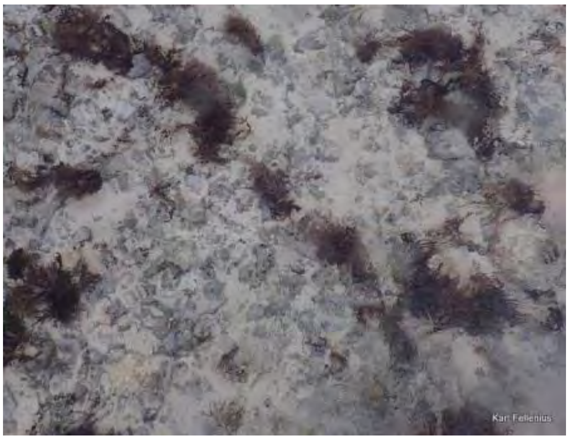


Fig. 4.1.49 Betio reef flat at point 19

Fig. 4.1.50 Betio outer intertidal reef flat

Fig. 4.1.51 Betio reef flat at point 23 looking South

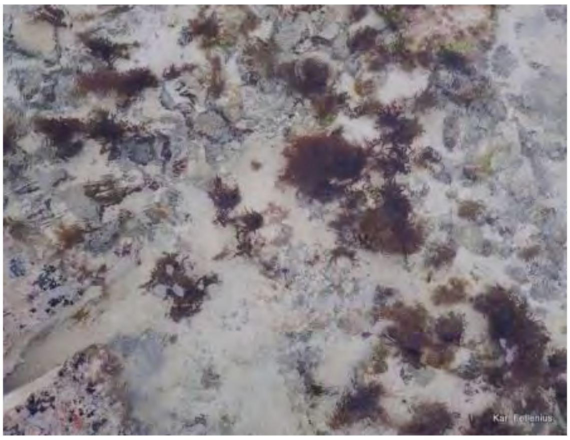


Fig. 4.1.52 Betio reef flat at point 23


Fig. 4.1.53 Betio reef flat at point 23

Note: Figures 4.1.54 through 4.1.57 have been removed for brevity in the report. Existing ones were deemed sufficiently representative of the observed changes in substrate and algae with chainage.

Figures 4.1.58 to 4.1.69 show the substrate and algae that is representative of the outer 100m of the intertidal reef flat. There is negligible sand outside the trench with about 70% cover of turf algae. Roughly half of the turf algae are red cyanobacteria microalgae, and half are fleshy green microalgae. Both arise from high nutrient and high energy conditions with enough sunlight. Within the green varieties there are the thicker-branched algae that are not palatable for herbivorous fishes, and therefore spread quickly. Others known as sea lettuce (*Ulva* sp.) have soft sheet-like leaves that do get eaten, or quickly disintegrate. Because of the high amount of turf algae, there are less than 5% crustose coralline algae and no green-segmented coralline algae (*Halimeda* sp.) that are normally associated with good water quality on outer intertidal reef flats.

Fig. 4.1.58 Betio outer intertidal reef flat

Fig. 4.1.59 Betio reef flat at point 27 (BETCOLD) looking South

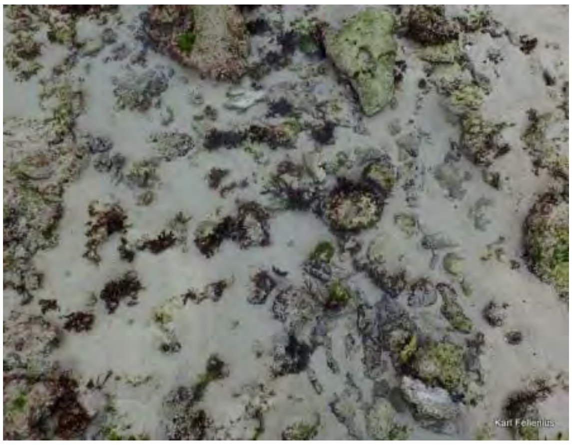


Fig. 4.1.60 Betio reef flat at point 27 (in trench)

Fig. 4.1.61 Betio reef flat at point 27 (beside trench)

Fig. 4.1.62 Betio outer intertidal reef flat

Fig. 4.1.63 Betio reef flat at point 28 looking South

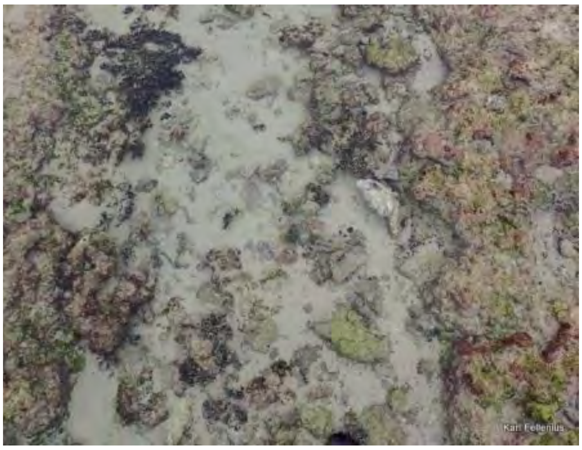


Fig. 4.1.64 Betio reef flat at point 28 (in trench)

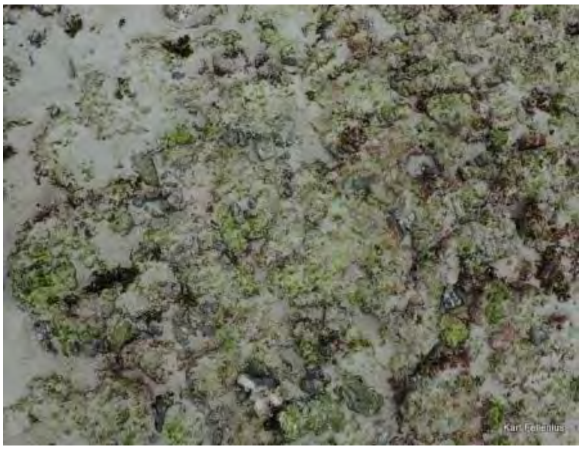


Fig. 4.1.65 Betio reef flat at point 28 (beside trench)

Figures 4.1.66 and 4.1.67 show a 20m section of the existing outfall pipe encased in concrete from approximately point 29 to point 30.

Fig. 4.1.66 Betio reef flat from point 29 looking South

Fig. 4.1.67 Betio reef flat at point 30 (people) looking NW

Figure 4.1.69 shows the last 13m section of the existing outfall pipe exposed from approximately point 30 to the end.

Fig. 4.1.68 Betio outer intertidal reef flat

Fig. 4.1.69 Betio reef flat from point 30 looking South, 20 min. after low tide of +66cm

Figures 4.1.70 and 4.1.71 are views in both the east and west direction from opposite sides of the end of existing pipe.

Fig. 4.1.70 Betio outfall looking East with point 1 (end of pipe) at ⬇ 20 min. after low tide of +66cm

Fig. 4.1.71 Betio outfall looking West with point 1 (end of pipe) at ⬇ 20 min. after low tide of +66cm

The existing end of the outfall pipe at Betio is shown in figures 4.1.72 and 4.1.73. The pipe itself appears in good condition except the portion that was attached from this point south has broken off. The broken pipe was not located on the reef flat, crest, or slope. The presence of dozens of concrete anchor blocks (CABs) strewn across the subtidal reef flat suggests that it has completely broken up into pieces and has washed away in recent years.

Fig. 4.1.72 From Betio end of existing pipe, looking South, corrected height +0.8m

Fig. 4.1.73 From Betio end of existing pipe, looking West, corrected height +0.8m

Directly south of the end of existing pipe at point 1 (fig. 4.1.74 in orange) is <u>not</u> the proposed extension route for reasons that are outlined in the subtidal reef flat section in 4.1.3. Therefore, an alternative route is proposed to the west of the current end of pipe through point 01 (fig. 4.1.74 in blue). The chainage for this point is listed along with the subtidal points in section 4.1.3. The proposed extension would connect to the existing pipe and trench at BETCOLD (27).

Fig. 4.1.74 Betio outer intertidal reef flat

Fig. 4.1.75 Betio proposed route from point 01 to 27 at ⬆ looking Northeast, 30 min. after low tide of +99cm

Figures 4.1.75 to 4.1.77 suggest that point 01 is not exposed on a moderate-to-high low tide. This will need to be factored in for the excavation of the new trench. The spur-and-groove morphology south of this point is also discussed in section 4.1.3.

Fig. 4.1.76 Betio proposed route looking South from point 01, 30 min. after low tide of +99cm

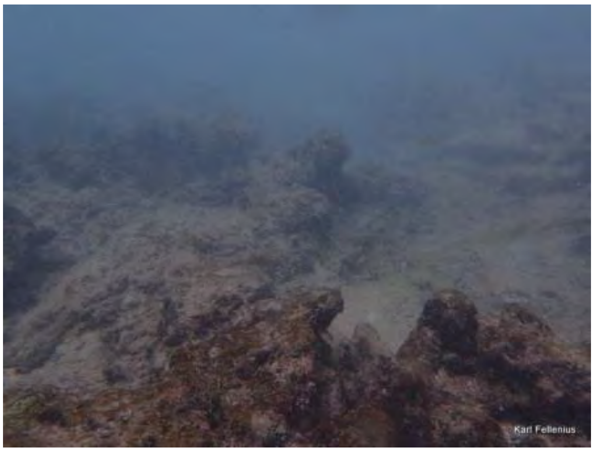


Fig. 4.1.77 Betio proposed route looking South from point 01, 30 min. after low tide of +99cm, 50cm depth

Only one palm-sized patch of encrusting coral and one cowrie were found on the intertidal reef flat in proximity to the existing and proposed outfall route (figs. 4.1.78 & 4.1.79).

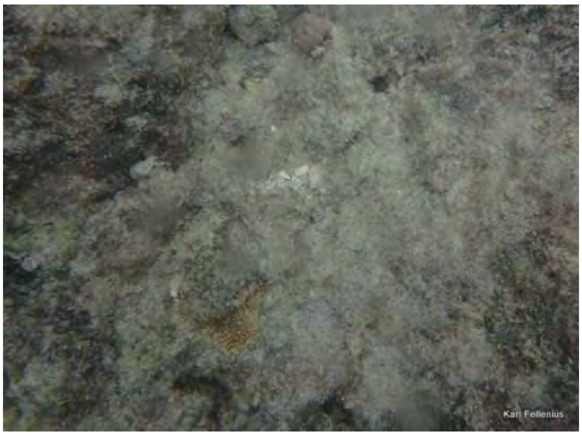


Fig. 4.1.78 Betio reef flat proposed route, 15m Northeast of point 01, only coral patch found

Fig. 4.1.79 Betio reef flat proposed route, 30m Northeast of point 01, only cowrie shell found

Cyanobacteria algae cover on the outermost part of the intertidal reef flat is largely present as mat-like or filamentous blue-green macroalgae (15% brownish-red patches in fig. 4.1.79) or within the fuzz of turf microalgae (30% fine reds in fig. 4.1.80). The green fleshy macroalgae sea grape (*Caulerpa* sp.) at the top of figure 4.1.79 can be associated with nutrient loading, but is generally healthy in moderation on the reef.

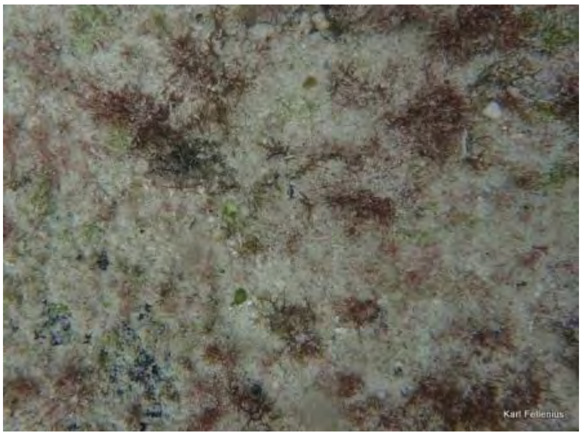


Fig. 4.1.80 Betio reef flat proposed route, half-way (51m) between points 27 (BETCOLD) & 01, typical algae cover

Fig. 4.1.81 Betio reef flat proposed route, from 20m Southwest of point 27 (BETCOLD), at person)

4.1.3 Subtidal Reef Flat beyond End of Existing Pipe

Figure 4.1.82 displays the coordinates of the GPS positions taken along the outfall route south of the connection point (in red) between the existing pipe and the proposed extension.

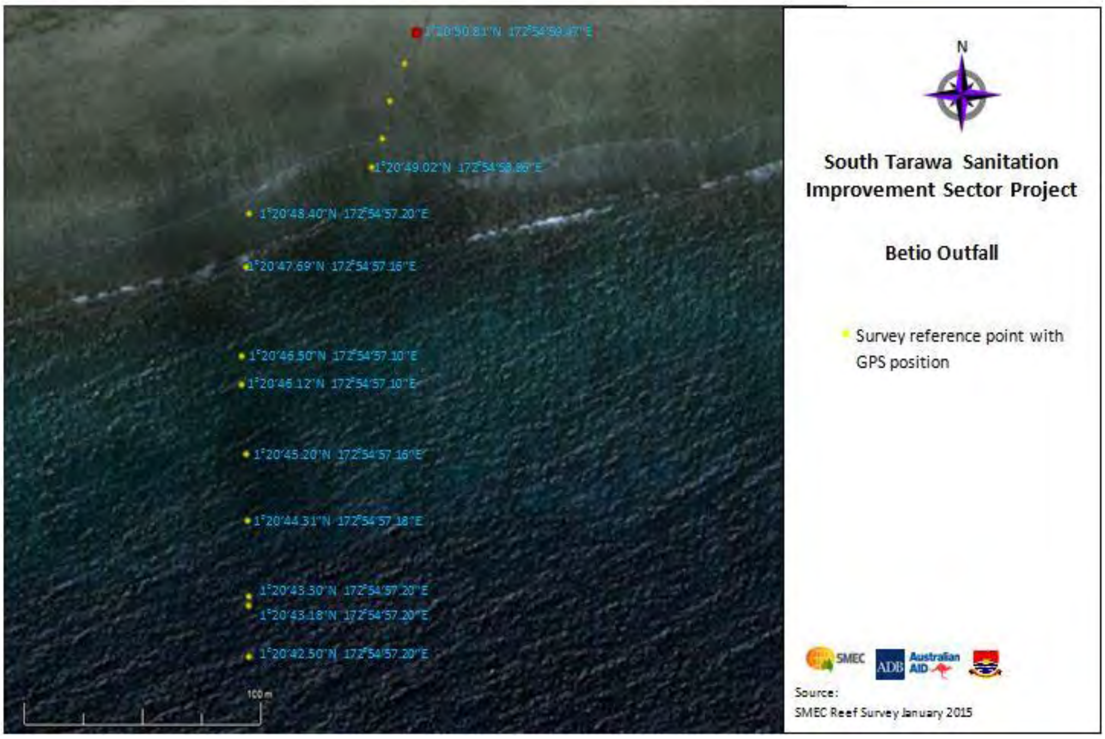


Fig. 4.1.82 GPS Position Coordinates of Proposed Betio Outfall Route
(North reef flat positions not included)

Figure 4.1.83a is a larger scale of figure 4.1.1a that shows the proposed extension (in blue) and the existing route (in orange). The existing route before and after the end of pipe (point 28 to 1) is not be used because of the lack of an appropriate route between points 1 and 8 (in orange). Significant effort was placed on navigating the myriad of channels and debris in this area, with the decision taken to find an alternative route (OOE 2015). Subsequent effort focused on locating a suitable channel within the spur-and-groove formation to the west of the existing end of pipe. Point 01 is 102m to the southwest of BETCOLD (27), and requires re-trenching of that portion of the reef flat, and some excavation within a 9m long channel terminating 22m south at point 2.

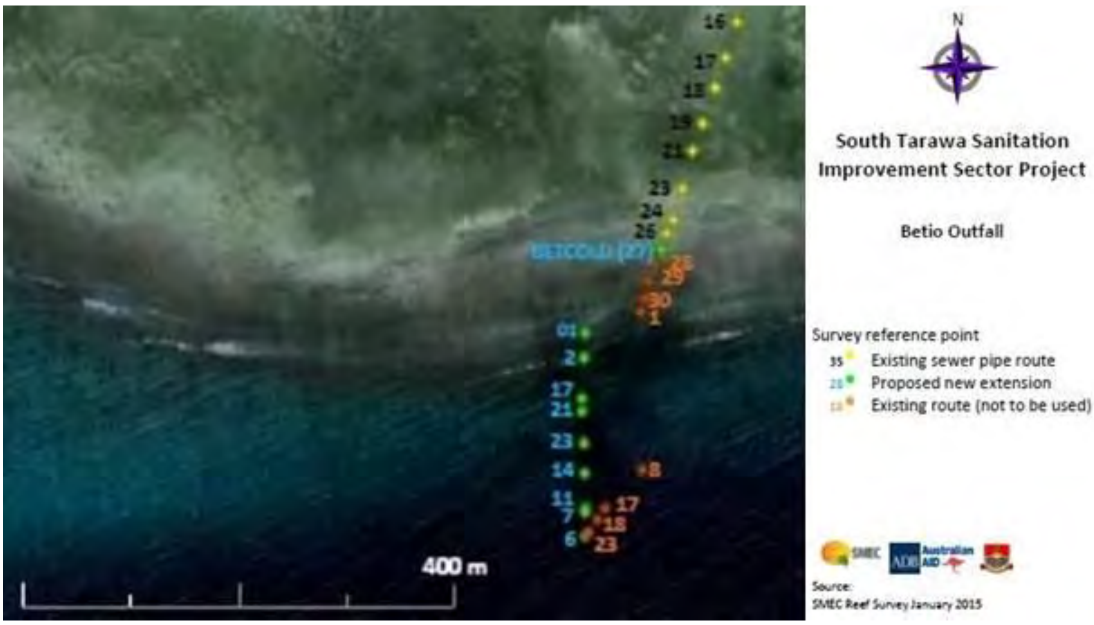


Fig. 4.1.83a Location of Existing and Proposed Betio Outfall Route
(North reef flat positions not included)

Figure 4.1.83b re-displays the pipeline route that was derived from the GPS points.

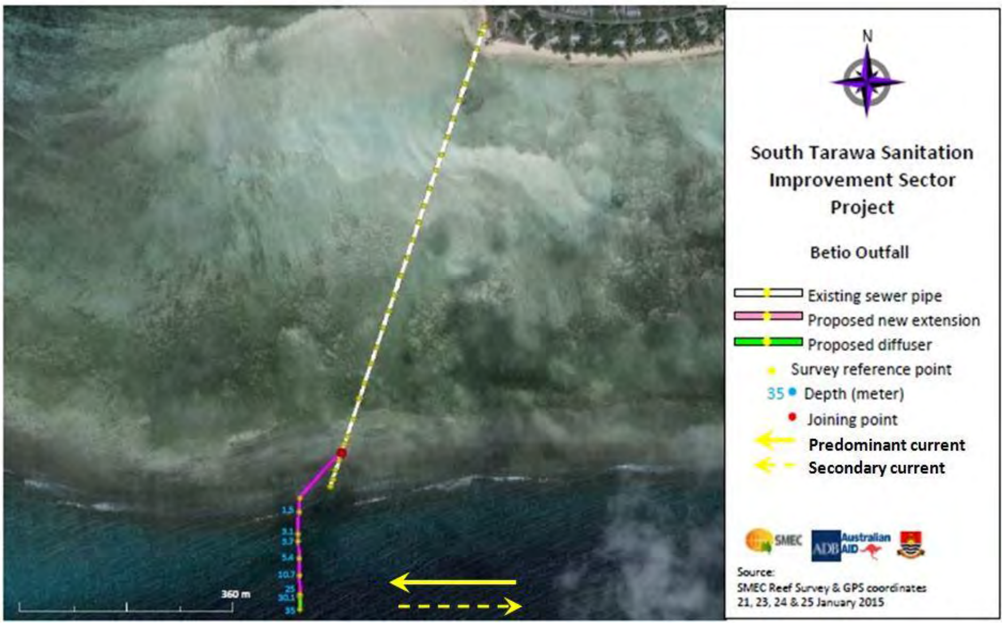


Fig. 4.1.83b Existing Outfall Pipe and Proposed Extension at Betio
(note: reference depths not corrected for 0 datum)

The total distance from the vent to the extension connection point BETCOLD (27) is 731m (figure 4.1.84). There is another 163m of intertidal and subtidal reef flat before the reef begins to crest. Point 01 is at a height of 0.72m above 0 tide datum. Point 2 is at the terminus of the channel at a depth of 0.65m below 0 tide datum.

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)	Depth (m)
Betio	reef flat, intertidal	BETCOLD(27)	--	731.4	--
Betio	reef flat, intertidal	01	102.4	828.4	0.72
Betio	reef flat, intertidal	2	22.5	850.0	-0.65
Betio	reef flat, subtidal	17	33.5	883.5	-2.28
Betio	reef flat, subtidal	21	10.5	894.0	-2.88
Betio	reef flat-crest	23	25.8	919.8	-4.58

Fig. 4.1.84 Reef Flat-Crest Chainage, Distance, and Depth

Most of the 9m long channel is therefore subtidal, with three rocky features crossing the proposed trench (fig. 4.1.86). The width is the 1m width required for the trench, and the length is 1.5m in one case (foreground 2m south) and 0.5m for each of the others (background 6m south). It is estimated to be total 2.5m^3 of rock. The outer 4m section is relatively open, although some shaving of rock surfaces to achieve an approximate level surface will be needed. These features are part of the spur of the reef, and need to be excavated by machine. Refer to channel part of video: *Betio 5 new route S to N vid 3m (pt17) to 0m* from 2:45 onwards. Figures 4.1.87 and 4.1.88 show the proposed outer section of the channel, and figures 4.1.89 and 4.1.90 look to the east and west of point 2.

Fig. 4.1.85 Betio outer reef flat, crest, and slope

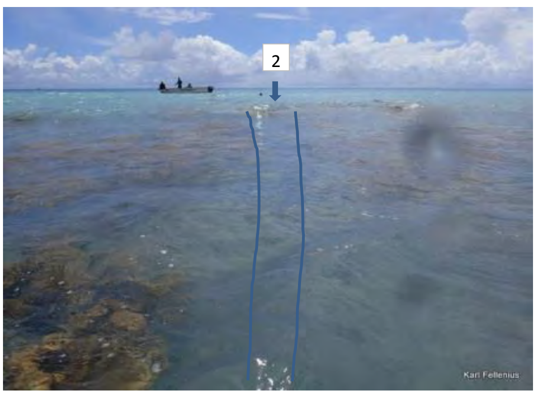


Fig. 4.1.86 Betio proposed channel access, half-way between points 01 & 2 with terminus at 2

Fig. 4.1.87 Betio proposed channel access from point 2, looking approximately North

Fig. 4.1.88 Betio proposed channel access from point 2, looking 330°

Fig. 4.1.89 Betio looking East from point 2

Fig. 4.1.90 Betio looking West from point 2

The 1.5m channel entrance is illustrated in figures 4.1.91 and 4.1.92. The channel is largely bare rock with only the outer portion having about 30% cover of zooanthids, commonly found in shallow spur-and-grooves (figs. 4.1.94 to 4.1.96). The zooanthid *Palythoa* sp. thrives under high nutrient conditions. It is possible its abundance is in response to the COTs outbreak in South Tarawa in 2009 (Houke 2015), which reduced coral cover throughout all three outfall areas.

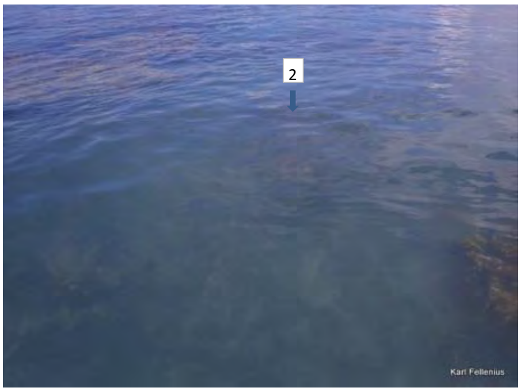


Fig. 4.1.91 Betio channel entrance at point 2 looking Southeast

Fig. 4.1.92 Betio channel entrance at point 2 looking North, corrected depth 0.65m

Fig. 4.1.93 Betio outer reef flat, crest, and slope

Fig. 4.1.94 Betio point 2 rocky outcrop

Fig. 4.1.95 Betio rocky outcrop at point 2

Fig. 4.1.96 Betio rocky outcrop detail of the common zooanthid *Palythoa* sp., corrected depth 0.15m

Figure 4.1.97 shows the proposed outfall route and the various features and obstructions found along the length of the proposed extension. The trench from BETCOLD and the channel north of point 2 are not noted as obstructions as they are features that need to be excavated rather than removed from the proposed outfall pipe route.

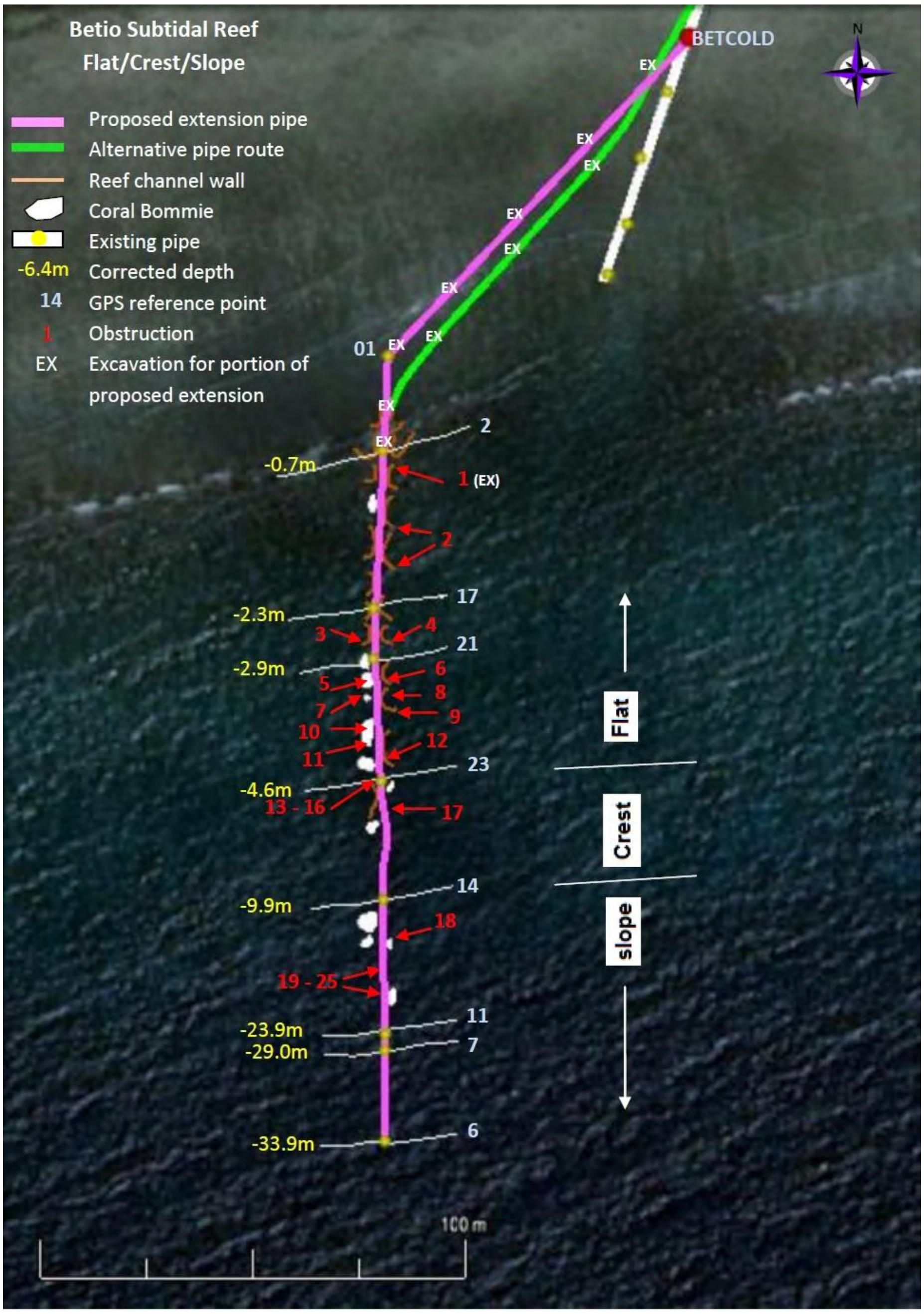


Fig. 4.1.97 Features and Obstructions along the Existing and Proposed Betio Outfall Route (digitized by SMEC)

Obstruction 1: Beyond the channel 1-3m south of point 2 are two adjacent rocks obstructing the route that are each 0.75m in diameter for a total of $0.5m^3$ that need to be removed. They are separate from the channel spur and are therefore not as solid. They are listed as an obstruction but it may be possible for the excavator to reach from the channel area. The reference is Betio video 5 at 1:27 and one rock is shown in figure 4.1.98. Each rock has about 10% cover of the same zooanthid noted for the channel. For most of the 33m route between point 2 and 17 the bottom is unobstructed and typical of figure 4.1.99. [dive team estimate 6 hrs.]

Fig. 4.1.98 Betio obstruction South of point 2, corrected depth 1.4m

Fig. 4.1.99 Betio typical of route between point 2 & 17, corrected depth 1.8m

Obstruction 2: Between this point and through to just north of point 17 are numerous minor knobs and edges that will require removal and levelling to ensure adequate space and surface for the pipe. The reference is Betio video 5 from 0:58 to 1:16. [dive team estimate 3 hrs.]

For the remainder of the subtidal reef flat refer to video: *Betio 6 new route N to S vid 3m (pt17) to 11m (pt14)*. Figure 4.1.101 shows the route at point 17 passing between two rocky outcrops 1m apart. There is no coral or other marine life in this heavily-silted area.

Fig. 4.1.100 Betio outer reef flat, crest, and slope

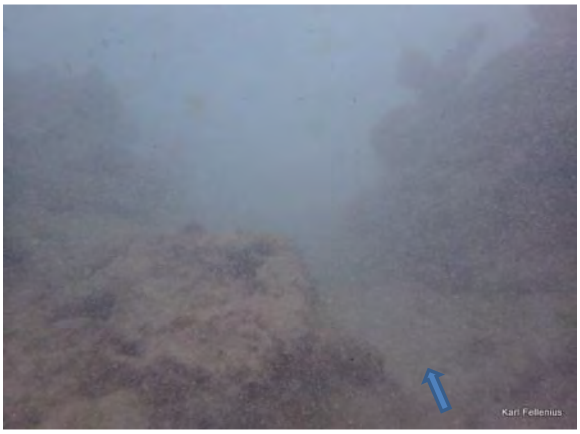


Fig. 4.1.101 Betio point 17 looking South, corrected depth 2.3m, route passes along ↑

A table of substrate and benthic categories and their frequency percentages is averaged across the subtidal reef flat and presented at the end of this section. The close visual inspection discussion includes highlights of the substrate and marine life including coral and algae, as a lead-up to the summary provided in the table.

The 10m of substrate between points 17 and 21 is silt, rubble, and debris at a slope of 3° (figures 4.102 and 4.103). There are no coral or other marine life present other than about 70% cover of turf algae.

Fig. 4.1.102 Betio typical substrate south of point 17, corrected depth 2.3m

Fig. 4.1.103 Betio typical substrate north of point 21, corrected depth 2.9m

<u>Obstruction 3</u>: The channel 5m north of point 21 is only 0.75m wide at this point and has a low ridge on the bottom. It needs to be widened about 0.2m on both sides and levelled (reference at 0:34 in Betio video 6). There are also two small coral colonies immediately south that can easily be moved out of the way to the side of the outfall route. [dive team estimate 2 hrs.]

<u>Obstruction 4</u>: Figures 4.1.104 and 4.1.105 show a 0.75m wide and 1m high *Porites* sp. coral bommie at point 21 with the proposed outfall route through the bommie (reference at 0:40 in Betio video 6). Immediately north is a 0.5m wide rocky outcrop and an *Acropora* sp. digitate coral colony. These need to be removed because the channel to the left in figure 4.1.105 is not wide enough. Effort to relocate *Acropora* sp. is recommended, although this is not needed for the abundant and habitat-poor *P. rus*. [dive team estimate 3 hrs.]

Coral cover begins here at about 5-10%, 44m from the south end of the access channel. Coral is dominated by massive, submassive, and encrusting growth forms, and very little *Acropora* sp.

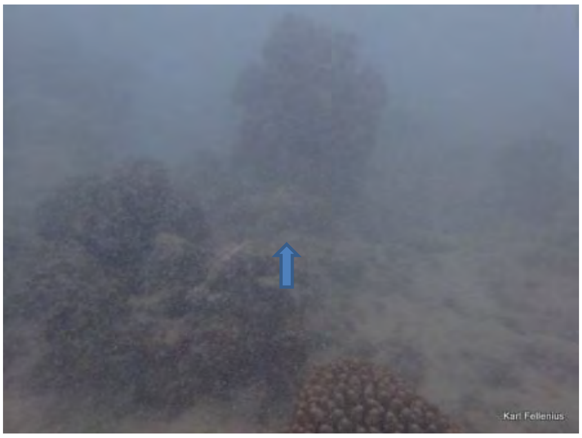


Fig. 4.1.104 Betio coral bommie at point 21 looking South, route marked ⬆ corrected depth 2.9m

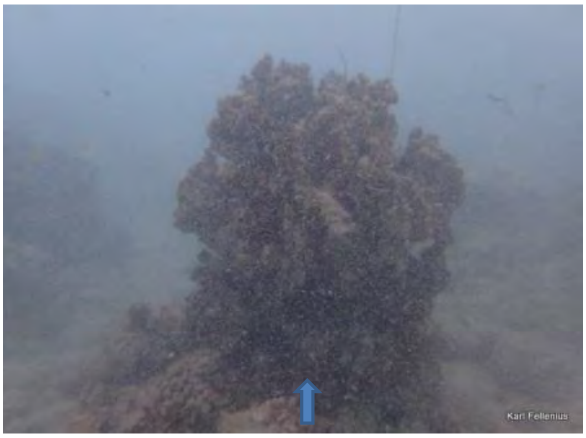


Fig. 4.1.105 Betio coral bommie at point 21 looking South, route marked ⬆ corrected depth 2.9m

The 26m of substrate between points 21 and 23 is silt, rubble, debris, and coral at a slope of 4° There are about 60% cover of turf algae with no macroalgae or coralline algae.

<u>Obstruction 5</u>: There is some minor rocky debris 4m south of point 21 to be moved on the right hand side of the channel (reference at 0:50 in Betio video 6). [dive team estimate 1 hr.]

<u>Obstruction</u> 6: The channel is only 0.75m wide 6m south of point 21. The left side rock needs to be shaved by about 0.3m (reference at 0:53 in Betio video 6). [dive team estimate 1 hr.]

<u>Obstruction 7</u>: The 3m section immediately south of obstruction 6 needs the bottom cleared of some larger debris and levelled via infilling with smaller debris (reference at 0:56 to 1:06 in Betio video 6). At the end of this section is a small *Pocillopora* sp. coral colony that can easily be relocated.

Obstruction 8: There is another small *Pocillopora* sp. coral colony 4m further south that can easily be relocated (reference at 1:14 in Betio video 6). [dive team estimate including #7 is 2 hrs.]

Obstruction 9: Figures 4.1.106 and 4.107 show the rocky and silt-laden substrate about half-way between points 21 and 23. The reference at 1:23 in Betio video 6 does not clearly show the area but there is some levelling needed for the bottom, and relocation of the left submassive coral colony. There is only a 0.75m wide space between the submassive and massive coral colonies, which are typical of the 10-15% coral cover in the area. [dive team estimate 2 hrs.]

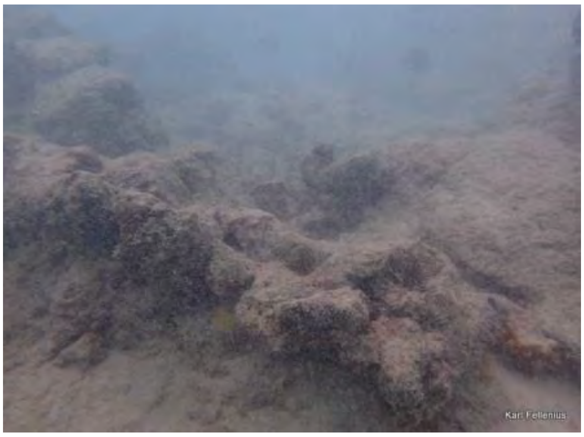


Fig. 4.1.106 Betio 13m South of point 21 looking South, corrected depth 3.4m

Fig. 4.1.107 Betio 15m South of point 21 looking South, corrected depth 3.6m

Obstruction 10: The substrate is uneven with a gently sloping rock base and rock debris across a section 4m long 8-11m north of point 23. This needs levelling and removal. (reference at 1:29 to 1:37 in Betio video 6). [dive team estimate 2 hrs.]

There are a few *Acropora* sp. digitate coral colonies starting at 5-8m north of point 23 (figs. 4.1.108 and 4.1.109 and reference from 1:38 to 1:52 in Betio video 6). Coral cover remains at 10-15%.

Obstruction 11: The uneven slope immediately north and right of the coral colony in the foreground of figure 4.1.109 needs to be levelled. The amount is less if the coral colony can be relocated. However, effort should be put to only relocating *Acropora* sp. where absolutely necessary.

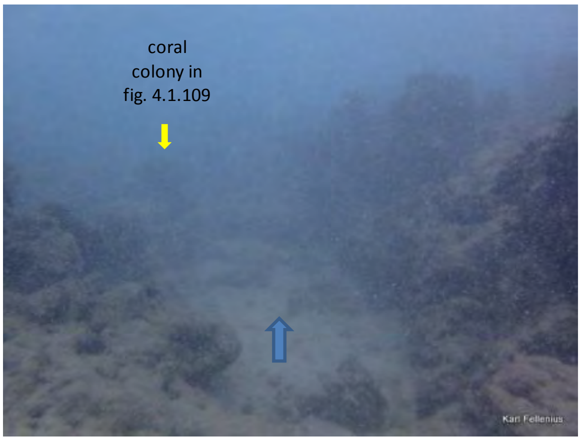


Fig. 4.1.108 Betio 8m North of point 23 looking South, route marked ⬆ corrected depth 4.2m

Fig. 4.1.109 Betio digitate coral colony 5m North of point 23 looking South, route marked ⬆ corrected depth 4.2m

Obstruction 12: The outfall route is obstructed 3m north of point 23 by the right side of rocky channel, which also has a *Heliopora coerulea* (blue coral) colony. The reference at 1:49 in Betio video 6 shows the video curving left to go around this obstruction in order to be in line with the dead table coral formation in the background. Instead, about a 0.5m wide and 1m long piece of this edge should be removed. The *H. coerulea* coral colony does not necessarily need relocating because it is a common species on the subtidal reef flat in South Tarawa, albeit uncommon elsewhere. [dive team estimate including #11 is 3 hrs.]

Obstructions 13-16: Point 23 lies on a dead table coral structure 1.5m in diameter (fig. 4.1.111 and reference at from 1:56 to 2:08 in Betio video 6). The structure has a very solid base and is adjacent to rock to the north, coral to the west, and coral to the south (fig. 4.1.112). The outfall route is proposed to be at this point as opposed to directly east to avoid significant curvature south of this point. It cannot sit on top so the table structure must be removed. The base of the structure can be pulled out from the substrate given significant floatation via lift bags (est. at 100L lift). The protruding edge north of the table needs to be shaved off, although the coral to the west can remain. The small live portion of the rock making up the *Acropora* sp. digitate coral colony to the south should be relocated. Immediately to the south of that point is a 0.3m diameter dead coral colony, which needs to be removed to allow the outfall pipe to pass unobstructed. [dive team estimate 3 hrs.]

Fig. 4.1.110 Betio outer reef flat, crest, and slope

Fig. 4.1.111 Betio point 23 looking South, route passes along ⬆ corrected depth 4.6m

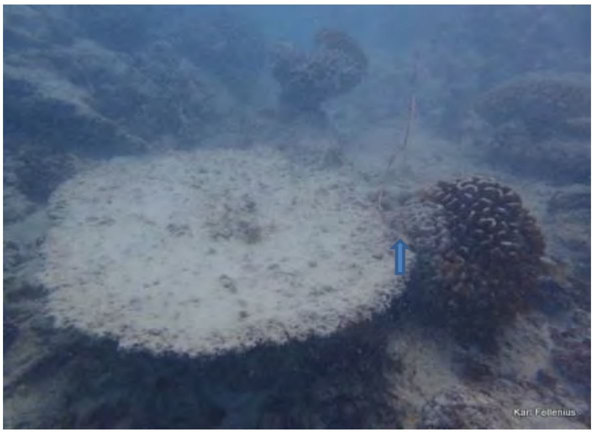


Fig. 4.1.112 Betio point 23 looking South, route passes along ⬆ corrected depth 4.6m

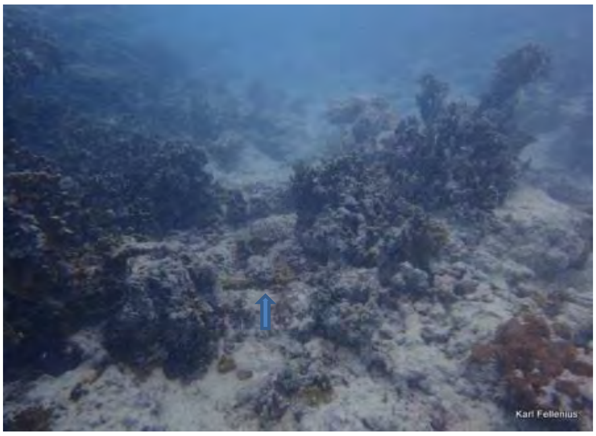


Fig. 4.1.113 Betio 5m South of point 23 looking South, route passes along ⬆ corrected depth 5.2m

The slope almost doubles to 7°over the next 5m south to a coral patch dominated by submassive *P. rus* and *H. coerulea* (reference at 2:16 in Betio video 6 and fig. 4.1.113). *Pocillopora* sp. also present, although no live *Acropora* sp. This point marks the beginning of significant rubble and debris for the remainder of the subtidal reef flat.

Obstruction 17: The uneven substrate from 5m to 8m south of point 23 needs levelling (reference from 2:16 to 2:24 in Betio video 6 and fig. 4.1.113). The channel is 0.5m wide through the rubble and coral, with minor amounts of *H. coerulea* needing removal to obtain a 1m wide access. [dive team estimate 2 hrs.]

The 26m of substrate between points 23 and 14 is silt, rubble, debris, and coral at a slope of 11° (figures 4.114 and 4.115, reference at 02:32 and 02:26 respectively in Betio video 6). There is 10% coral cover across similar genus and growth forms identified closer to point 23, although colonies are in a more degraded state due to heavy siltation and about 45% cover of turf algae. There is no obstruction along this part of the outfall route, although there is significant rubble and debris present.

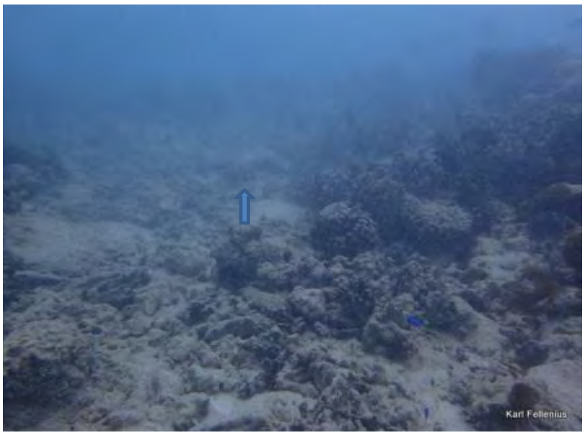


Fig. 4.1.114 Betio 10m South of point 23 looking South, route passes along ⬆ corrected depth 6.3m

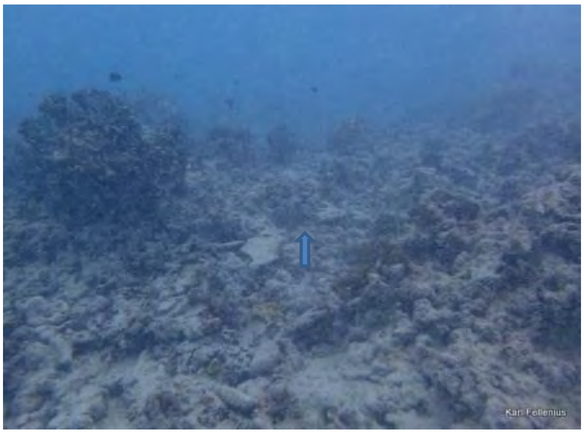


Fig. 4.1.115 Betio 14m South of point 23 looking South, route passes along ⬆ corrected depth 7.2m

The proposed route passes adjacent to the coral bommie in figure 4.1.115 and through figure 4.116 (reference 02:53 in Betio video 6). At that point the video goes slightly off course to the east (in grey), while the proposed route follows as shown in figures 4.1.116 and 4.1.117. The arrow in figure 4.1.117 is point 14. Note that Betio video 6 from 02:54 to 03:34 informs the typical substrate for the area although it terminates about 5m east of point 14 instead of at point 14.

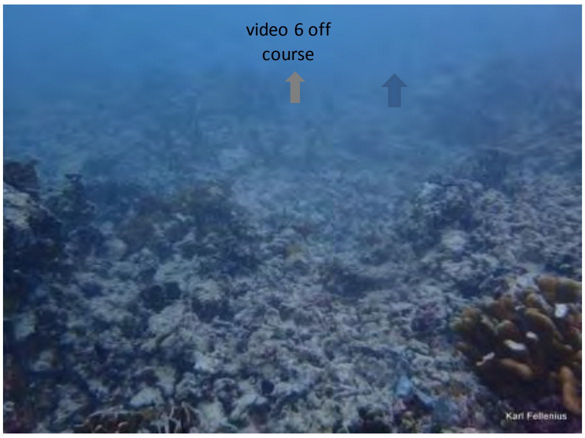


Fig. 4.1.116 Betio 16m South of point 23 looking South, route passes along ⬆ corrected depth 7.7m

Fig. 4.1.117 Betio 20m South of point 23 looking South, route passes along ⬆ corrected depth 8.2m

Figure 4.1.118 gives the average percent cover for substrate and benthic categories on the subtidal reef flat. All invertebrates other than coral and zoanthids are absent. In contrast with Bairiki and Bikenibeu, there is no baseline comparison for Betio in the survey by Lovell (2000). It is likely that the low coral cover, lack of coralline algae, high turf algae, and the high rubble, debris, and rock cover for all three outfalls across the reef flat, crest, and slope can be attributed to both the 2009 COTs infestation and to nutrient loading conditions since the outfall pipes broke in the shallows a half decade ago. The heavy siltation combined with limited variety in coral growth forms is consistent with the transition towards an algae-dominated reef.

Total Substrate		Stony Coral Growth Form		Algae		Invertebrates	
% cover		% cover within *		% cover on substrate**			Incidence
mud	0	massive	30	crustose coralline algae	0	sponge	0
silt	20	submassive	50	*Halimeda* sp.	0	anemone	0
sand	5	encrusting	15	*Caulerpa* sp.	0	ascidian	0
rubble	20	table	0	**algae+silt+sand+coral = 100	0	gorgonian soft coral	0
debris	10	digitate	5			sea cucumber	0
rock	25	branching	0			sea urchin	0
dead coral formation	5	foliose	0	fleshy coralline algae	5	giant clam	0
dead coral debris	4	mushroom	0	turf algae (microalgae)	60	oyster	0
live stony coral	10*	fire	0	other macroalgae	0	COTs sea star	0
zoanthid corallimorph	1			blue-green algae***	0	other sea star	0
soft coral	0				65		
	100		100	***filamentous & mat cyanobacteria			

Fig. 4.1.118 Betio Subtidal Reef Flat Substrate and Benthic Categories

4.1.4 Reef Crest and Slope

Figure 4.1.119 re-displays the coordinates of the GPS positions taken along the outfall route south of the connection point (in red) between the existing pipe and the proposed extension.

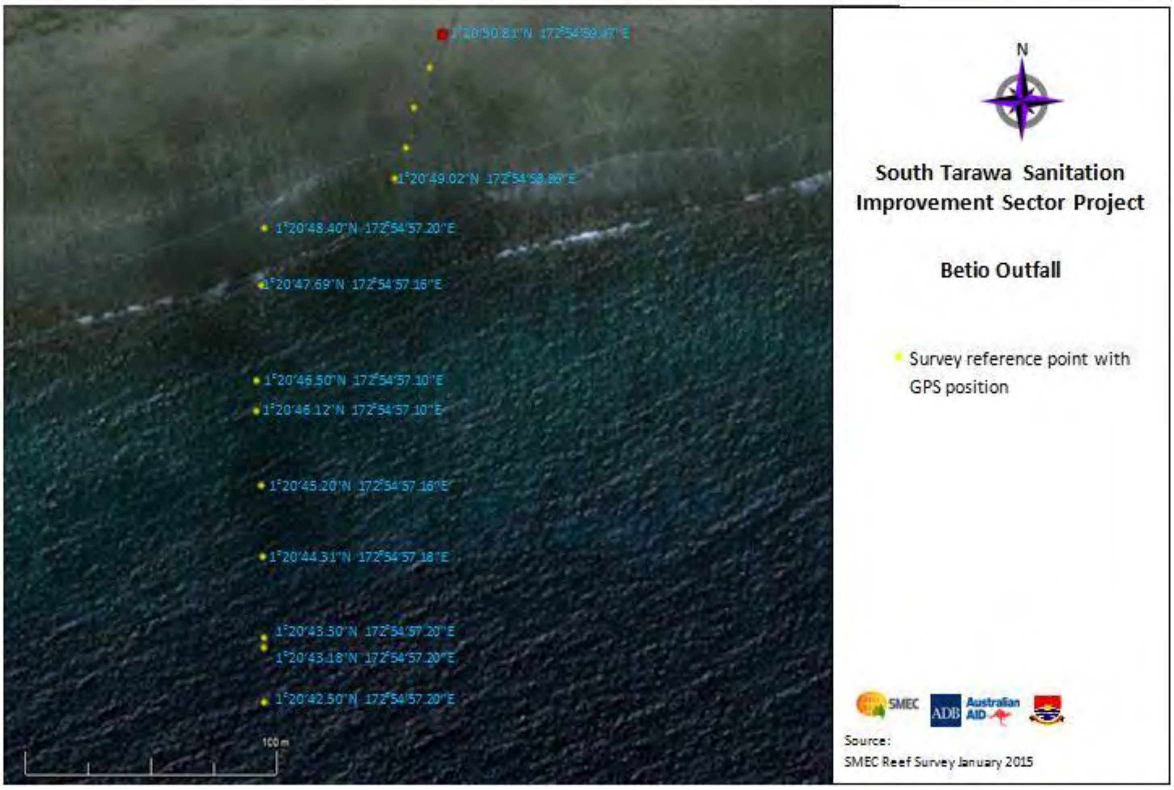


Fig. 4.1.119 GPS Positions of Proposed Betio Wastewater Line
(North reef flat positions not included)

Figure 4.1.120 re-displays the pipeline route that was derived from the GPS points.

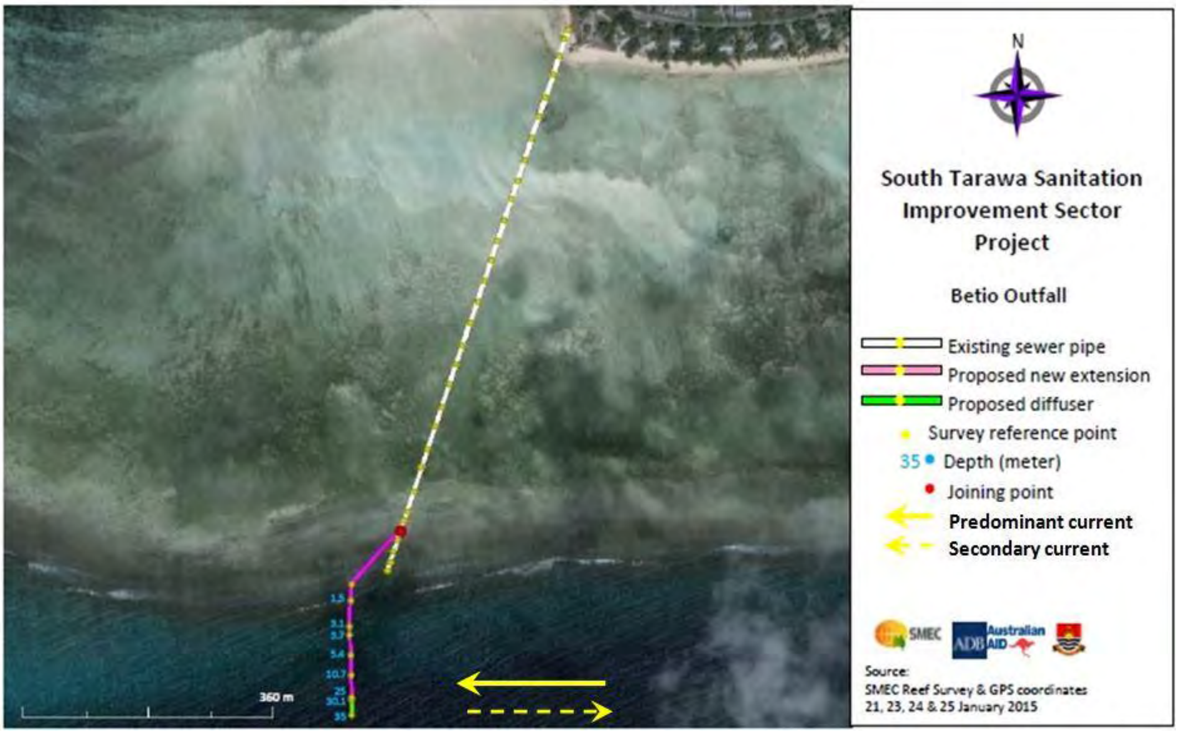


Fig. 4.1.120 Existing Outfall Pipe and Proposed Extension at Betio
(note: reference depths not corrected for 0 datum)

The total distance from the vent to the deepest survey point 6 at 34m is 1000m (figure 4.1.121). Compared with the subtidal reef flat, the reef crest and slope are much narrower covering only a distance of 80m. The lack of a rise defining the reef crest in South Tarawa means that the crest is broadly taken as the gently sloping area immediately before the reef drops off sharply. Thus the reef crest is a 26m wide area between point 23 and 14. Generally the reef crest rises from the reef flat to an algal ridge, where the backside of the crest is the back reef and the more exposed side is the fore reef before the reef slope. These features are largely absent in South Tarawa.

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)	Depth (m)
Betio	reef flat-crest	23	--	919.8	-4.58
Betio	reef crest	14	26.4	946.2	-9.85
Betio	reef slope	11	28.7	974.9	-23.92
Betio	reef slope	7	4.0	978.9	-29.00
Betio	reef slope	6	21.3	1000.2	-33.92

Fig. 4.2.121 Reef Crest-Slope Chainage, Distance, and Depth

In this section refer to videos: *Betio 7 new route N to S 11m (pt14) to 35m (pt6) and Betio 8 new route S to N vid 35m (pt6) to 11m (pt14)*. Figure 4.1.123 shows the area adjacent to point 14, which is the coral head to the right. The proposed outfall route is 2m to the east as shown. Figure 4.1.124 is a close-up of the dominant rubble and debris substrate and figure 4.1.125 is the view over the south part of the reef crest before the slope (reference from 0:00 to 0:14 in Betio video 7 and 2:17 to 2:25 in Betio video 8).

Fig. 4.1.122 Betio outer reef flat, crest, and slope

Fig. 4.1.123 From Betio 3m North of point 14, looking South, route passes along ↑corrected depth 9.9m

Fig. 4.1.124 Betio rubble substrate at point 14

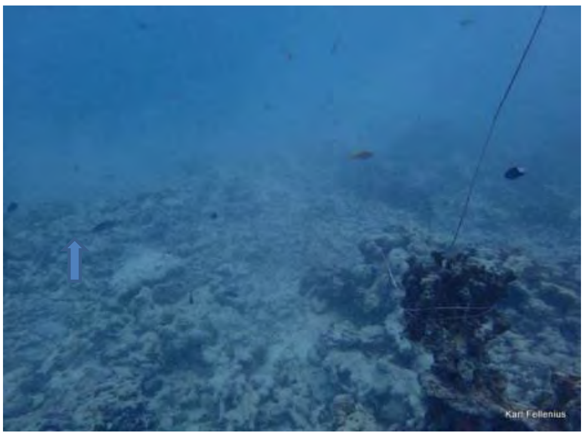


Fig. 4.1.125 From Betio point 14, looking South, route passes along ↑ corrected depth 9.9m

A table of substrate and benthic categories and their frequency percentages is averaged across the subtidal reef flat and presented at the end of this section. The close visual inspection discussion includes highlights of the substrate and marine life including coral and algae, as a lead-up to the summary provided in the table. Coral cover on the outer reef crest is less than 5% to the east and about 15% to the west of point 14 (figs. 4.1.126 and 4.1.127). It is mainly *H. coerulea* with some encrusting varieties. There is less silt than was observed on the subtidal reef flat. There are slightly less turf algae at 50% cover, consistent with lower energy on the crest than on the subtidal reef flat yet with a significant nutrient load. Fleshy coralline algae are present at 15%. Crustose coralline algae are absent.

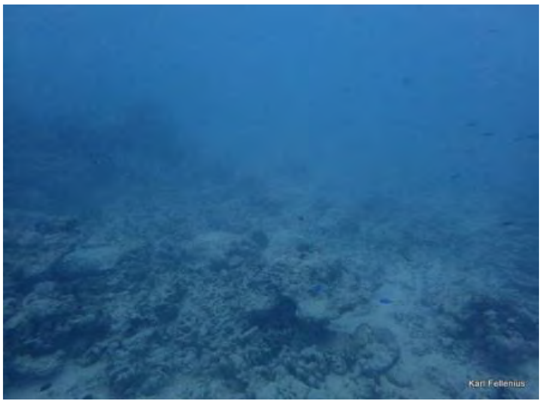


Fig. 4.1.126 From Betio point 14 looking East, corrected depth 9.9m

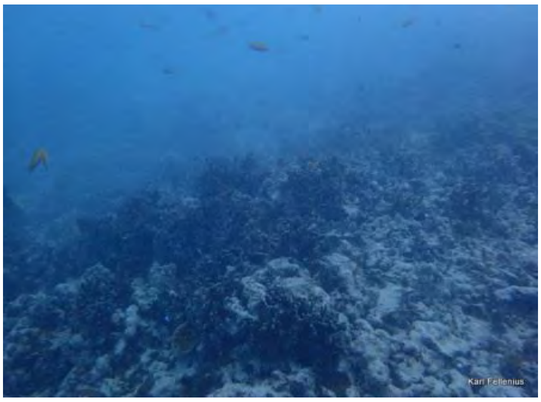


Fig. 4.1.127 From Betio point 14 looking West, corrected depth 9.9m

The 29m of substrate between points 14 and 11 is rubble, debris, with silt and minor coral at a slope of 26° (reference from 0:11 and 01:16 in Betio video 7 and from 1:05 to 2:25 in Betio video 8). Figure 4.1.128 re-displays the proposed outfall route and the various features and obstructions found along the length of the proposed extension.

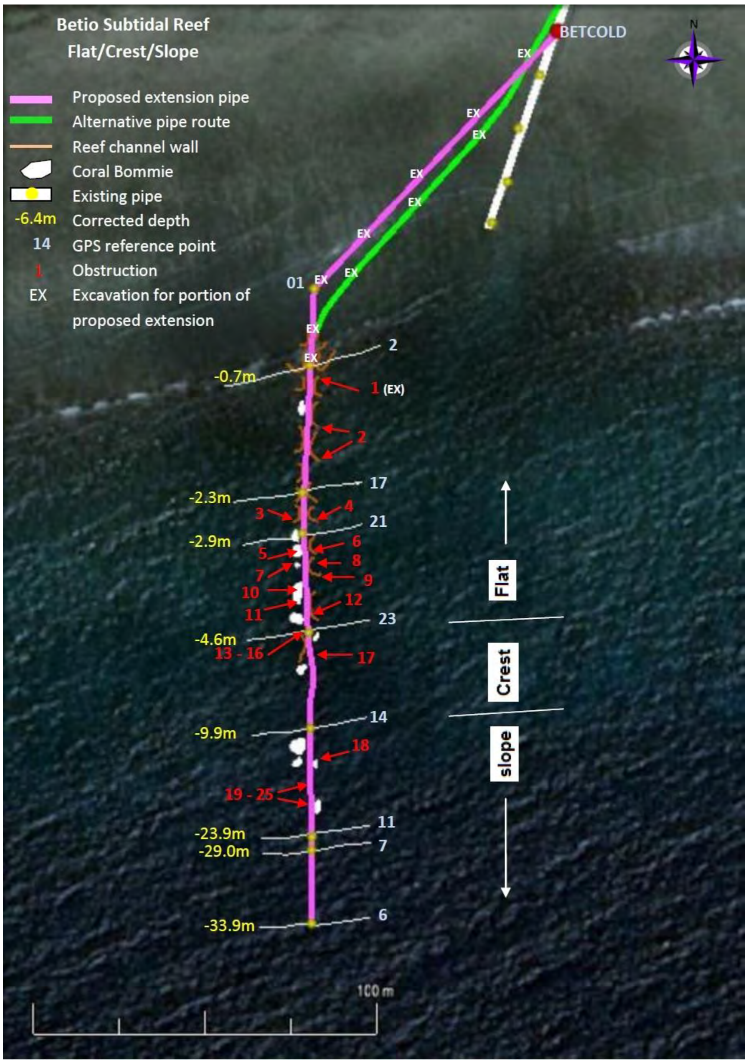


Fig. 4.1.128 Features and Obstructions along the Existing and Proposed Betio Outfall Route (digitized by SMEC)

Obstruction 18: There is a collapsed dead table coral structure 1.5m wide and 2.5m long that is loose and needs to be removed from the outfall route (figure 4.1.129). There is some minor adjacent debris as well. The route is relatively clear for about 6m beyond that point as shown in figure 4.1.130. The reference is from 0:35 to 0:42 in Betio video 7. The corresponding reference is from 1:58 to 2:05 in Betio video 8. Note however that there are issues with both video segments. Video 7 stays right after heading south from point 14 from 0:20 to 0:35, when it should have stayed left. Video 7 (descending) at 0:35 is to the right of the arrow in figure 4.1.129, and video 8 (ascending) is to the left of the coral bommie noted in figure 4.1.130. [dive team estimate 1 hr. at 14m depth]

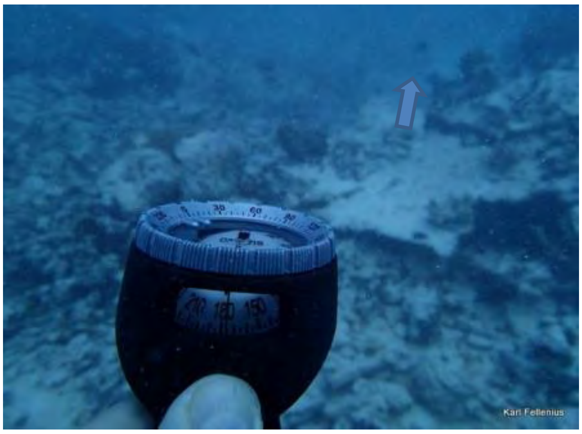


Fig. 4.1.129 Betio 7m South of point 14 looking South, route passes along ⬆ corrected depth 12.7m

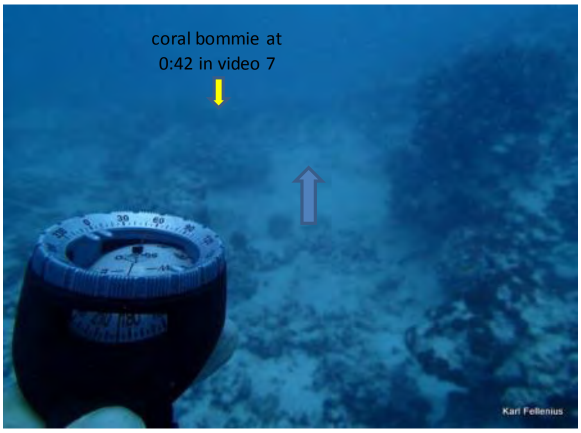


Fig. 4.1.130 Betio 10m South of point 14 looking South, route passes along ⬆ corrected depth 13.5m

The upper reef slope is largely devoid of coral except for the large rocky outcrop where there are several colonies of *H. coerulea* and one colony of *Sarcophton* sp. soft coral (reference from 0:26 to 0:37 in Betio video 7). The coral cover is slightly better than the reef crest at about 15%, with more debris than rubble, similar sedimentation, and about 20% fleshy coralline algae. There is a slight but brief increase to 60% cover of turf algae, likely due to localized pooling of nutrient-rich silt.

Obstructions 19-25: For a 9m distance from 14m south of point 14 to 6m north of point 11 there are 6 obstructions of dead *Plerogyra sinuosa* (bubble coral) structures ranging from 1-2m diameter. The depth ranges from 16-22m (reference from 0:26 to 1:16 in Betio video 7 and from 1:17 to 1:32 in Betio video 8. The shallow half of the video 7 segment and the deeper half of the video 8 segment is most representative of the proposed outfall route. These will require considerable effort to remove given the working depth. However, the skeletal structure is relatively weak compared with other varieties of massive corals, and a completely level surface for the CABs and outfall pipe is not critical at that depth. *P. sinuosa* is common at depth in South Tarawa, but uncommon elsewhere. [dive team estimate 3 hrs. at 16-22m depth]

Figure 4.1.132 shows no obstructions beyond point 11 at 24m depth.

Fig. 4.1.131 Betio outer reef flat, crest, and slope

Fig. 4.1.132 From Betio at point 11, looking South, route passes along ⬆ corrected depth 23.9m

There is no coral on the middle reef slope, neither immediately east nor west of point 11 (figs. 4.1.133 and 4.1.134). Dead coral structures are remains of *P. sinuosa*, likely killed off during the COTs infestation of 2009 with contributing stressors related to sedimentation and nutrient loading from the sewage outfall over the years.


Fig. 4.1.133 From Betio point 11 looking East, corrected depth 23.9m


Fig. 4.1.134 From Betio point 11 looking West, corrected depth 23.9m

The 4m of substrate between points 11 and 7 is silt, sand, rubble, debris, and no coral at a slope of 52° (reference from 1:37 to 2:08 in Betio video 7 and 0:45 to 1:06 in Betio video 8).

Figures 4.1.136 shows no obstructions beyond point 7 at 29m depth.


Fig. 4.1.135 Betio outer reef flat, crest, and slope

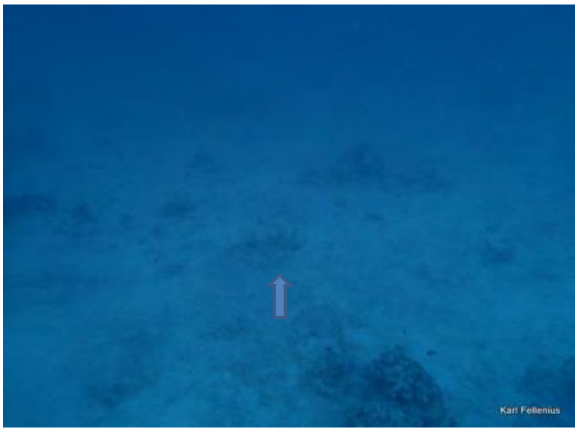


Fig. 4.1.136 From Betio at point 7, looking South, route passes along ↑ corrected depth 29.0m

There is no coral on the lower reef slope, neither immediately east nor west of point 7 (figs. 4.1.137 and 4.1.138). Dead coral structures are remains of *P. sinuosa.* There are about 40% cover of turf algae, and no fleshy or crustose coralline algae.


Fig. 4.1.137 From Betio point 7 looking East, corrected depth 29.0m


Fig. 4.1.138 From Betio point 7 looking West, corrected depth 29.0m

The 21m of substrate between points 7 and 6 is sand, rubble, debris, with some silt and no coral at a slope of 13° (reference from 0:11 and 01:16 in Betio video 7 and 0:05 to 0:45 in Betio video 8).

Figures 4.1.140 shows no obstructions beyond point 6 at 34m depth.

Fig. 4.1.139 Betio outer reef flat, crest, and slope

Fig. 4.1.140 From Betio at point 6, looking South, route passes along ⬆ corrected depth 33.9m

There is no coral on the lower reef slope, neither immediately east nor west of point 6 (figs. 4.1.141 and 4.1.142). Dead coral structures are remains of *P. sinuosa,* and there is 10% blue-green algae.

Fig. 4.1.141 From Betio point 6 looking East, corrected depth 33.9m

Fig. 4.1.142 From Betio point 6 looking West, corrected depth 33.9m

Note that terminating the outfall within 2m south of point 7 (reference at 2:15 in Betio video 7 and 0:38 in Betio video 8) is warranted because it achieves the desired 30m depth (corrected), and keeps the diffuser and the immediate area of discharge away from the *H. coerulea* that is on the upper reef slope. If the diffuser is 10m long and ends at this location, it would be 47m south of the shallower *H. coerulea*. It is expected but not confirmed via surveying, that the reef conditions on the slope are similar 25m east and west of the outfall location based on the visibility at the time.

Depth (m)	Time (hours)
1-9	30.0
10-14	1.0
15-19	1.5
20-24	1.5
25-29	0.0
30-34	0.0
Total	34.0

Fig. 4.1.143 Betio Obstruction Time Underwater

Figure 4.2.143 lists that the total estimated underwater time to rectify the obstructions noted for Betio is 34 hours. At 5 hours underwater per day +10% contingency it totals 7.5 days of diving. Dives need to be from deep to shallow so the first few days would focus on the reef slope in the morning and the reef flat in the afternoons. Subsequent days would focus on the reef crest in the mornings and reef flat in the afternoons. The last days would be only on the reef flat. This does not include the time needed for marking the alignment of the route with stakes and lines (est. 2 d), guiding the placement of the pipeline (est. 1d) or the time needed for adjusting the CABs (est. 2d). With 10% contingency it totals 13 days of diving.

Figure 4.1.143 and 4.1.144 give the average percent cover for substrate and benthic categories on the reef crest and reef slope, respectively. The crest has the same 65% undesirable algae and 10% coral cover as for the subtidal reef flat. The slope has less of both, although blue-green algae are at 10%. In contrast with the subtidal reef flat, the positive attributes of the reef crest are that it has less turf algae and more coralline algae, albeit the fleshy variety. It has more submassive coral, but with limited species richness beyond *H. coerulea*. The negatives are that it has less rock and more rubble, and therefore less stable surfaces available for re-growth.

Total Substrate		Stony Coral Growth Form		Algae		Invertebrates	
% cover		% cover within *		% cover on substrate**			Incidence
mud	0	massive	10	crustose coralline algae	5	sponge	0
silt	15	submassive	80	*Halimeda* sp.	0	anemone	0
sand	10	encrusting	10	*Caulerpa* sp.	0	ascidian	0
rubble	29	table	0	**algae+silt+sand+coral = 100	5	gorgonian soft coral	0
debris	20	digitate	0			sea cucumber	0
rock	15	branching	0			sea urchin	0
dead coral formation	0	foliose	0	fleshy coralline algae	10	giant clam	0
dead coral debris	0	mushroom	0	turf algae (microalgae)	50	oyster	0
live stony coral	10*	fire	0	other macroalgae	0	COTs sea star	0
zoanthid corallimorph	1			blue-green algae***	0	other sea star	0
soft coral	0				60		
	100		100	***filamentous & mat cyanobacteria			

Fig. 4.1.144 Betio Reef Crest Substrate and Benthic Categories

In contrast with the reef crest, the positive attributes of the reef slope are that it has less turf algae. The negatives are that it has less rock and more debris, and therefore minimal stable surfaces available for re-growth. This is in part mitigated by the lower energy environment.

Total Substrate		Stony Coral Growth Form		Algae		Invertebrates	
% cover		% cover within *		% cover on substrate**			Incidence
mud	0	massive	0	crustose coralline algae	5	sponge	0
silt	15	submassive	95	*Halimeda* sp.	0	anemone	0
sand	30	encrusting	5	*Caulerpa* sp.	0	ascidian	0
rubble	15	table	15	**algae+silt+sand+coral = 100	5	gorgonian soft coral	0
debris	20	digitate	0			sea cucumber	0
rock	5	branching	0			sea urchin	0
dead coral formation	7	foliose	0	fleshy coralline algae	5	giant clam	0
dead coral debris	1	mushroom	0	turf algae (microalgae)	30	oyster	0
live stony coral	<5*	fire	0	other macroalgae	0	COTs sea star	0
zoanthid corallimorph	1			blue-green algae***	10	other sea star	0
soft coral	1				45		
	100		100	***filamentous & mat cyanobacteria			

Fig. 4.1.145 Betio Reef Slope Substrate and Benthic Categories

There is no baseline comparison for Betio in the marine survey for South Tarawa by Lovell (2000).

4.1.4.1 Transect 1 West-East by Distance

Ten photo quadrats are shown along a 100m west-east transect with the mid-point at 50m on the proposed outfall route at a corrected depth of 24m (figs. 4.1.147 to 4.1.156). Five quadrats are taken west of the mid-point, and five are taken east. Depths along the transect direction vary due west and east of the mid-point. Each quadrat ideally covers $1m^2$ of substrate at 10m distance intervals. Note that several quadrats are biased and cover only $0.25m^2$ as indicated by the dive computer, which is only 0.09m wide.

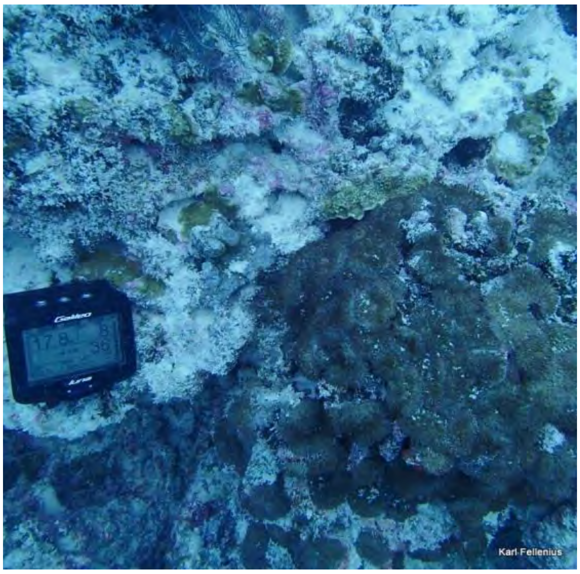


Fig. 4.1.147 transect 1 - 45m West of route, 17m depth

Fig. 4.1.148 transect 1 - 35m West of route, 18m depth

Fig. 4.1.149 transect 1 - 25m West of route, 18.5m depth

Fig. 4.1.150 transect 1 - 15m West of route, 21.5m depth

Fig. 4.1.151 transect 1 - 5m West of route, 23.5m depth

Fig. 4.1.152 transect 1 - 5m East of route, 24.5m depth

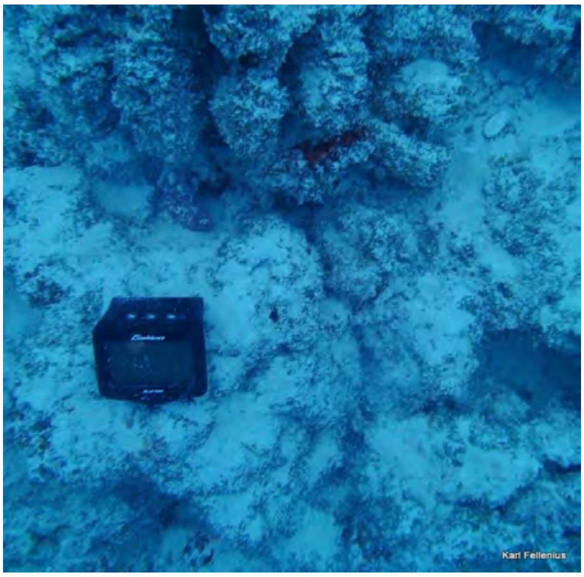


Fig. 4.1.153 transect 1 - 15m East of route, 24.5m depth

Fig. 4.1.154 transect 1 - 25m East of route, 24m depth

Fig. 4.1.155 transect 1 - 35m East of route, 23.5m depth

Fig. 4.1.156 transect 1 - 45m East of route, 23m depth

Figure 4.1.157 presents the analysis for each photo quadrat in transect 1 for a number of marine life and substrate variables on a degradation scale of 1-5, where 5 is highly degraded. Transect 2 and 3 are included, although accompanying photos are in the next section.

A healthy reef would be diverse in coral genus and species, and with values from 1-2. Such good indicators are coral, crustose coralline algae, *Halimeda sp*., sand, rock, and invertebrates (except for sponge and COTs). Even dead coral is valuable if herbivores clean off bad algae and coralline algae cement any debris and rubble, which would give it 1-2. Higher than 2 is not ideal. Similarly, indicators of an unhealthy reef are if values exceed 2 in undesirables. It is important to keep undesirable flora, fauna, and loose substrate in check. These include the remaining items on the list. Undesirables with high values should not be interpreted as pertaining to the organism itself, which it does for the good indicators above. Rather, a high degradation value of an undesirable reflects the overall ability of the organism or substrate to contribute to degradation of the coral reef overall. Note that the transect analysis does not reflect frequency of occurrence (%) or coral growth form, which was addressed in the preceding section.

Direction	**W**	**Transect 1**								**E**	**S**	**Transect 2**							**N**	**S**	**Transect 3**					**N**
Quadrat	W45	W35	W25	W15	W5	E5	E15	E25	E35	E45	S25	S15	S5	N5	N15	N25	N35	N45	1-35	1-30	1-25	1-20	1-15	1-10	1-5
Depth (m)	17	18	18.5	21.5	23.5	24.5	24.5	24	23.5	23	35	31	25	23.5	18.5	14.5	10.5	5.5	35	30	25	20	15	10	5
STONY CORAL																									
Acropora plumosa																									
Acropora valida																									
Acropora sp.																									
Blastmussa wellsi	2															3	1								
Favia sp.																									
Fungia sp.																									
Halomitra pileus																	3								
Heliopora coerulea			2							3						2	1	2					2		4
Lepastrea sp.																									
Leptoseris sp.																									
Lobophyllia sp.																									
Montipora sp.																									
Oxypora sp.																									
Pavona sp.																									
Plerogyra sinuosa		3															2								
Pocillopora sp.															2			1							
Porites rus	2		3														1	1					5	1	1
Porites sp.		3				5	5		5	3				5						5					
Turbinaria sp.																									5
ALGAE																									
crustose coralline algae	1	2								2				1	1	1	1	1				1		2	2
Halimeda sp.										2															
Caulerpa sp.			2																						
fleshy coralline algae	2		2							2				2	2	2	2	2				2		2	2
turf algae (microalgae)	3	3	3	4	4	3	3	4	4	3	3	3	3	3	3	2	2	3	4	4	3	3	3	3	2
Dictyota sp. macroalgae	3																								
other macroalgae																									
blue-green algae					4					5			4	5									4	5	5
INVERTEBRATES																									
Palythoa sp. (zoanthid)								5						5	5			3				5	5	5	
other zooanthids																									
sponge	2		3											2											
anemone																									
ascidian			5		5																				
crinoid	1								1							1									
leather soft corals																									
gorgonian soft coral			2																						
sea cucumber																									
sea urchin																									
giant clam																									
oyster																									
COTs sea star																									
other sea star																									
SUBSTRATE																									
mud																									
silt	3	4	4	4	5	5	4	4	4	2	4	3	4	3	3	2	2	2	4	3	4	3	3	2	
sand		2	2	2	4	3	3	3		3	2	2							2		2	3			
rubble				4	5	5	3				4	3							4		4	3	3	2	
debris		4		4				4	4											3	4				
rock	4		4	4			4			3		4	4	3	3	2	2	3		4		3		2	2
dead coral formation		4		4			4	4					4							4		4			
dead coral debris					5																				
DISEASED CORAL																									
Bleached Coral																									3
Other Disease																									
UNKNOWNS																									
Unknowns																									

Fig. 4.1.157 Betio Transect 1-3 Substrate and Benthic Degradation

Definition of degraded state:

		notes:
1 = least	near pristine	-colony with some live coral is 2-4
2 =	slightly degraded	-smaller or isolated coral colonies for the species are vulnerable, thus 2-3
3 =	moderately degraded	-coral colonies in proximity to COTs are vulnerable, thus 2-3
4 =	very degraded	-silt ranges from 2-5 depending on mild to heavy
5 = most	totally degraded	-crustose coralline algae are 1-2, fleshy coralline algae is 2-3
		-*Halimeda* sp. is 1-3, *Caulerpa* sp. is 2-3, other macroalgae 2-5
		-turf algae is 2-5, blue-green algae are 4-5, bleached coral 3-5
		-substrates are 1-2 if mild silt & coralline algae, 3-5 if heavy silt & turf or blue-greens
		-Zooanthids are 2-5 depending on colony size and condition, and invertebrates are 1-3

4.1.4.2 Transect 2 South-North by Distance

Eight photo quadrats are shown along a 70m south-north transect with the “mid-point” (MP) at 25m north of point 6 on the proposed outfall route at a corrected depth of 24m (figs. 4.1.158 to 4.1.165). The transect length is less than 100m because no quadrats were taken deeper than the 35m maximum diving depth of the survey (1m deeper than point 6). It ends at 5m depth on the subtidal reef flat close to point 23 a full 45m north of the “mid-point.” Three quadrats are taken south of the mid-point, and five are taken north. Each quadrat ideally covers 1m^2 of substrate at 10m distance intervals. Note that several quadrats are biased and cover only 0.25m^2 as indicated by the dive computer in the photos, which is only 0.09m wide.

Fig. 4.1.158 transect 2 - 25m South of MP, 35m depth

Fig. 4.1.159 transect 2 - 15m South of MP, 31m depth

Fig. 4.1.160 transect 2 - 5m South of MP, 25m depth

Fig. 4.1.161 transect 2 - 5m North of MP, 23.5m depth

Fig. 4.1.162 transect 2 - 15m North of MP, 18.5m depth

Fig. 4.1.163 transect 2 - 25m North of MP, 14.5m depth

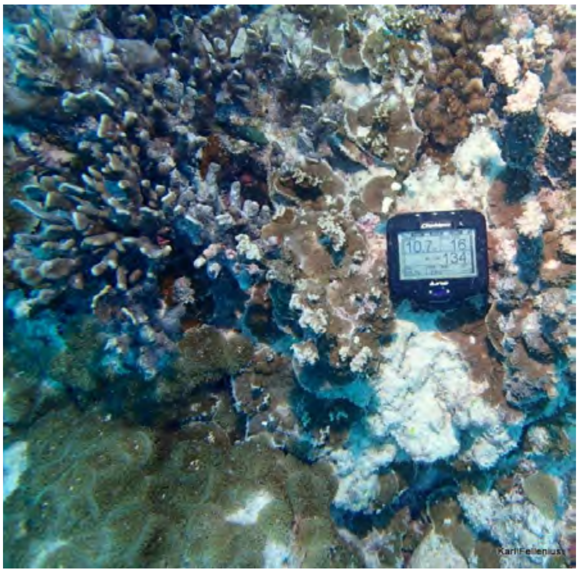


Fig. 4.1.164 transect 2 - 35m North of MP, 10.5m depth

Fig. 4.1.165 transect 2 - 45m North of MP, 5.5m depth

Figure 4.1.166 re-displays the analysis for each photo quadrat for a number of marine life and substrate variables on a degradation scale of 1-5, where 5 is highly degraded.

Direction	W	Transect 1								E	S	Transect 2						N	S	Transect 3					N
Quadrat	W45	W35	W25	W15	W5	E5	E15	E25	E35	E45	S25	S15	S5	N5	N15	N25	N35	N45	1-35	1-30	1-25	1-20	1-15	1-10	1-5
Depth (m)	17	18	18.5	21.5	23.5	24.5	24.5	24	23.5	23	35	31	25	23.5	18.5	14.5	10.5	5.5	35	30	25	20	15	10	5
STONY CORAL																									
Acropora plumosa																									
Acropora valida																									
Acropora sp.																									
Blastmussa wellsi	2															3	1								
Favia sp.																									
Fungia sp.																									
Halomitra pileus																	3								
Heliopora coerulea			2							3						2	1	2					2		4
Lepastrea sp.																									
Leptoseris sp.																									
Lobophyllia sp.																									
Montipora sp.																									
Oxypora sp.																									
Pavona sp.																									
Plerogyra sinuosa		3															2								
Pocillopora sp.															2			1							
Porites rus	2		3														1	1					5	1	1
Porites sp.		3				5	5		5	3				5						5					
Turbinaria sp.																									5
ALGAE																									
crustose coralline algae	1	2								2				1	1	1	1	1				1		2	2
Halimeda sp.										2															
Caulerpa sp.			2																						
fleshy coralline algae	2		2							2				2	2	2	2	2				2		2	2
turf algae (microalgae)	3	3	3	4	4	3	3	4	4	3	3	3	3	3	3	2	2	3	4	4	3	3	3	3	2
Dictyota sp. macroalgae	3																								
other macroalgae																									
blue-green algae					4					5			4	5									4	5	5
INVERTEBRATES																									
Palythoa sp. (zoanthid)								5						5	5			3				5	5	5	
other zooanthids																									
sponge	2		3											2											
anemone																									
ascidian			5		5																				
crinoid	1								1							1									
leather soft corals																									
gorgonian soft coral			2																						
sea cucumber																									
sea urchin																									
giant clam																									
oyster																									
COTs sea star																									
other sea star																									
SUBSTRATE																									
mud																									
silt	3	4	4	4	5	5	4	4	4	2	4	3	4	3	3	2	2	2	4	3	4	3	3	2	
sand		2	2	2	4	3	3	3		3	2	2							2		2	3			
rubble				4	5	5	3				4	3							4		4	3	3	2	
debris		4		4				4	4											3	4				
rock	4		4	4			4			3		4	4	3	3	2	2	3		4		3		2	2
dead coral formation		4		4			4	4					4							4		4			
dead coral debris					5																				
DISEASED CORAL																									
Bleached Coral																									3
Other Disease																									
UNKNOWNS																									
Unknowns																									

Fig. 4.1.166 Betio Transect 1-3 Substrate and Benthic Degradation

Definition of degraded state:

1 = least	near pristine	notes:	-colony with some live coral is 2-4
2 =	slightly degraded		-smaller or isolated coral colonies for the species are vulnerable, thus 2-3
3 =	moderately degraded		-coral colonies in proximity to COTs are vulnerable, thus 2-3
4 =	very degraded		-silt ranges from 2-5 depending on mild to heavy
5 = most	totally degraded		-crustose coralline algae are 1-2, fleshy coralline algae is 2-3
			-*Halimeda* sp. is 1-3, *Caulerpa* sp. is 2-3, other macroalgae 2-5
			-turf algae is 2-5, blue-green algae are 4-5, bleached coral 3-5
			-substrates are 1-2 if mild silt & coralline algae, 3-5 if heavy silt & turf or blue-greens
			-Zooanthids are 2-5 depending on colony size and condition, and invertebrates are 1-3

4.1.4.3 Transect 3 South-North by Depth

Seven photo quadrats are shown, one every 5m depth from a non-corrected depth of 35m to 5m alternating left and right along the proposed outfall route (figs. 4.1.167 to 4.1.173). Each quadrat covers 1m^2 of substrate. The four deepest quadrats are along the reef slope. The 15m quadrat is just seaward of the reef crest, and the 10m quadrat is on the reef crest. Finally, the 5m quadrat is 10m north of point 23 on the outer subtidal reef flat.

Fig. 4.1.167 transect 3 - 35m depth, South of point 6

Fig. 4.1.168 transect 3 - 30m depth, South of point 7

Fig. 4.1.169 transect 3 - 25m depth, South of point 11

Fig. 4.1.170 transect 3 - 20m depth, North of point 11

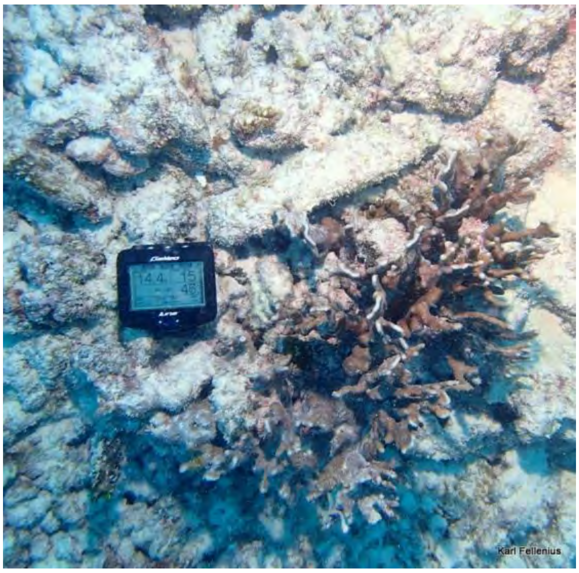


Fig. 4.1.171 transect 3 - 15m depth, South of point 14

Fig. 4.1.172 transect 3 - 10m depth, South of point 14

Fig. 4.1.173 transect 3 - 5m depth, South of point 23

Fig. 4.1.174 Betio reef flat, crest, and slope

Figure 4.1.175 re-displays the analysis for each photo quadrat for a number of marine life and substrate variables on a degradation scale of 1-5, where 5 is highly degraded.

Direction	W	Transect 1								E	S	Transect 2						N	S	Transect 3					N
Quadrat	W45	W35	W25	W15	W5	E5	E15	E25	E35	E45	S25	S15	S5	N5	N15	N25	N35	N45	1-35	1-30	1-25	1-20	1-15	1-10	1-5
Depth (m)	17	18	18.5	21.5	23.5	24.5	24.5	24	23.5	23	35	31	25	23.5	18.5	14.5	10.5	5.5	35	30	25	20	15	10	5
STONY CORAL																									
Acropora plumosa																									
Acropora valida																									
Acropora sp.																									
Blastmussa wellsi	2															3	1								
Favia sp.																									
Fungia sp.																									
Halomitra pileus																	3								
Heliopora coerulea			2							3						2	1	2					2		4
Lepastrea sp.																									
Leptoseris sp.																									
Lobophyllia sp.																									
Montipora sp.																									
Oxypora sp.																									
Pavona sp.																									
Plerogyra sinuosa		3															2								
Pocillopora sp.															2			1							
Porites rus	2		3														1	1					5	1	1
Porites sp.		3				5	5		5	3				5						5					
Turbinaria sp.																									5
ALGAE																									
crustose coralline algae	1	2								2				1	1	1	1	1				1		2	2
Halimeda sp.										2															
Caulerpa sp.			2																						
fleshy coralline algae	2		2							2				2	2	2	2	2				2		2	2
turf algae (microalgae)	3	3	3	4	4	3	3	4	4	3	3	3	3	3	3	2	2	3	4	4	3	3	3	3	2
Dictyota sp. macroalgae	3																								
other macroalgae																									
blue-green algae					4					5			4	5									4	5	5
INVERTEBRATES																									
Palythoa sp. (zoanthid)								5						5	5			3				5	5	5	
other zooanthids																									
sponge	2		3											2											
anemone																									
ascidian			5		5																				
crinoid	1								1							1									
leather soft corals																									
gorgonian soft coral			2																						
sea cucumber																									
sea urchin																									
giant clam																									
oyster																									
COTs sea star																									
other sea star																									
SUBSTRATE																									
mud																									
silt	3	4	4	4	5	5	4	4	4	2	4	3	4	3	3	2	2	2	4	3	4	3	3	2	
sand		2	2	2	4	3	3	3		3	2	2							2		2	3			
rubble				4	5	5	3				4	3							4		4	3	3	2	
debris		4		4				4	4											3	4				
rock	4		4	4			4			3		4	4	3	3	2	2	3		4		3		2	2
dead coral formation		4		4			4	4					4							4		4			
dead coral debris					5																				
DISEASED CORAL																									
Bleached Coral																									3
Other Disease																									
UNKNOWNS																									
Unknowns																									

Fig. 4.1.175 Betio Transect 1-3 Substrate and Benthic Degradation

Definition of degraded state:

1 = least	near pristine	notes:	-colony with some live coral is 2-4
2 =	slightly degraded		-smaller or isolated coral colonies for the species are vulnerable, thus 2-3
3 =	moderately degraded		-coral colonies in proximity to COTs are vulnerable, thus 2-3
4 =	very degraded		-silt ranges from 2-5 depending on mild to heavy
5 = most	totally degraded		-crustose coralline algae are 1-2, fleshy coralline algae is 2-3
			-*Halimeda* sp. is 1-3, *Caulerpa* sp. is 2-3, other macroalgae 2-5
			-turf algae is 2-5, blue-green algae are 4-5, bleached coral 3-5
			-substrates are 1-2 if mild silt & coralline algae, 3-5 if heavy silt & turf or blue-greens
			-Zooanthids are 2-5 depending on colony size and condition, and invertebrates are 1-3

4.2 Bairiki Outfall

Each section begins with a description of the chainage with photos referenced accordingly. Figure 4.2.1 shows the distribution of GPS positions taken along the existing and proposed outfall route.

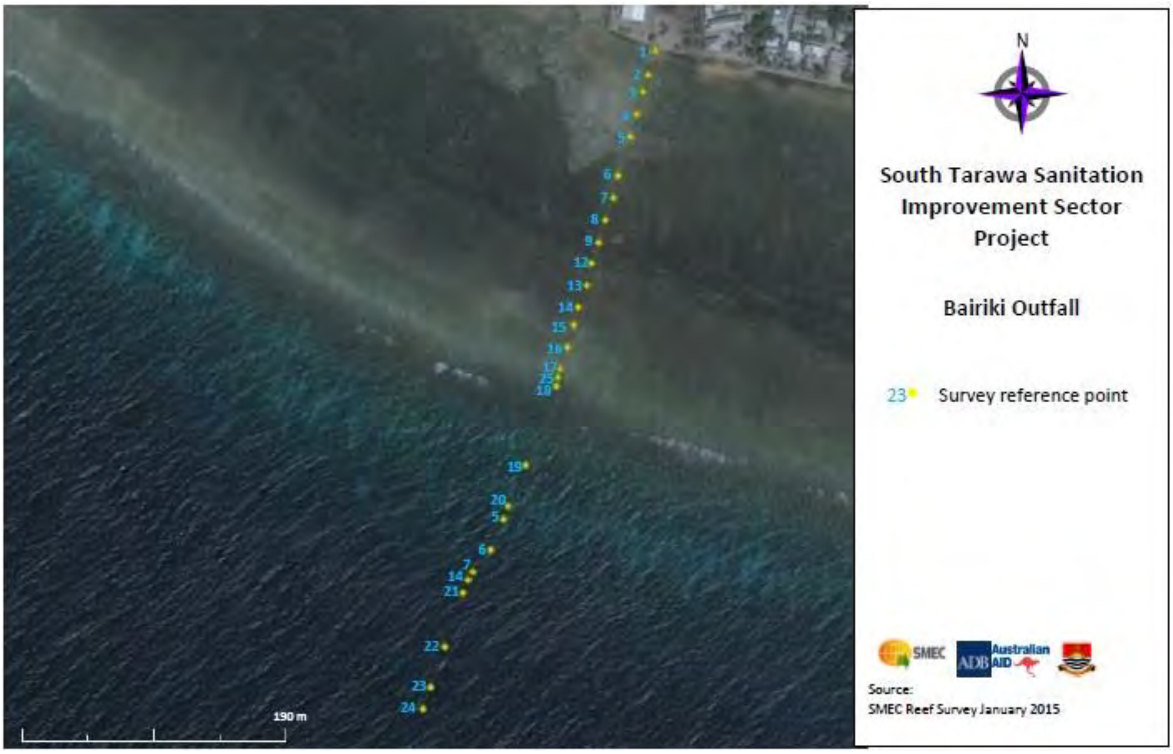


Fig. 4.2.1 Location of Existing and Proposed Bairiki Outfall Route

Figure 4.2.2 shows the pipeline route that was derived from the GPS points.

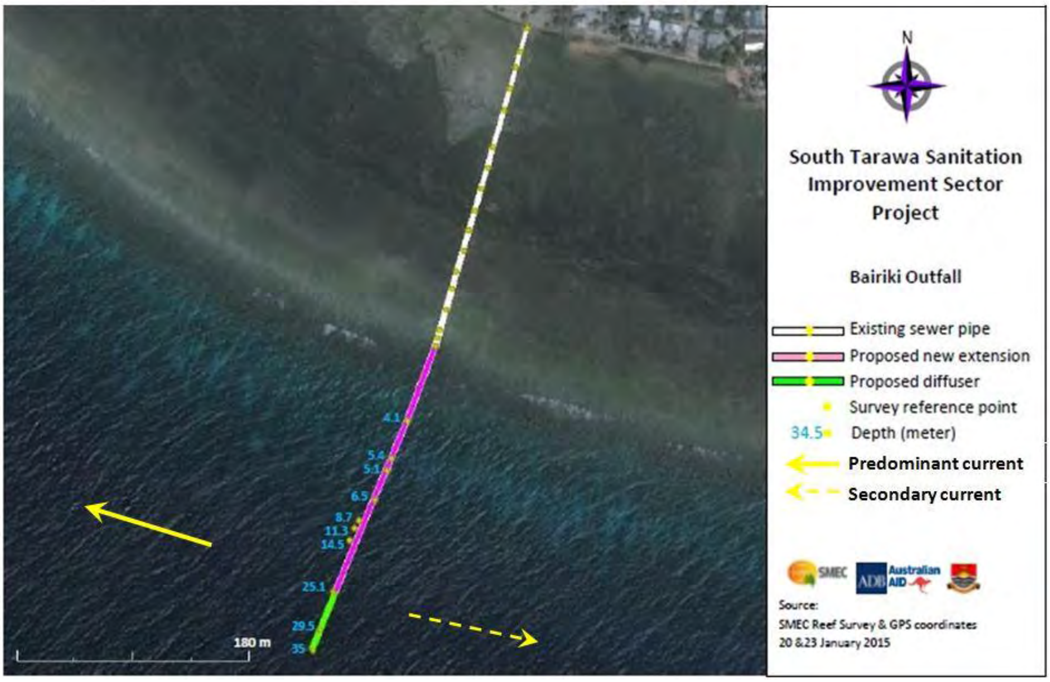


Fig. 4.2.2 Existing Outfall Pipe and Proposed Extension at Bairiki
(note: reference depths not corrected for 0 datum)

Figure 4.2.2 is the depth profile for the existing wastewater line and proposed extension from point 1 at the vent on the shoreline to point 24 at 34m depth on the reef slope. Total distance covered is 489m. Note that GPS points on the intertidal reef flat to end of existing pipe are all displayed as 0m.

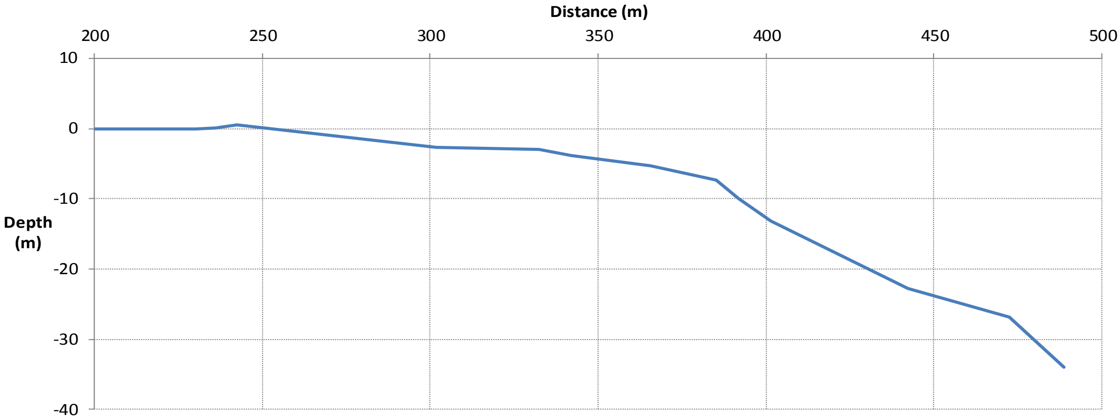


Fig. 4.2.2 Reef Depth Profile along the Existing Bairiki Outfall Route and Proposed Extension

4.2.1 Shoreline and Foreshore

Figures 4.2.3 and 4.2.4 of the vent location on the shoreline show point 1 as the 0m chainage point.

Fig. 4.2.3 Bairiki vent looking North

Fig. 4.2.4 Bairiki vent looking South

4.2.2 Intertidal Reef Flat to End of Pipe

The total distance from the vent to the existing end of existing pipe is 236m (figure 4.2.5). This is 554m shorter than at Betio. The end of existing pipe (EOP) is at a height of 0.10m above 0 tide datum (LAT, BOM).

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)	Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)
Bairiki	vent	1	0.0	0.0	Bairiki	reef flat	9	16.8	138.0
Bairiki	reef flat	2	17.2	17.2	Bairiki	reef flat	12	15.2	153.2
Bairiki	reef flat	3	12.0	29.2	Bairiki	reef flat	13	15.6	168.8
Bairiki	reef flat	4	15.9	45.1	Bairiki	reef flat	14	16.5	185.3
Bairiki	reef flat	5	15.9	61.0	Bairiki	reef flat	15	13.0	198.3
Bairiki	reef flat	6	28.6	89.6	Bairiki	reef flat	16	16.1	214.4
Bairiki	reef flat	7	15.4	105.0	Bairiki	reef flat, near EOP	17	15.8	230.3
Bairiki	reef flat	8	16.2	121.2	Bairiki	reef flat, EOP	25	5.8	236.1

Fig. 4.2.5 Intertidal Reef Flat Chainage

Figures 4.2.6 to 4.2.31 show the location and representative substrate and algae characteristics of the intertidal reef flat to the end of existing pipe. Quadrat photos are taken to the left and right of the transect line. Refer to video *Bairiki N to S vid 1m to 35m (pt 24)*.

Approximately the first 60m of the inner intertidal reef flat is rubble with no algae, followed by 25% cover of turf algae for about 30m, dropping off to 10% near the end of existing pipe. The odoriferous and fast-growing red macroalgae, *Hypnea* sp. starts at about 150m from the shoreline and persists at 75% cover for about 30m, dropping off to 5% at 40m before the end of existing pipe. At that point (15) through to 20m before the existing end of pipe there flourishes a 60% cover of *Caulerpa* sp. sea grape algae, albeit with a few patches of cyanobacteria mat macroalgae. The overriding point is that there is a dominance of fleshy and other undesirable algae across the intertidal reef flat, with no presence of any calcifying algae.

Fig. 4.2.6 Bairiki intertidal reef flat

Fig. 4.2.7 From Bairiki reef flat point 4 looking South


Fig. 4.2.8 Bairiki reef flat point 4 rubble


Fig. 4.2.9 Bairiki reef flat point 4 rubble

Fig. 4.2.10 Bairiki intertidal reef flat

Fig. 4.2.11 From Bairiki reef flat point 6 looking South

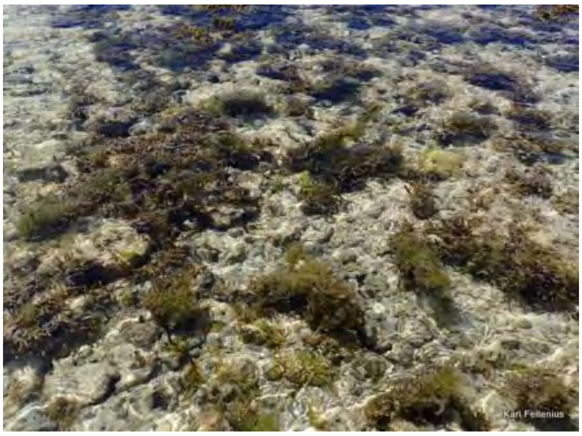


Fig. 4.2.12 Bairiki reef flat at point 6


Fig. 4.2.13 Bairiki reef flat at point 6

Fig. 4.2.14 Bairiki intertidal reef flat

Fig. 4.2.15 From Bairiki reef flat point 12 looking South

Fig. 4.2.16 Bairiki reef flat at point 12, *Hypnea* sp. algae

Fig. 4.2.17 Bairiki reef flat at point 12, green turf algae

Fig. 4.2.18 Bairiki intertidal reef flat

Fig. 4.2.19 From Bairiki reef flat point 13 looking South

Fig. 4.2.20 Bairiki reef flat at point 13, *Hypnea* sp. and stringy green algae

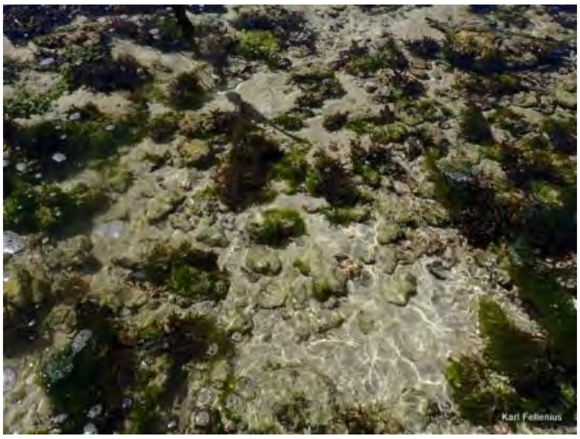


Fig. 4.2.21 Bairiki reef flat at point 13, green turf algae

Fig. 4.2.22 Bairiki intertidal reef flat

Fig. 4.2.23 From Bairiki reef flat point 15 looking South

Fig. 4.2.24 Bairiki reef flat at point 15, Cyanobacteria mat algae

Fig. 4.2.25 Bairiki reef flat at point 15, *Caulerpa* sp. sea grape algae

Fig. 4.2.26 Bairiki intertidal reef flat

Fig. 4.2.27 From Bairiki reef flat point 16 looking South

Figures 4.2.28 and 4.2.31 show the only coral presence within 10m of the outfall pipe in both directions. There is effectively no coral cover on the intertidal reef flat.

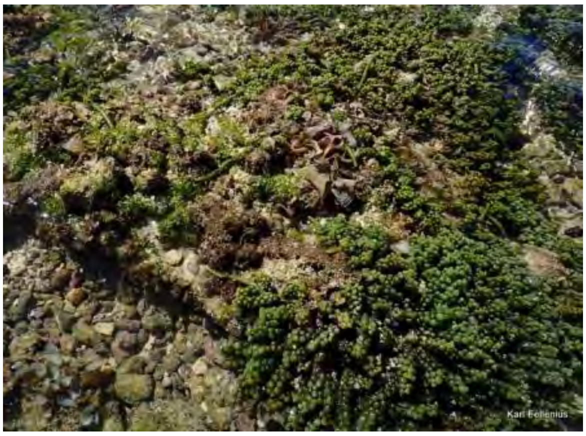


Fig. 4.2.28 Bairiki reef flat at point 16, encrusting coral patch

Fig. 4.2.29 Bairiki reef flat at point 16, *Padina* sp. funnelweed and *Caulerpa* sp. sea grape algae

Fig. 4.2.30 Bairiki reef flat at point 17, exposed outfall pipe, looking South

Fig. 4.2.31 Bairiki reef flat at point 17, palm-sized massive coral

The end of existing pipe during active pumping is shown in figures 4.2.32 and 4.2.33. The pipe itself appears in good condition except the portion that was attached from this point south has broken off. There is a significant pile of CABs immediately south of the end of existing pipe, and these are discussed along with excavations and obstructions in section 4.2.3.

Fig. 4.2.32 Bairiki reef flat at point 25, end of existing pipe, looking South

Fig. 4.2.33 Bairiki reef flat at point 25, end of existing pipe

Figures 4.2.34 through 4.2.37 show the area of the end of existing pipe from a number of directions.

Fig. 4.2.34 Bairiki reef flat from 2m NE of end of existing pipe, looking North along outfall route

Fig. 4.2.35 Bairiki reef flat from 15m West of end of existing pipe, looking Northeast

Fig. 4.2.36 Bairiki reef flat from 12m West of end of existing pipe, looking East along shoreline

Fig. 4.2.37 Bairiki reef flat from 10m east of end of existing pipe, looking West along shoreline

4.2.3 Subtidal Reef Flat beyond End of Existing Pipe

Figure 4.2.38 displays the coordinates of the GPS positions taken along the outfall route for the proposed extension south of the end of the existing pipe.

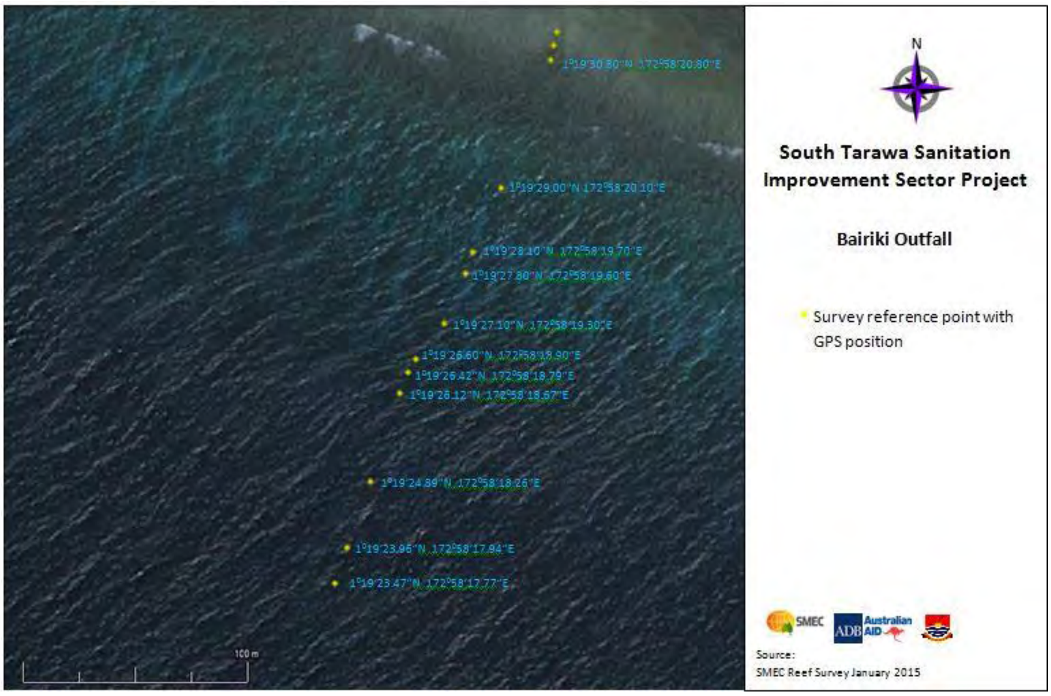


Fig. 4.2.38 GPS Position Coordinates of Proposed Bairiki Outfall Route
(North reef flat positions not included)

Figure 4.2.39 re-displays the pipeline route that was derived from the GPS points.

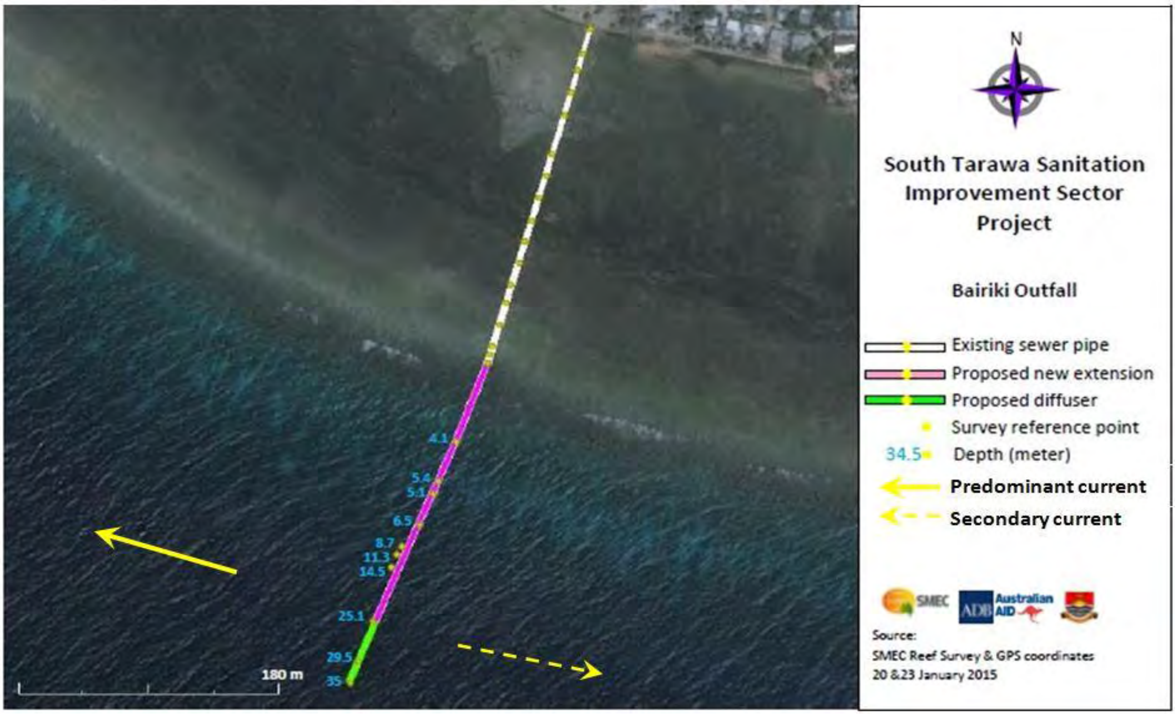


Fig. 4.2.39 Existing Outfall Pipe and Proposed Extension at Bairiki
(note: reference depths not corrected for 0 datum)

The total distance from the vent to the end of the existing pipe (25) is 236m, over 550m shorter than at Betio (fig. 4.2.40). There is another 129m of subtidal reef flat before the reef begins to crest, 34m shorter than at Betio. Point 18 at the pile of CABs just beyond the end of existing pipe is at a height of 0.6m above 0 tide datum.

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)	depth (m)
Bairiki	reef flat, EOP	25	5.8	236.1	0.10
Bairiki	reef flat, subtidal	18	6.4	242.5	0.59
Bairiki	reef flat, EOP broken	19	59.5	302.0	-2.63
Bairiki	reef flat, subtidal	20	30.4	332.4	-2.99
Bairiki	reef flat, small bommie	5	9.6	342.0	-3.91
Bairiki	reef flat, small bommie	6	23.5	365.5	-5.28
Bairiki	reef flat, S channel	7	19.8	385.3	-7.33

Fig. 4.2.40 Reef Flat Chainage, Distance, and Depth

Figure 4.2.41 shows the proposed outfall route and the various features and obstructions found along the length of the proposed extension.

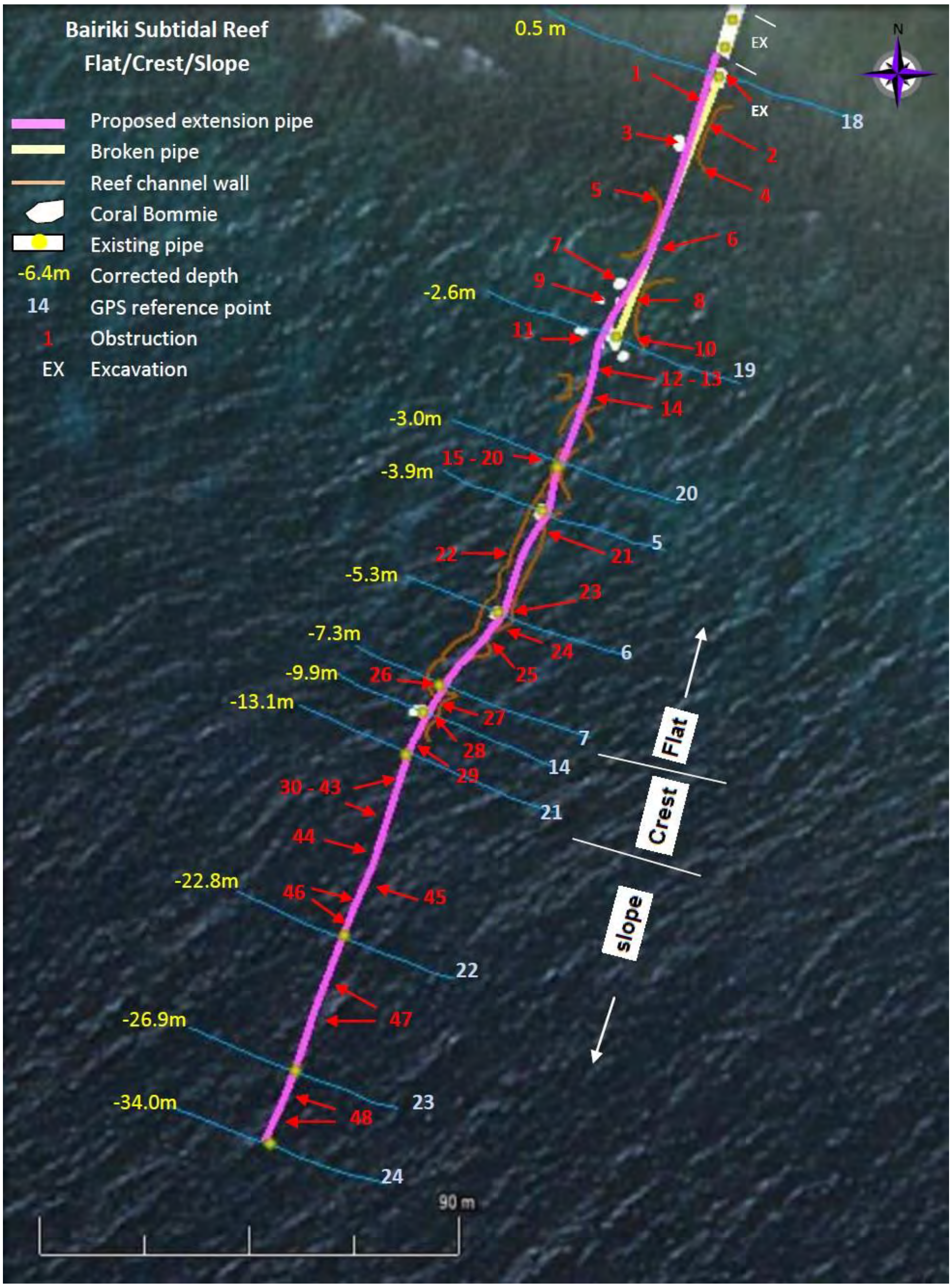


Fig. 4.2.41 Features and Obstructions along the Existing and Proposed Bairiki Outfall Route (digitized by SMEC)

The existing outfall pipe needs to be cut approximately 10m north of the end of the existing pipe, and the trench excavated (figs. 4.2.42 and 4.2.43, reference from 2:00 to 2:40 in video). A 10m^3 pile of small and large CABs at point 18 from 1-7m south of the end of existing pipe also needs to be removed via excavation (figs. 4.2.44 and 4.2.45, reference from 2:50 to 3:15 in video). There is about 20m^3 of CABs present, but no more than half are along the outfall route.

Fig. 4.2.42 Bairiki reef flat from 1m South of end of existing pipe, looking South, corrected height +0.1m

Fig. 4.2.43 Bairiki reef flat from 1m West of end of existing pipe, looking East, corrected height +0.1m

Fig. 4.2.44 From Bairiki end of existing pipe, looking South across point 18, corrected height +0.6m

Fig. 4.2.45 From Bairiki end of existing pipe, looking Soutwest to point 18, corrected height +0.6m

The entire length of the broken pipe from point 25 to 19 (66m) and its still-attached 22 CABs need to be removed (reference from 2:50 to 5:12 in video).

There is no significant coral or other marine life in this moderately-silted area. A table of substrate and benthic categories and their frequency percentages is averaged across the subtidal reef flat and presented at the end of this section. The close visual inspection discussion includes highlights of the substrate and marine life including coral and algae, as a lead-up to the summary provided in the table.

The 60m of substrate between points 18 and 19 (end of broken pipe) is silt, rubble, and debris, and minor coral at a slope of 3°.There are about 55% cover of turf algae, but no coralline algae.

Obstruction 1: Three small CABs and miscellaneous debris 6m south of point 18 need to be removed (reference at 3:28 in video). [dive team estimate 0.5hr.]

Obstruction 2: One rock 3m long, 1m wide, and 0.5m high obstructs the route 9m south of point 18 (video capture fig. 4.2.45 and reference at 3:34 in video). It is solid reef foundation and at best can be shaved down as needed as it would be very difficult to remove. A trench 0.5m wide is sufficient for the pipe, but this means that the position of adjacent CABs may need to be adjusted. [dive team estimate 1.5hrs.]


Fig. 4.2.45 Bairiki 9m south of point 18, looking South, corrected depth 0.9m

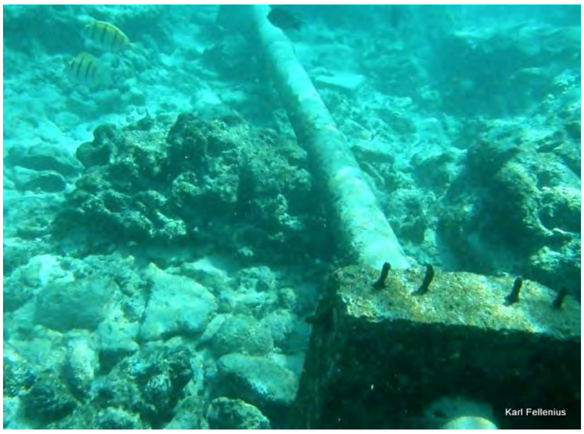


Fig. 4.2.46 Bairiki 12m south of point 18, looking South, corrected depth 1.0m

Obstruction 3: One loose rock 1m long along with miscellaneous debris 12m south of point 18 needs to be removed (video capture fig. 4.2.46 and reference at 3:43 in video). [dive team estimate 0.5hr.]

Obstruction 4: Miscellaneous debris needs to be removed from 14-19m south of point 18 (reference from 3:47 to 4:02 in video). [dive team estimate 0.5hr.]

Obstruction 5: Miscellaneous debris needs to be removed from 23-27m south of point 18 (figure 4.2.47 and reference from 4.08 to 4:11 in video). [dive team estimate 0.5hr.]


Fig. 4.2.47 Bairiki 23m south of point 18, looking South, corrected depth 1.4m


Fig. 4.2.48 Bairiki 26m south of point 18, looking South, corrected depth 1.4m

Figure 4.2.48 is a typical CAB attachment from along the broken pipe at this location. It also shows heavier siltation than at the end of existing pipe, which is expected with decreasing wave energy away from the immediate discharge area in the shallows. There are slightly less turf algae at 50% cover, and no coral.

Obstruction 6: Several loose rocks 0.5m in diameter and miscellaneous debris need to be removed from 20-17m north of point 19 (reference from 4.16 to 4:27 in video). [dive team estimate 1hr.]

Obstruction 7: One rock 1.5m long, 0.75m wide, and 0.5m high obstructs the route 11m north of point 19 (video capture fig. 4.2.49 and reference at 4:39 in video). It is solid reef foundation and at best can be shaved down into a trench 0.5m wide, and requires that any adjacent CABs be adjusted. [dive team estimate 1 hr.]

The first coral colony on the subtidal reef flat is 9m north of point 19, growing on the broken outfall pipe (fig. 4.2.50). This *Pocillopora* sp. coral can easily be relocated.

Fig. 4.2.49 Bairiki 9m North of point 19, looking South, corrected depth 2.0m

Fig. 4.2.50 Bairiki 9m North of point 19, looking South, corrected depth 2.0m

Obstruction 8: One loose rock 1m long along with minor debris 9m north of point 19 needs to be removed (video capture fig. 4.2.50 and reference at 4:43 in video). [dive team estimate 0.5hr.]

At 5m north of point 19 (reference at 4:53 in the video), the outfall route shows the proposed alignment as indicated in the video capture in figure 4.2.51. The video proceeds to show the end of the broken pipe before re-aligning with the route at 5:04 and again at 5:18.

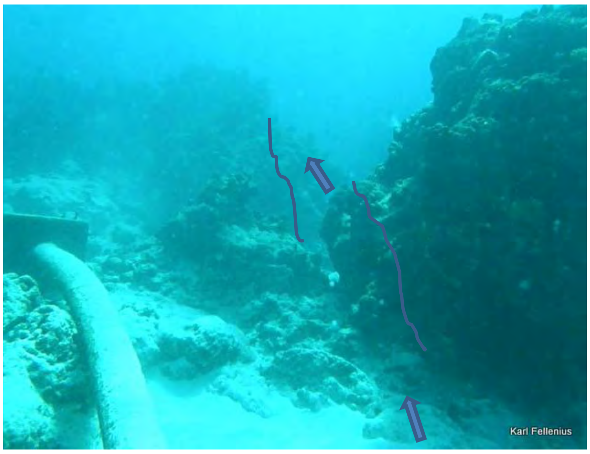


Fig. 4.2.51 Bairiki 5m North of point 19, looking South-Soutwest, route through ⬆ corrected depth 2.5m

Fig. 4.2.52 Bairiki 3m Northwest of point 19, looking Southwest, route through ⬆ corrected depth 2.7m in channel

Obstruction 9-10: The right foreground edge and left background edge of rock in figures 4.2.51 and 4.2.52 need to be removed as shown to accommodate the proposed outfall route at point 19. The portion of the right foreground edge to be shaved is 1m long, 0.5m wide, and 0.75m high. Conversely, the shaving of the left background edge needs to be 1.5m long, 1m wide, and 1m high. There is also miscellaneous debris on the bottom that needs to removed and levelled in both the foreground of figure 4.2.51 and background of figure 4.2.52. It will require that any adjacent CABs be adjusted. There are 2 small *Pocillopora* sp. and 2 *H. coerulea* colonies on the left background edge. The former can easily be relocated, and the latter with some effort. [dive team estimate 5hrs.]

Figure 4.2.53 emphasizes that there is no route option directly south of the broken end of pipe. There would be more reef rock to remove in that direction than described in obstruction 9-10. Figure 4.2.54 shows obstruction 10 from the northwest looking southeast, with the proposed route along the side of the 5m long and 2-3m wide coral bommie.

Fig. 4.2.53 From Bairiki point 19, looking South, no route through ⊗ corrected depth 2.6m

Fig. 4.2.54 Center at 3m West of Bairiki point 19, looking Southeast, route along ↑ corrected depth 2.7m in channel

Obstruction 11: Adjacent to obstruction 10 is the need for continued shaving of the side of the large coral bommie. This is marked by the right arrow in figure 4.2.54 (reference 5:30 in video). The width of the edge needs to be reduced by 0.5m along a 1m section. [dive team estimate 1.5hrs.]

Coral cover approaches 5% for the area at point 19. There remains significant debris and silt, but rubble cover is declining and sand in the channel is increasing. No other marine life except algae.

The 30m of substrate between points 19 and 20 is sand, debris, rock, and more coral cover at a slope of 1°. Coral cover is non-*Acropora* sp. at 10% for the shoreward half, with *Acropora* sp. table corals present at 15% for the seaward portion. There are about 50% cover of turf algae, 10% fleshy coralline algae, and only 5% of the more desirable crustose coralline algae.

Figure 4.2.56 shows the proposed outfall route heading south from the area of point 19, with the coral bommie in the center making up obstruction 12.

Fig. 4.2.55 Bairiki subtidal reef flat, crest, and slope

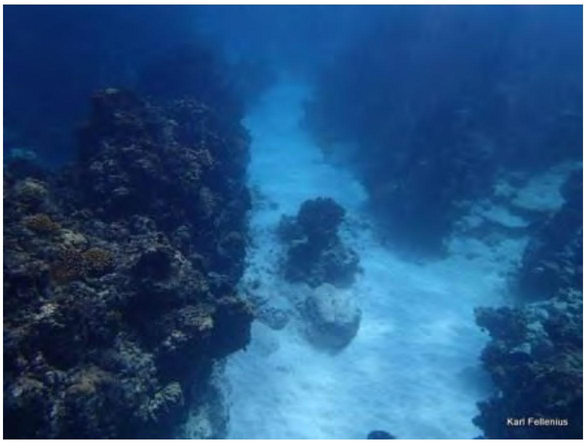


Fig. 4.2.56 From Bairiki 4m West of point 19 looking South, corrected depth 3.7m (foreground channel)

Obstruction 12-13: One *Pocillopora* sp. coral colony on a solid rock base 1.5m long and 0.75m width, with some debris 6m south of point 19 needs to be removed (video capture figs. 4.2.57 and 4.2.58, and reference from 5:42 to 5:52 in video). [dive team estimate 1.5 hrs.]

Fig. 4.2.57 Bairiki 6m South of point 19, looking South, coral colony on base, corrected depth 3.8m

Fig. 4.2.58 Bairiki 6m South of point 19, looking South, debris in background behind coral colony, corrected depth 3.8m

<u>Obstruction 14</u>: One *H. coerulea* coral colony with rock base on an edge 0.75m wide and 0.5m long 12 m south of point 19 needs to be removed (video capture figs. 4.2.58 and 4.2.59, and reference at 6:07 in video). [dive team estimate 1hr.]

Fig. 4.2.59 Bairiki 14m South of point 19, looking South, route follows ⬆ corrected depth 3.6m

Fig. 4.2.60 Bairiki 16m South of point 19, looking South, route follows ⬆ corrected depth 3.6m

Starting approximately 12m north of point 20 the coral cover increases to about 15%, with mid to large-size *Acropora* sp. table corals amongst the more dominant *H. coerulea*. This is 320m from shore, 84m from the end of the existing outfall pipe, and only 18m from the previous end of pipe before it broke off in the shallows (reference at 6:15 in video). Other coral making up lesser parts of the coral cover include *Pocillopora* sp., *Porites* sp., and a variety of encrusting forms. By comparison, the subtidal reef flat at *Betio* did not show this diversity.

Figures 4.2.61 through 4.2.65 give an overview of an area of obstruction from 2m north to 3m south of point 20 that requires careful levelling, shaving, and infilling to accommodate the proposed outfall route while protecting all *Acropora* sp. table corals. The first two figures are along the south route while the latter ones are side and top views.

Fig. 4.2.61 From Bairiki point 20, looking South, route follows ↑ corrected depth 3.0m

Fig. 4.2.62 From Bairiki point 20, looking South, route follows ↑ corrected depth 3.0m

Fig. 4.2.63 From Bairiki 3m East of point 20, looking West, route follows ↑ corrected depth 3.0m

Fig. 4.2.64 From Bairiki 3m West of point 20, looking East, route follows ↑ corrected depth 3.0m

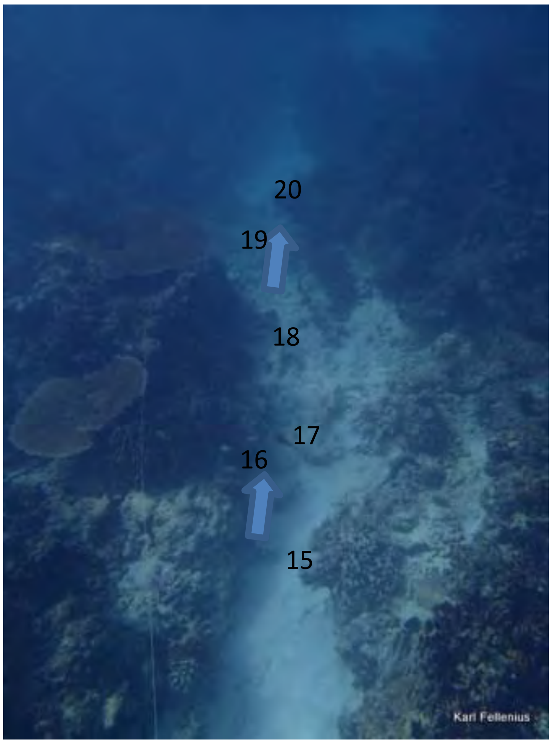


Fig. 4.2.65 From surface at Bairiki point 20, looking South, route follows ↑ corrected depth 3.0m

<u>Obstruction 15</u>: The edge on the right side of the channel needs to be shaved by 0.75m (figs. 4.2.65 and video capture fig. 4.2.66, and reference at 6:30 in video). [dive team estimate 0.5hr.]

<u>Obstructions 16-17</u>: The edge on the left side of the channel needs to be shaved by 0.2m (part of *H. coerulea* removed) and the bottom levelled (figs. 4.2.65 and video capture fig. 4.2.67, and reference at 6:31 in video). [dive team estimate 1hr.]

<u>Obstruction 18</u>: Two *Pocillopora* sp. and *H. coerulea* colony bases need to be removed (figs. 4.2.65 and video capture fig. 4.2.68, and reference at 6:34 in video). [dive team estimate 1hr.]

<u>Obstruction 19-20</u>: Levelling down and infilling of 0.4m height on the downward slope with removal of 0.3m on the right side edge (figs. 4.2.65 and video capture fig. 4.2.69, and reference at 6:38 in video). [dive team estimate 1.5hrs.]

For ease of reference, each set of proposed outfall route arrows in each of figures 4.2.61 to 4.2.65 is in the same location.

Fig. 4.2.66 From Bairiki 2m North of point 20, looking South, corrected depth 3.0m

Fig. 4.2.67 From Bairiki 1m North of point 20, looking South, corrected depth 2.9m

Fig. 4.2.68 From Bairiki 1m South of point 20, looking South, corrected depth 2.8m

Fig. 4.2.69 From Bairiki 2-3m South of point 20, looking South, corrected depth 3.0-3.4m

The 10m of substrate between points 20 and 5 is sand, debris, rock, and 15% coral cover at a slope of 5°. Coral cover is submassive, with no *Acropora* sp. table corals present. Algae cover is the same as the previous section.

A 3m long and 1m wide *H. coerulea* bommie at point 5 is shown in figure 4.2.71 and video capture figures 4.2.72 and 4.2.73 (reference from 6:45 to 6:57 in video). This is not an obstruction as the proposed route passes to the left.

Fig. 4.2.70 Bairiki subtidal reef flat, crest, and slope

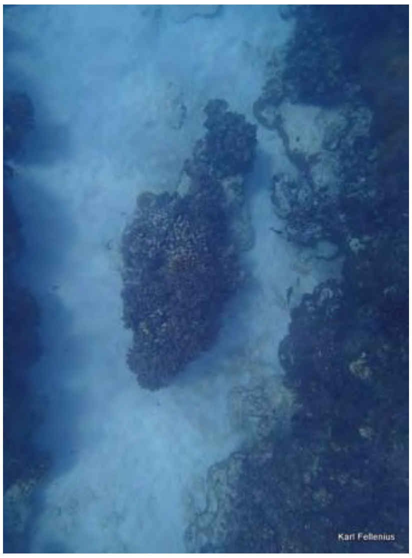


Fig. 4.2.71 From surface at point 5, South at top, corrected depth 3.9m

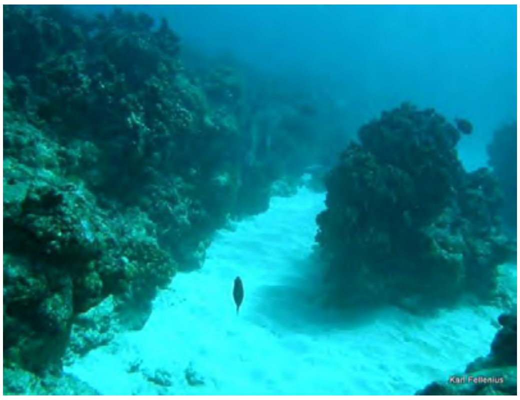


Fig. 4.2.72 From Bairiki 4m North of point 5, looking South, corrected depth 3.7m

Fig. 4.2.73 From Bairiki point 5, looking South, corrected depth 3.9m

<u>Obstruction 21</u>: The 0.75m diameter and 1m high *H. coerulea* bommie 3m south of point 5 <u>may</u> need to be removed (figs. 4.2.74 and reference at 7:02 in video). [dive team estimate 0.5hr.]

<u>Obstruction 22</u>: The channel narrows to 0.9m 10m south of point 5 (figs. 4.2.75 and reference at 7:26 in video). The edge at the right needs shaving by 0.3m [dive team estimate 0.5hr.]

Fig. 4.2.74 From Bairiki 3m South of point 5, looking South, corrected depth 4.2m

Fig. 4.2.75 From Bairiki 10m South of point 5, looking South, corrected depth 3.6m

The 24m of substrate between points 5 and 6 is sand, debris, rock, and 20% coral cover at a slope of 3°. Coral cover is mainly submassive *H. coerulea*, some massive and encrusting *Porites* sp., with no *Acropora* sp. present. There are about 40% cover of turf algae, 10% fleshy coralline algae, and an increase to 15% of the more desirable crustose coralline algae.

<u>Obstructions 23-24</u>: :The 0.75m diameter rock just north of point 6 partially covered with encrusting *Porites* sp. in the channel in video capture figure 4.2.76 needs to be removed, along with 0.2m of shaving necessary on the left channel edge. (reference at 7:37 and 7:43 in video). The 1.5m diameter *H. coerulea* colony at point 6 can largely be left in place as the channel passes to the left (video capture figure 4.2.77 and reference at 7:47 in video). However, the 0.75m wide rock base with 0.3m of the coral to the left needs to be removed. [dive team estimate 1hr.]

Fig. 4.2.76 From Bairiki 4m North of point 6, looking South, corrected depth 5.2m

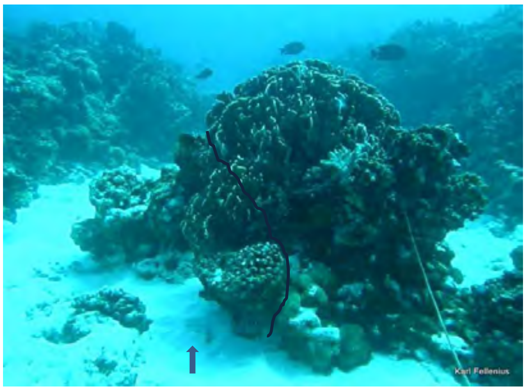


Fig. 4.2.77 From Bairiki 1m North of point 5, looking South, route along ↑ corrected depth 5.3m

The 20m of substrate between points 6 and 7 is sand, debris, rock, and 20% coral cover at a slope of 6°. Coral cover is mainly submassive *H. coerulea*, some massive and encrusting *Porites* sp., with no *Acropora* sp. present. There are about 45% cover of turf algae, 5% fleshy coralline algae, and 15% of the more desirable crustose coralline algae.

<u>Obstruction 25</u>: Between 3-5.5m south of point 6 the channel narrows to 0.7m wide. The left side needs shaving of 0.5m through partial cover of encrusting *Porites* sp. coral. (video capture figures 4.2.78 and 4.2.79, reference from 7:57 to 7:59 in video). The right side is to be left intact. There is also some debris immediately to the south. [dive team estimate 1.5hr.]

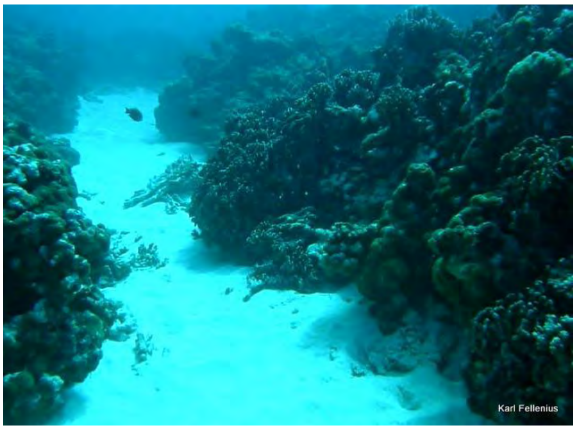


Fig. 4.2.78 From Bairiki 3m South of point 6, looking South, corrected depth 5.7m

Fig. 4.2.79 From Bairiki 5m South of point 5, looking South, corrected depth 5.8m

Figure 4.2.80 gives the average percent cover for substrate and benthic categories on the subtidal reef flat. The 55% cover for undesirable algae is slightly less than for the Betio reef flat, and the 10% coral cover is the same. In contrast with Betio, the Bairiki subtidal reef flat has slightly less turf algae and some crustose coralline algae. It also has some significant *Acropora* sp. table corals, and slightly more rock and less silt. It has the same dominance of *H. coerulea*. The negative is that it has no zooanthids in the shallows populating bare rock surfaces, albeit with their limited habitat benefits.

Total Substrate		Stony Coral Growth Form		Algae		Invertebrates	
% cover		% cover within *		% cover on substrate**			Incidence
mud	0	massive	10	crustose coralline algae	10	sponge	0
silt	15	submassive	60	*Halimeda* sp.	0	anemone	0
sand	10	encrusting	15	*Caulerpa* sp.	<u>0</u>	ascidian	0
rubble	15	table	15		10	gorgonian soft coral	0
debris	10	digitate	0	**algae+silt+sand+coral = 100		sea cucumber	0
rock	35	branching	0			sea urchin	0
dead coral formation	5	foliose	0	fleshy coralline algae	5	giant clam	0
dead coral debris	5	mushroom	0	turf algae (microalgae)	50	oyster	0
live stony coral	10*	fire	<u>0</u>	other macroalgae	0	COTs sea star	0
zoanthid corallimorph	0			blue-green algae***	<u>0</u>	other sea star	0
soft coral	<u>0</u>				55		
	100		100	***filamentous & mat cyanobacteria			

Fig. 4.2.80 Bairiki Subtidal Reef Flat Substrate and Benthic Categories

In contrast with Betio, there is a baseline comparison for Bairiki in the survey by Lovell (2000, 20). The shallow surge channels at that time had 15% coral cover to 2m depth, as well as zoanthids present. There was 33% coral cover at 3m depth, and submassive *P. rus* at 5m was at present at 75-90%. By 10m depth the coral cover had increased to 56%, with continued abundance of zooanthids. The situation is very different today, with coral cover at 10% and no zooanthids.

4.2.4 Reef Crest and Slope

Figure 4.2.81 re-displays the coordinates of the GPS positions taken along the outfall route for the proposed extension south of the end of the existing pipe.

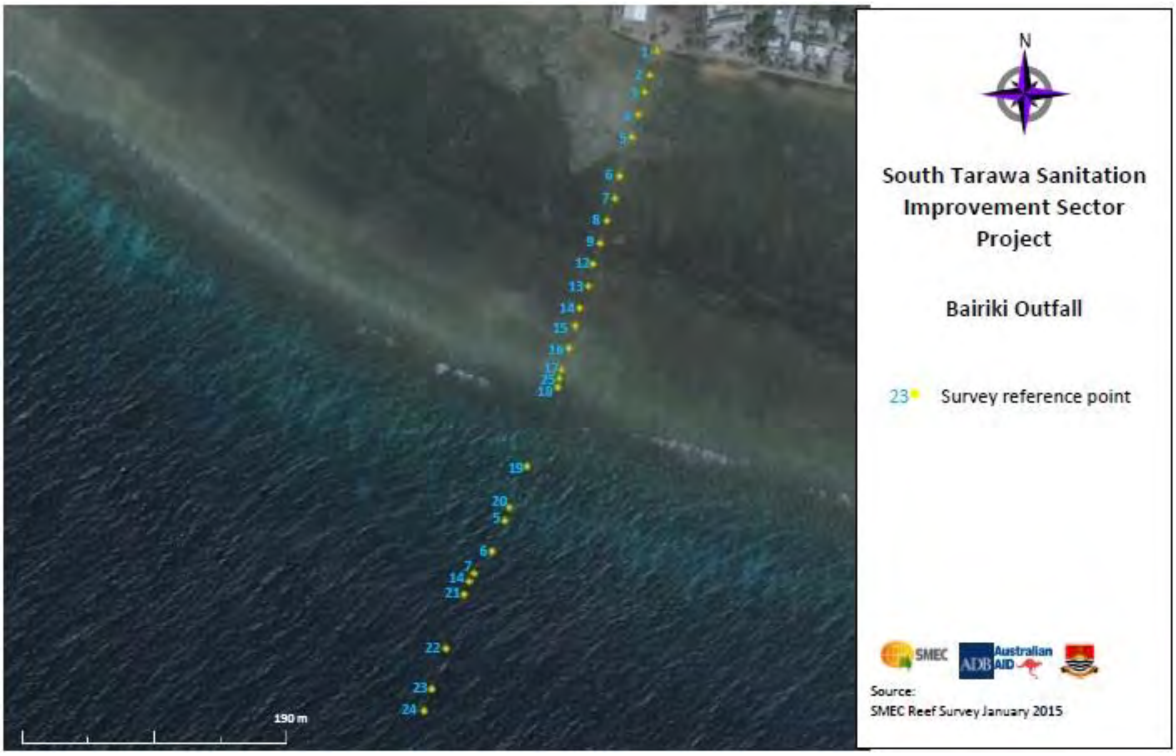


Fig. 4.2.81 Location of Existing and Proposed Bairiki Outfall Route

Figure 4.2.82 re-displays the pipeline route that was derived from the GPS points.

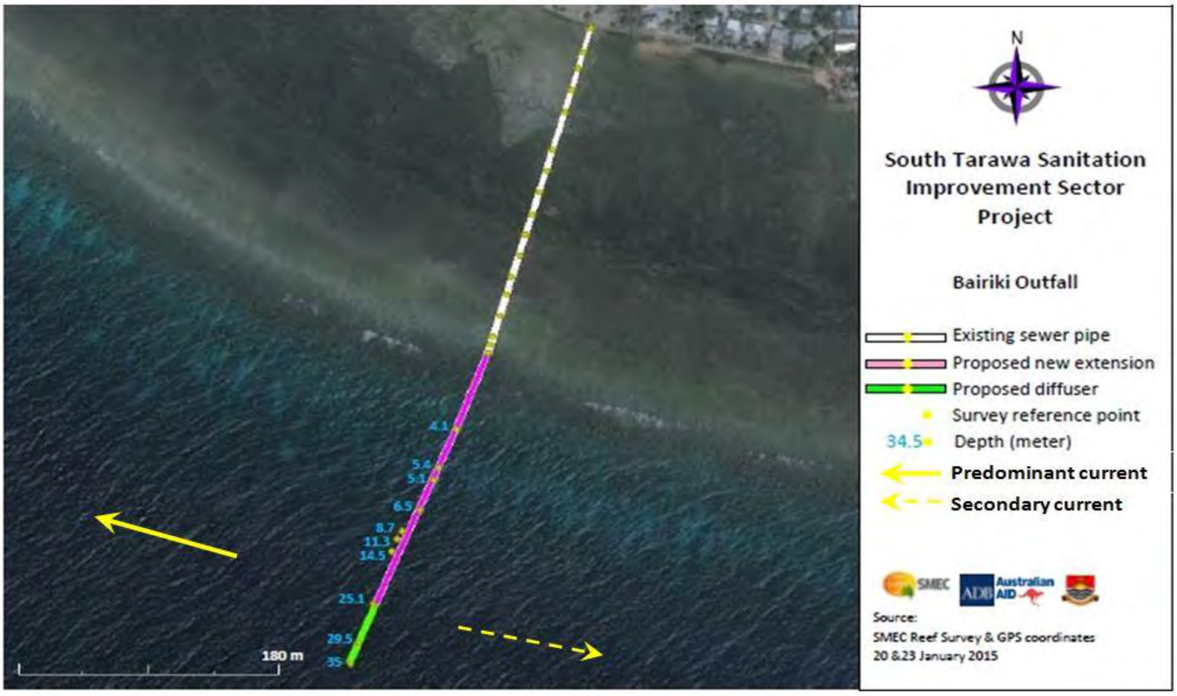


Fig. 4.2.82 Existing Outfall Pipe and Proposed Extension at Bairiki
(note: reference depths not corrected for 0 datum)

The total distance from the vent to the deepest survey point 24 at 34m is 489m (figure 4.2.83). Compared with the subtidal reef flat, the reef crest and slope are much narrower covering only a distance of 96m. This is 16m longer than at Betio. The reef crest is a 16m wide area between just south of both points 7 and 21, which is just over half the distance of the same stretch at Betio. In contrast, the reef slope to depth is 1.5 times longer than at Betio.

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)	depth (m)
Bairiki	reef crest, large bommie	14	6.7	392.0	-9.92
Bairiki	reef crest	21	9.6	401.6	-13.13
Bairiki	reef slope	22	40.7	442.2	-22.80
Bairiki	reef slope	23	30.5	472.7	-26.91
Bairiki	reef slope	24	16.2	488.9	-34.04

Fig. 4.2.83 Reef Crest-Slope Chainage, Distance, and Depth

In this section refer to video *Bairiki N to S vid 1m to 35m (pt 24)*. The 7m of substrate between points 7 and 14 is sand, debris, rock, and 35% coral cover at a slope of 21°. Coral is represented by a diversity of growth forms and genus types. There are about 25% cover of turf algae, 10% fleshy coralline algae, and 15% of the more desirable crustose coralline algae. Figure 4.2.84 re-displays the proposed route and the various features and obstructions found along the length of the proposed extension pipe.

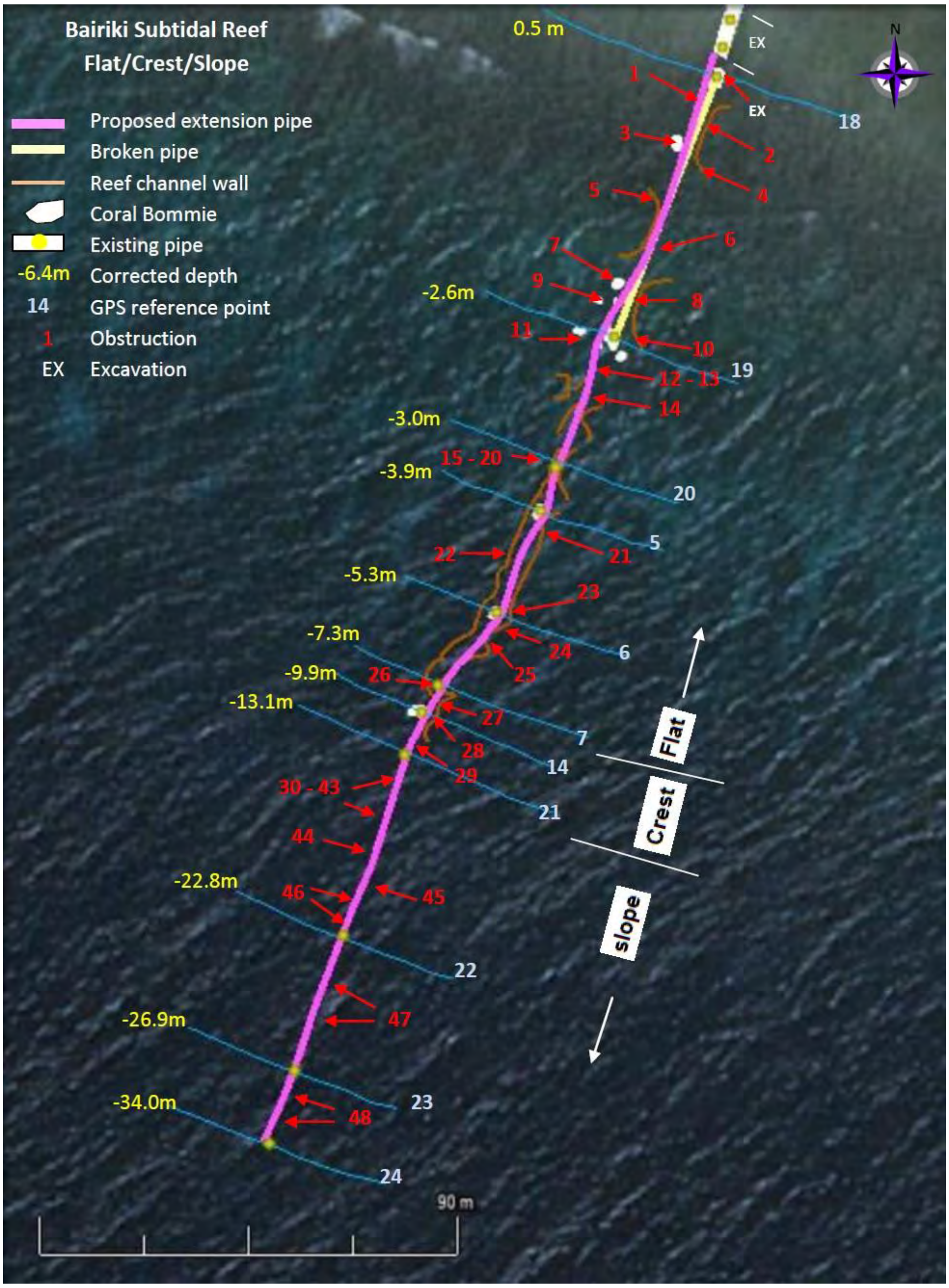


Fig. 4.2.84 Features and Obstructions along the Existing and Proposed Bairiki Outfall Route (digitized by SMEC)

Figure 4.2.85 shows part of obstruction 25 (from the end of the subtidal reef flat section) at the bottom left, and the channel heading south towards point 7 (reference from 8:00 to 8:21 in video). Two coral colonies are noted as coral A and B at point 7 in figures 4.2.85 and 4.2.86 (reference for coral B at 8:22 in video).

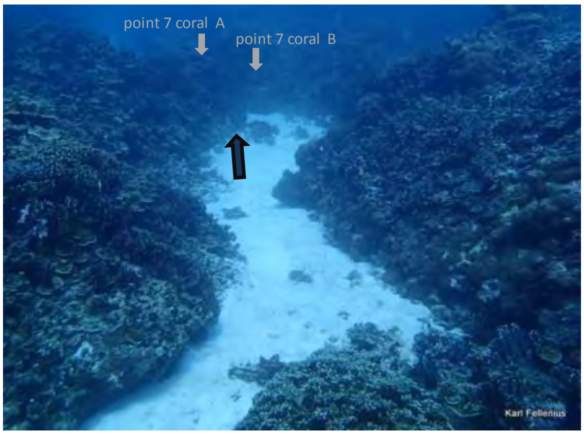


Fig. 4.2.85 From Bairiki 4m South of point 6, looking South to point 7, route along ⬆ corrected depth 5.7-7.3m

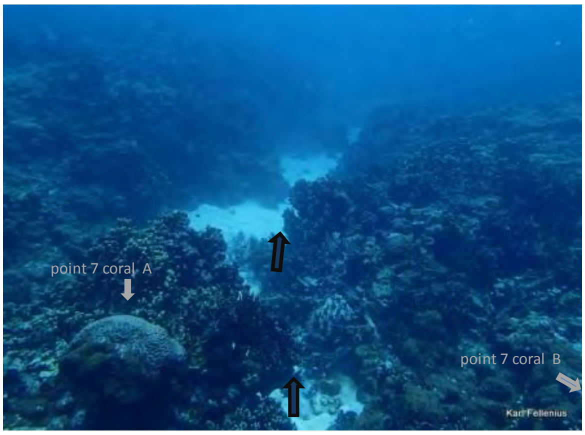


Fig. 4.2.86 From Bairiki point 7, looking South, route along ⬆ corrected depth 7.3m (bottom)

These same coral colonies are noted in figures 4.2.87 and 4.2.88, from the side and top view respectively (reference from 8:22 in the video for both figures, and through to 8:32 for figure 4.2.88).

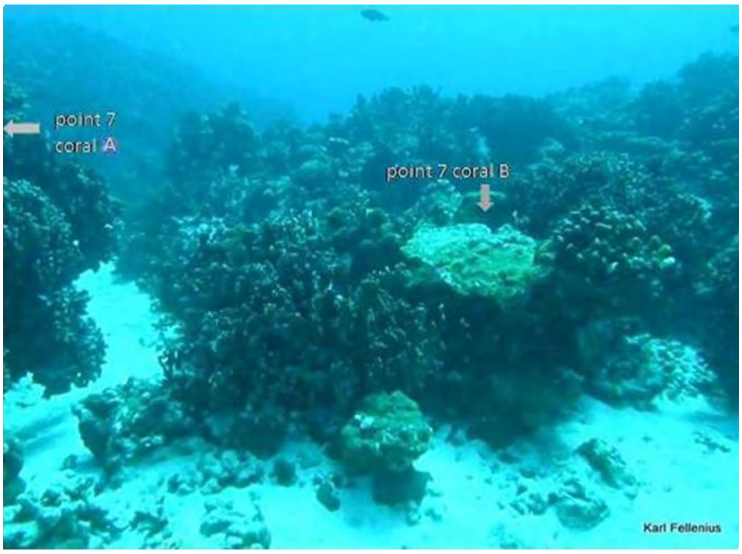


Fig. 4.2.87 From Bairiki point 7, looking South, corrected depth 7.3m

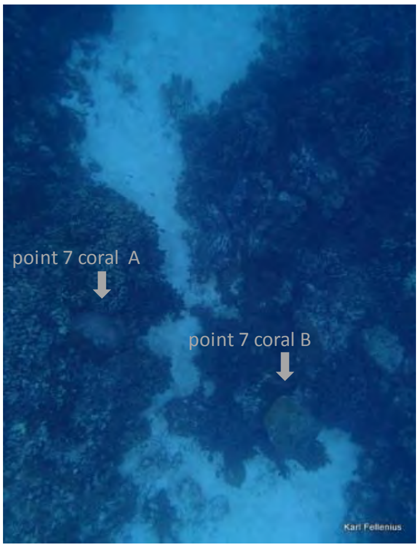


Fig. 4.2.88 From surface at point 5, South at top, corrected depth 3.9m

<u>Obstruction 26</u>: The 4m long and 0.5m wide channel running between coral A and B needs to be widened to 2.5m to account for the slight bend in the alignment of the proposed outfall route. The edge on both sides, as well as the overhang on the left side needs to be removed. It requires that any adjacent CABs be adjusted. Moreover, the cut needs to include 1m north (on the left) and 1m south (on the right) of the channel for a total distance of 6m. (reference from 8:21 to 8:34 in video). One quarter of the area to be removed is covered in *H. coerulea* and *P. rus* and three-quarters is rock and debris. The former is able to be partially relocated. [dive team estimate 5hrs. at 7m depth]

<u>Obstruction 27</u>: The 1.5m diameter common *P. rus* coral bommie in figure 4.2.89 and the bottom of figure 4.2.90 needs to be removed and relocated. (reference at 8:47 in video). The base cuts in underneath so it may loosen with effort. There is also some miscellaneous debris to be removed immediately north. [dive team estimate 2hrs. at 9m depth]

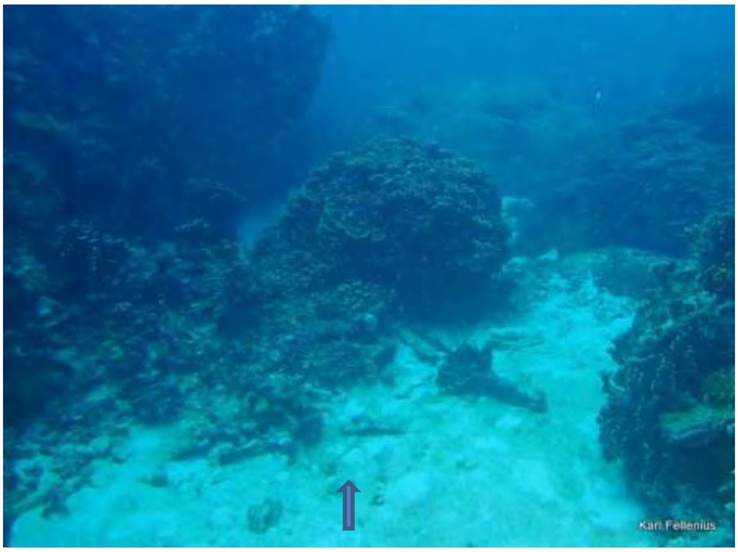


Fig. 4.2.89 From Bairiki 5m north of point 14, looking South, route along ⇧ corrected depth 9.4m

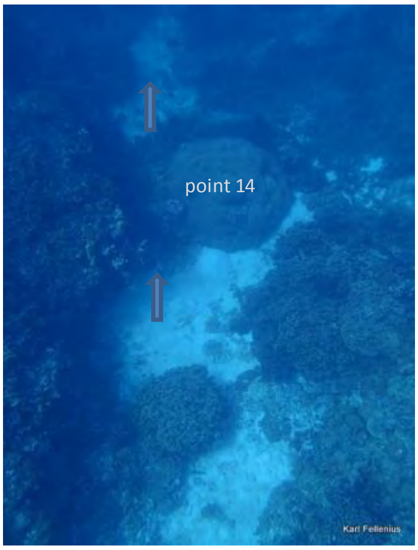


Fig. 4.2.90 From surface at point 14, South at top, route along ⇧ corrected depth 9.9m

There is a 6mm diameter *Lobophyllia* sp. coral bommie at point 14 in figures 4.2.90 through 4.2.92 (reference at 8:56 in video). It cannot be moved for both environmental and technical reasons. Moreover, the outfall route cannot be placed on top (OOE 2015). Therefore, the route must pass to the east at the left shown in the three figures.

<u>Obstruction 28</u>: There is miscellaneous debris to be removed and levelling needed along a 4m long and 1.2m wide area immediately to the east of point 14. It requires that any adjacent CABs be adjusted. Effort should be put to limit damage to the adjacent *Acropora* sp. coral colony, which can otherwise be relocated (yellow arrow). Therefore, the left side edge of this proposed route may need to be shaved by 0.2m [dive team estimate 2.5hrs. at 10m depth]

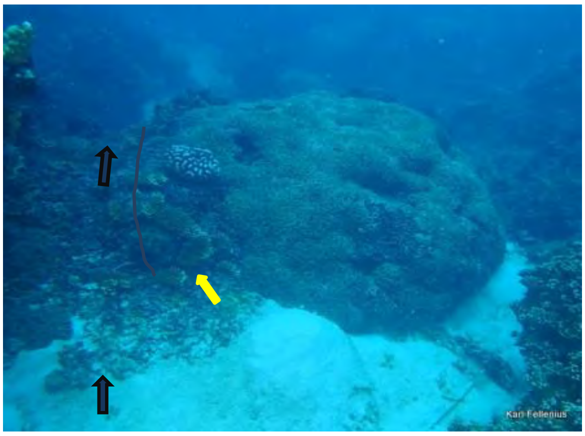


Fig. 4.2.91 From Bairiki 3m North of point 14, looking South, route along ⇧ corrected depth 9.9m

Fig. 4.2.92 Bairiki point 14, looking Southeast, route along ⇧ corrected depth 9.9m

It appears on figure 4.2.91 that immediately south of the upper arrow is another obstruction on the downward slope. This is not the case.

The 10m of substrate between points 14 and 21 is debris, rock, and 30% coral cover at a slope of 18°. Coral cover is mainly submassive *P. rus* and massive *P. sinuosa*, with minor *H. coerulea* and encrusting *Porites* sp., and no *Acropora* sp. present. There are about 35% cover of turf algae, 10% fleshy coralline algae, and 15% of the more desirable crustose coralline algae.

Figures 4.2.93 and 4.2.94 are reefscape views of the crest and upper slope on either side of the proposed outfall route looking back towards shore. They emphasize that the proposed route is the only option for the area, in the valley channel in between (not shown).

Fig. 4.2.93 From Bairiki 6m South of point 14, looking Northwest to top of crest west of point 14

Fig. 4.2.94 From Bairiki 6m South of point 14, looking Southeast to top of crest east of point 14

<u>Obstruction 29</u>: The 0.2m wide space for the route 4m north of point 21 needs to be widened to 1.2m via removal of miscellaneous debris on both sides (video capture figure 4.2.96 and reference at 9:10 in the video). There is also one *Pocillopora* sp. and the edge of one *P. sinuosa* colony on the left that need to be removed and relocated. The *P. sinuosa* grows in distinct columns, which are visible when the polyp retreats on disturbance. Therefore, these dislodge with relative ease and relocate with reasonable effort. [dive team estimate 2hrs. at 13m depth]

Fig. 4.2.95 Bairiki outer reef flat, crest, and slope

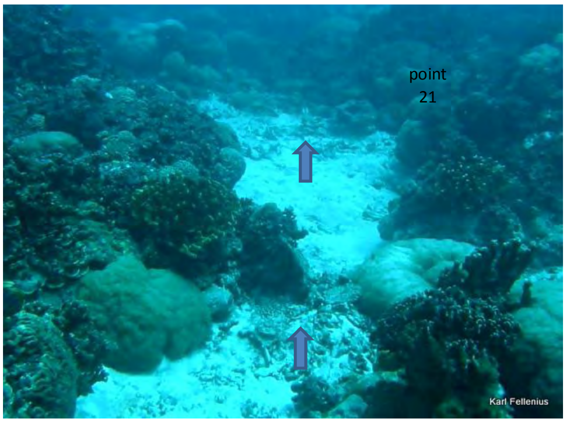


Fig. 4.2.96 From Bairiki 5m North of point 21, looking South, route passes along ⬆ corrected depth 12.8m

The 41m of substrate between points 21 and 22 is silty sand, rubble, and debris, with 15% coral cover at a slope of 12°. Coral cover is mainly massive *P. sinuosa*, some massive *Lobophyllia* sp. and submassive *P. rus*, with minor *Pocillopora* sp. and encrusting *Porites* sp. There is no *Acropora* sp. or *H. coerulea* present. The debris is mainly dead and scattered *P. sinuosa* colonies. There are about 15% cover of blue-green algae, 15% turf algae, 10% fleshy coralline algae, and none of the more desirable crustose coralline algae. The upper slope on either side of the proposed route at point 21 is shown in figures 4.2.97 and 4.2.98.

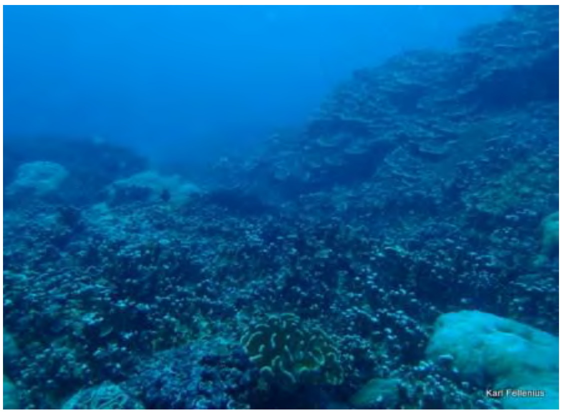


Fig. 4.2.97 From Bairiki point 21, looking West

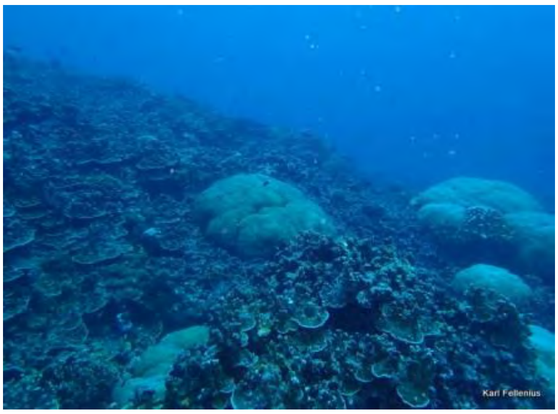


Fig. 4.2.98 From Bairiki point 21, looking East

The first 15m south of point 21 is a concentrated live *P. sinuosa* coral field with numerous obstructions (fig. 4.2.99 and reference at 09:45 in the video). It is nonetheless narrower than on both sides of the proposed route. Deeper than about 16m the *P. sinuosa* continue but obstructions are minimal. The entire area has a patchwork of COTs feeding scars on the *P. sinuosa* (fig. 4.2.100). This suggests that the 2009 infestation continues, albeit at a more subtle rate as only one animal was seen deeper at 20m (see transect sections following this section).

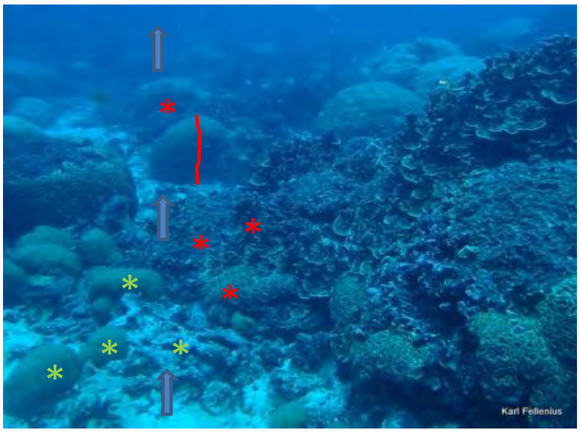


Fig. 4.2.99 From Bairiki 2-7m South of point 21, looking South, route along ⬆ corrected depth 13-15m

Fig. 4.2.100 From Bairiki 15m South of point 21, recent COTs feeding scar, corrected depth 16.5m

Obstruction 30-43: There are three partial (red line) and one complete (red *) 1.5m diameter *P. sinuosa* colonies that need to be relocated between 2-17m south of point 21 (video capture figures 4.2.99, 4.2.101 and 4.2.102, reference from 09:45 to 10:38 in video). Within this stretch there are three patches of miscellaneous debris (green *) to be removed, four areas of rock to be levelled or removed (red *), and a rocky outcrop 0.5m wide to be shaved (red line). Figure 4.2.99 shows a number of small and loose *P. sinuosa* outcrops (green *) and figure 4.2.101 has a small *Pocillopora* sp. colony in the foreground that should also be relocated [dive team estimate 7hrs. at 15m depth]

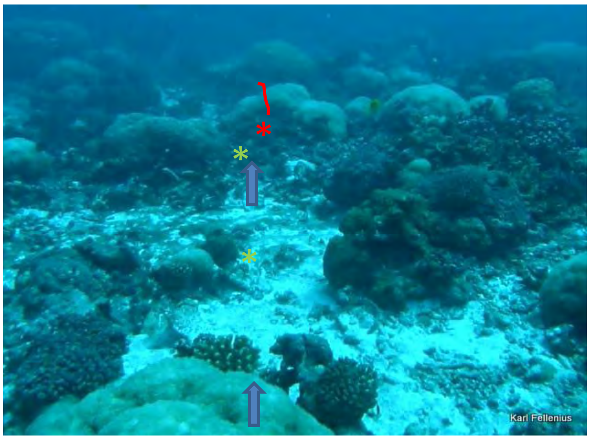


Fig. 4.2.101 From Bairiki 7-12m South of point 21, looking South, route passes along ⬆ corrected depth 15m

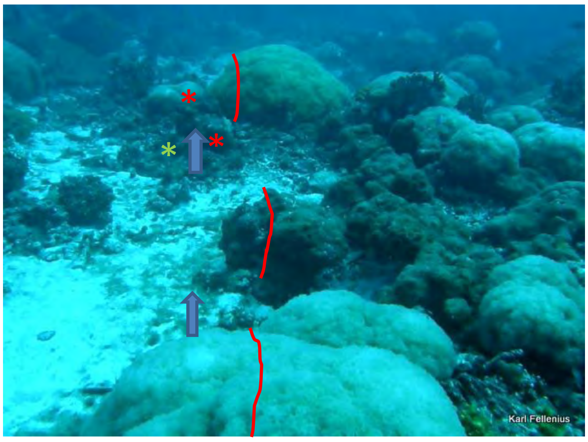


Fig. 4.2.102 From Bairiki 12-17m South of point 21, looking South, route passes along ⬆ corrected depth 15-17m

Obstruction 44: A dead table coral 2m in diameter 22m south of point 21 needs to be removed (video capture figure 4.2.103 and reference at 10:51 in the video. The proposed route runs down the middle of the table. [dive team estimate 1hr. at 18m depth]

Obstruction 45: Rock needs levelling and debris removed from 23-26m south of point 21 (reference from 10:57 to 11:05 in the video. [dive team estimate 1.5hrs. at 18m depth]

Obstruction 46: Up to 3 coral rock structures 1m in diameter for the last 7m north of point 22 need to be removed (video capture figure 4.2.104 and reference from 11:17 to 11:31 in the video. The route is not marked because the distance from the previous obstruction gives flexibility in exact placement of the outfall pipe. [dive team estimate 2.5hrs. at 21m depth]

Fig. 4.2.103 From Bairiki 22m South of point 21, looking South, corrected depth 18m

Fig. 4.2.104 From Bairiki 7m North of point 22, looking South, corrected depth 21.5m

The 31m of substrate between points 22 and 23 is rubble, debris, and 5% coral cover at a slope of 8°. Coral cover is only massive *P. sinuosa*. COTs feeding scars are present, but the low cover suggests this area has been largely depleted. There is about 15% cover of blue-green algae but no turf or coralline algae (reference from 11:42 to 12.29 in video). Figures 4.2.106 to 4.2.108 show the area around point 22.

Fig. 4.2.105 Bairiki subtidal reef flat, crest, and slope

Fig. 4.2.106 From Bairiki at point 22, looking South, route along ⬆ corrected depth 22.8m

Fig. 4.2.107 From Bairiki point 22, looking East, corrected depth 22.8m

Fig. 4.2.108 From Bairiki point 22, looking West, corrected depth 22.8m

<u>Obstruction 47</u>: There is low-lying debris along the entire route from points 22 to 23, but especially for the first 10m stretch south of point 22 (video capture figure 4.2.106 and reference from 11:45 to 12:15 in the video). The depth below 20m suggests that there is more flexibility for CABs to sit on top of low relief structures than at shallower depths. Therefore, a generalized obstruction for the route is noted. [dive team estimate 2hrs. at 25m depth]

The 16m of substrate between points 23 and 24 is rubble, debris, and back up to 15% coral cover at a slope of 24°. Coral cover is only massive *P. sinuosa* and one highly algae-impacted *Acropora* sp. table coral. The average of 15% represents 5% for the first 8m south of point 23 and 25% for the last 8m north of point 24. Recent COTs feeding scars are especially prevalent along this section, which suggests that the proportionately higher coral cover maybe short-lived. There is about 5% cover of blue-green algae but no turf or coralline algae (reference from 12:56 to 13.26 in video). Figures 4.2.110 to 4.2.112 show the area around point 23.

Fig. 4.2.109 Bairiki subtidal reef flat, crest, and slope

Fig. 4.2.110 From Bairiki at point 23, looking South, route along ↑ corrected depth 26.9m

Fig. 4.2.111 From Bairiki point 23, looking East, corrected depth 26.9m

Fig. 4.2.112 From Bairiki point 23, looking West, corrected depth 26.9m

<u>Obstruction 48</u>: There is low-lying debris along the entire route from points 23 to 24. A generalized obstruction for the route is noted. [dive team estimate 1hr. at 30m depth]

Figures 4.2.114 to 4.2.116 show the area around point 24, with *P. sinuosa* well beyond 34m depth.

Fig. 4.2.113 Bairiki subtidal reef flat, crest, and slope

Fig. 4.2.114 From Bairiki at point 24, looking South, corrected depth 34.0m

Fig. 4.2.115 From Bairiki point 24, looking East, corrected depth 34.0m

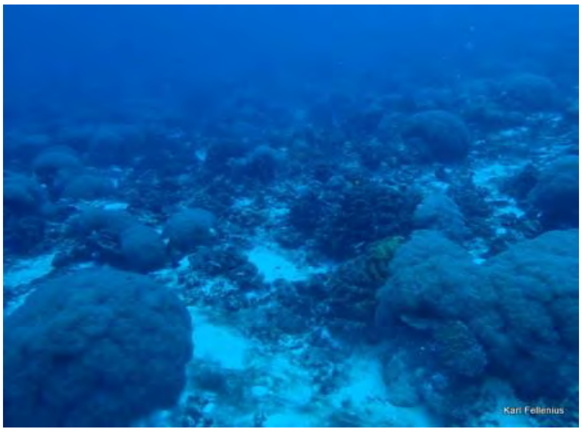


Fig. 4.2.116 From Bairiki point 24, looking West, corrected depth 34.0m

Note that terminating the outfall 3m south of point 23 (reference 12:15 in video) is warranted because it achieves the desired 30m depth (corrected), and keeps the diffuser and the immediate area of discharge away from the *P. sinuosa* that is both shallower and deeper but not in the debris field in the middle. If the diffuser is 10m long and ends at this precise location, it would be 5m north of the deeper *P sinuosa*. This is not significant, but it is better than terminating it in the deeper coral patch, which would necessitate further obstruction work, damage coral from both removal of obstructions and from more concentrated effluent plume discharge, and therefore not yield the perceived benefits that a deeper outfall might suggest.

If the design allows for it, it would be even better from an environmental standpoint for the diffuser to terminate 7m north of point 23 (reference 12:06 in video) at 25m depth (corrected) because it gives a longer buffer down to the deeper coral patch. Moreover, it would eliminate some of the deeper obstruction removal work needed.

Depth (m)	Time (hours)
1-9	29.5
10-14	4.5
15-19	9.5
20-24	2.5
25-29	2.0
30-34	1.0
Total	49.0

Fig. 4.2.117 Bairiki Obstruction Time Underwater

Figure 4.2.117 lists that the total estimated underwater time to rectify the obstructions noted for Bairiki is 49 hours. At 5 hours underwater per day +10% contingency it totals 11 days of diving. Dives need to be from deep to shallow so the first few days would focus on the reef slope in the morning and the reef flat in the afternoons. Subsequent days would focus on the reef crest in the mornings and reef flat in the afternoons. The last days would be only on the reef flat. This does not include the time needed for marking the alignment of the route with stakes and lines (est. 2 d), guiding the placement of the pipeline (est. 1d) or the time needed for adjusting the CABs (est. 2d). With 10% contingency it totals 16.5 days of diving

Figure 4.2.118 and 4.2.119 give the average percent cover for substrate and benthic categories on the reef crest and reef slope, respectively. Combined they have less undesirable algae than on the subtidal reef flat and the coral cover averages about double at 20%. In contrast with the subtidal reef flat, the positive attributes of the reef crest are that it has less turf algae, more coralline algae, and significantly more coral at 30% cover across several growth forms and species. In contrast with the reef crest at Betio, Bairiki has more coral and rock and less rubble and debris.

Total Substrate		Stony Coral Growth Form		Algae		Invertebrates	
% cover		% cover within *		% cover on substrate**			Incidence
mud	0	massive	25	crustose coralline algae	15	sponge	0
silt	5	submassive	60	*Halimeda* sp.	0	anemone	0
sand	10	encrusting	10	*Caulerpa* sp.	0	ascidian	0
rubble	10	table	5	**algae+silt+sand+coral = 100	15	gorgonian soft coral	0
debris	15	digitate	0			sea cucumber	0
rock	25	branching	0			sea urchin	0
dead coral formation	5	foliose	0	fleshy coralline algae	10	giant clam	0
dead coral debris	0	mushroom	0	turf algae (microalgae)	30	oyster	0
live stony coral	30*	fire	0	other macroalgae	0	COTs sea star	0
zoanthid corallimorph	0			blue-green algae***	0	other sea star	0
soft coral	0				40		
	100		100	***filamentous & mat cyanobacteria			

Fig. 4.2.118 Bairiki Reef Crest Substrate and Benthic Categories

The reef slope by comparison has the same amount of coral as the reef flat, but virtually all are massive *P. sinuosa* that continue to be under threat from COTS as shown by the increased proportions of dead coral formations and debris. The further negative is that while turf algae is less than on the reef flat, blue-green algae is present on the reef slope. In contrast with the reef slope at Betio, parts of Bairiki have significantly more coral. It occurs in concentrated patches deep and shallow, thus averages at 10% cover across the slope.

Total Substrate		Stony Coral Growth Form		Algae		Invertebrates	
% cover		% cover within *		% cover on substrate**			Incidence
mud	0	massive	90	crustose coralline algae	5	sponge	1
silt	20	submassive	5	*Halimeda* sp.	0	anemone	0
sand	20	encrusting	5	*Caulerpa* sp.	0	ascidian	0
rubble	10	table	0	**algae+silt+sand+coral = 100	5	gorgonian soft coral	0
debris	15	digitate	0			sea cucumber	0
rock	5	branching	0			sea urchin	0
dead coral formation	19	foliose	0	fleshy coralline algae	10	giant clam	0
dead coral debris	0	mushroom	0	turf algae (microalgae)	20	oyster	0
live stony coral	10*	fire	0	other macroalgae	0	COTs sea star	3
zoanthid corallimorph	1			blue-green algae***	15	other sea star	0
soft coral	0				45		
	100		100	***filamentous & mat cyanobacteria			

Fig. 4.2.119 Bairiki Reef Slope Substrate and Benthic Categories

In contrast with the reef flat, there is no baseline comparison for the reef crest and slope in the survey by Lovell (2000).

4.2.4.1 Transect 1 West-East by Distance

Ten photo quadrats are shown along a 100m west-east transect with the mid-point at 50m on the proposed outfall route at a corrected depth of 24m (figs. 4.2.120 to 4.2.129). Five quadrats are taken west of the mid-point, and five are taken east. Depths along the transect direction vary due west and east of the mid-point. Each quadrat ideally covers 1m^2 of substrate at 10m distance intervals. Note that several quadrats are biased and cover only 0.25m^2 as indicated by the dive computer, which is only 0.09m wide.

Fig. 4.2.120 transect 1 - 45m West of route, 24m depth

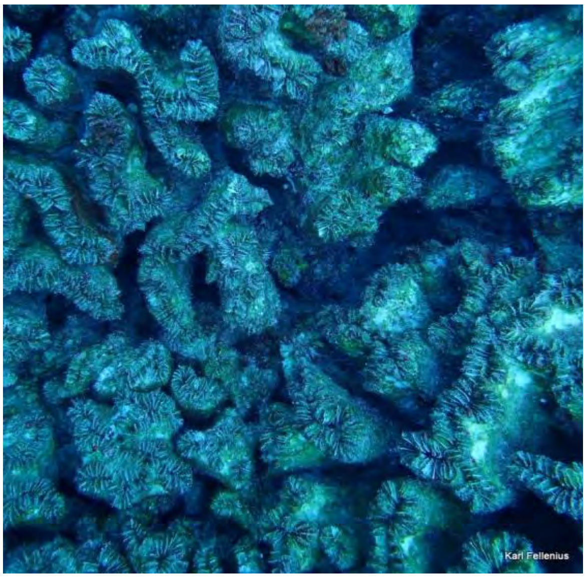


Fig. 4.2.121 transect 1 - 35m West of route, 24m depth

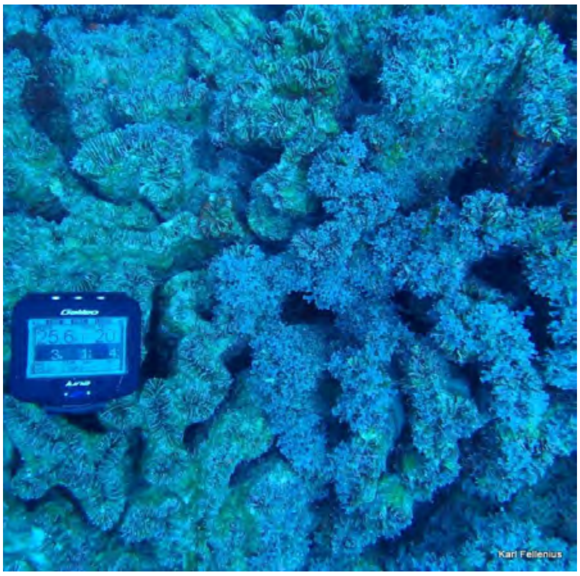


Fig. 4.2.122 transect 1 - 25m West of route, 24.5m depth

Fig. 4.2.123 transect 1 - 15m West of route, 25m depth

Fig. 4.2.124 transect 1 - 5m West of route, 24m depth

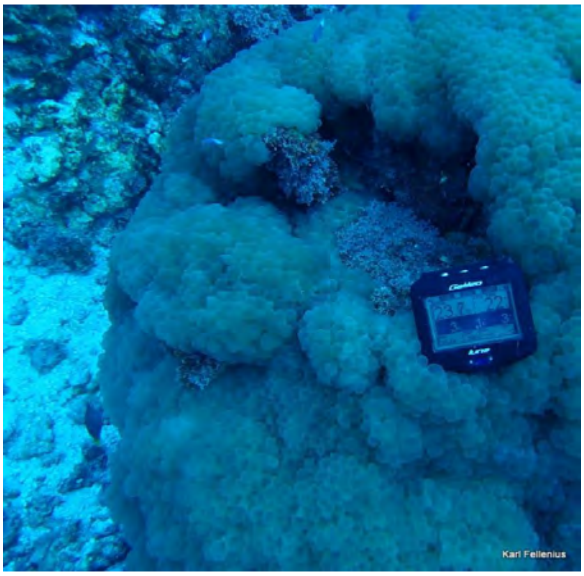


Fig. 4.2.125 transect 1 - 5m East of route, 22.5m depth

Fig. 4.2.126 transect 1 - 15m East of route, 24.5m depth

Fig. 4.2.127 transect 1 - 25m East of route, 25m depth

Fig. 4.2.128 transect 1 - 35m East of route, 24m depth

Fig. 4.2.129 transect 1 - 45m East of route, 24m depth

Figure 4.2.130 presents the analysis for each photo quadrat in transect 1 for a number of marine life and substrate variables on a degradation scale of 1-5, where 5 is highly degraded. Transect 2 and 3 are included, although accompanying photos are in the next section.

Direction	W	Transect 1								E	S	Transect 2						N	S	Transect 3					N
Quadrat	W45	W35	W25	W15	W5	E5	E15	E25	E35	E45	S25	S15	S5	N5	N15	N25	N35	N45	2-35	2-30	2-25	2-20	2-15	2-10	2-5
Depth (m)	17	18	18.5	21.5	23.5	24.5	24.5	24	23.5	23	35	31	25	23.5	18.5	14.5	10.5	5.5	35	30	25	20	15	10	5
STONY CORAL																									
Acropora plumosa																									
Acropora valida																									
Acropora sp.																									
Blastmussa wellsi																							1		1
Favia sp.																									
Fungia sp.																									
Halomitra pileus																							2		
Heliopora coerulea																							4	2	2
Lepastrea sp.																									4
Leptoseris sp.																									
Lobophyllia sp.																									
Montipora sp.																									
Oxypora sp.																									
Pavona sp.																									
Plerogyra sinuosa				1		2					1					5		4	1			1			
Pocillopora sp.																						2	3		1
Porites rus																1	1					3	1	1	
Porites sp.					4																				
Turbinaria sp.																									
ALGAE																									
crustose coralline algae							2			2	1	2		1	2	1	1	1	1	1	2	2	2	1	2
Halimeda sp.																									
Caulerpa sp.																								2	
fleshy coralline algae				2	2		3		3		2			3	2			2	2	2		3	3	3	2
turf algae (microalgae)	4	3	3	4	5	3	3	4	5	4	3	3	5	2	3	2	3	2	2	4	2	3		2	2
Dictyota sp. macroalgae			5	3	4	4		3	5	4	4	3	4	3		4		3	2	5	2	3	4		
other macroalgae										5															
blue-green algae	5			5	5	4	5	5	5	5	4	4	5	4	5	3	5	5	4		5	4		4	
INVERTEBRATES																									
Palythoa sp. (zoanthid)											3								5						
other zooanthids																									
sponge					1																				
anemone																									
ascidian																									
crinoid																						1			
leather soft corals																									
gorgonian soft coral																									
sea cucumber																									
sea urchin																									
giant clam																									
oyster																									
COTs sea star																5		5			5				
other sea star																									
SUBSTRATE																									
mud																									
silt	2						3	3		2		2	3		3		2	3	2						
sand	2			1		1	2	3	2	2	2	2	2	2	3		3	4	2	2	2	2			
rubble	2			3	3	2	3	4				3		1	2	3	3	5	2		3	2			
debris						4		4				3	4		3										
rock	3	2	2	3	5					4	2	4							2	3		2		1	2
dead coral formation	4	3	3							5				2		2		1	3		1	3			
dead coral debris																									
DISEASED CORAL																									
Bleached Coral				4																					
Other Disease																									
UNKNOWNS																									
Unknowns																									

Fig. 4.2.130 Bairiki Transect 1-3 Substrate and Benthic Degradation

Definition of degraded state:

1 = least	near pristine	notes:	-colony with some live coral is 2-4
2 =	slightly degraded		-smaller or isolated coral colonies for the species are vulnerable, thus 2-3
3 =	moderately degraded		-coral colonies in proximity to COTs are vulnerable, thus 2-3
4 =	very degraded		-silt ranges from 2-5 depending on mild to heavy
5 = most	totally degraded		-crustose coralline algae are 1-2, fleshy coralline algae is 2-3
			-*Halimeda* sp. is 1-3, *Caulerpa* sp. is 2-3, other macroalgae 2-5
			-turf algae is 2-5, blue-green algae are 4-5, bleached coral 3-5
			-substrates are 1-2 if mild silt & coralline algae, 3-5 if heavy silt & turf or blue-greens
			-Zooanthids are 2-5 depending on colony size and condition, and invertebrates are 1-3

4.2.4.2 Transect 2 South-North by Distance

Eight photo quadrats are shown along a 70m south-north transect with the "mid-point" (MP) at 25m north of point 24 on the proposed outfall route at a corrected depth of 24m (figs. 4.2.131 to 4.2.138). The transect length is less than 100m because no quadrats were taken deeper than the 35m maximum diving depth of the survey (1m deeper than point 24). It ends at 13m depth on the crest at point 21 a full 45m north of the "mid-point." Three quadrats are taken south of the mid-point, and five are taken north. Each quadrat ideally covers $1m^2$ of substrate at 10m distance intervals. Note that several quadrats are biased and cover only $0.25m^2$ as indicated by the dive computer in the photos, which is only 0.09m wide.

Fig. 4.2.131 transect 2 - 25m South of MP, 35m depth

Fig. 4.2.132 transect 2 - 15m South of MP, 31m depth

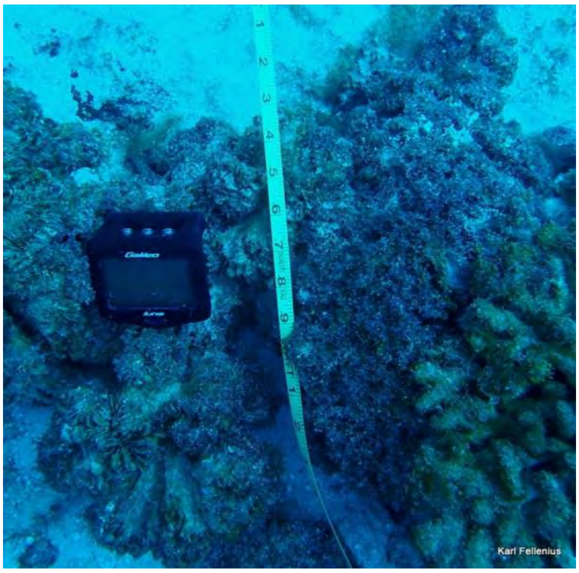


Fig. 4.2.133 transect 2 - 5m South of MP, 28m depth

Fig. 4.2.134 transect 2 - 5m North of MP, 24m depth

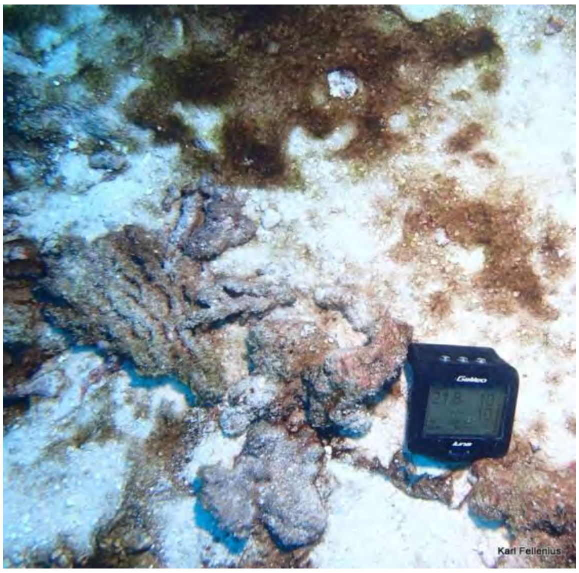


Fig. 4.2.135 transect 2 - 15m North of MP, 22m depth

Fig. 4.2.136 transect 2 - 25m North of MP, 20m depth

Fig. 4.2.137 transect 2 - 35m North of MP, 17m depth

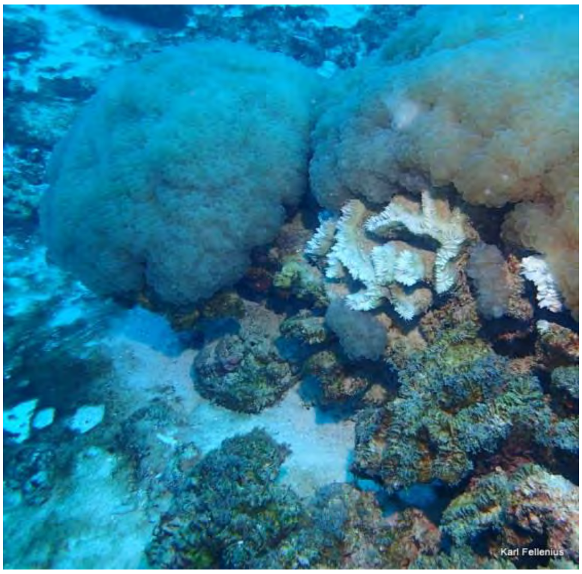


Fig. 4.2.138 transect 2 - 45m North of MP, 13m depth

Figure 4.2.139 re-displays the analysis for each photo quadrat.

Direction	W				Transect 1					E	S			Transect 2				N	S			Transect 3			N
Quadrat	W45	W35	W25	W15	W5	E5	E15	E25	E35	E45	S25	S15	S5	N5	N15	N25	N35	N45	2-35	2-30	2-25	2-20	2-15	2-10	2-5
Depth (m)	17	18	18.5	21.5	23.5	24.5	24.5	24	23.5	23	35	31	25	23.5	18.5	14.5	10.5	5.5	35	30	25	20	15	10	5
STONY CORAL																									
Acropora plumosa																									
Acropora valida																									
Acropora sp.																									
Blastmussa wellsi																							1		1
Favia sp.																									
Fungia sp.																									
Halomitra pileus																							2		
Heliopora coerulea																							4	2	2
Lepastrea sp.																									4
Leptoseris sp.																									
Lobophyllia sp.																									
Montipora sp.																									
Oxypora sp.																									
Pavona sp.																									
Plerogyra sinuosa				1		2					1					5		4	1			1			
Pocillopora sp.																						2	3		1
Porites rus																1	1					3	1	1	
Porites sp.					4																				
Turbinaria sp.																									
ALGAE																									
crustose coralline algae							2			2	1	2		1	2	1	1	1	1	1	2	2	2	1	2
Halimeda sp.																									
Caulerpa sp.																								2	
fleshy coralline algae				2	2		3		3		2			3	2			2	2	2		3	3	3	2
turf algae (microalgae)	4	3	3	4	5	3	3	4	5	4	3	3	5	2	3	2	3	2	2	4	2	3		2	2
Dictyota sp. macroalgae			5	3	4	4		3	5	4	4	3	4	3		4		3	2	5	2	3	4		
other macroalgae										5															
blue-green algae	5			5	5	4	5	5	5	5	4	4	5	4	5	3	5	5	4		5	4		4	
INVERTEBRATES																									
Palythoa sp. (zoanthid)											3								5						
other zooanthids																									
sponge					1																				
anemone																									
ascidian																									
crinoid																						1			
leather soft corals																									
gorgonian soft coral																									
sea cucumber																									
sea urchin																									
giant clam																									
oyster																									
COTs sea star																5		5			5				
other sea star																									
SUBSTRATE																									
mud																									
silt	2						3	3		2		2	3		3		2	3	2						
sand	2			1		1	2	3	2	2	2	2	2	2	3		3	4	2	2	2	2			
rubble	2			3	3	2	3	4				3		1	2	3	3	5	2		3	2			
debris						4		4				3	4		3										
rock	3	2	2	3	5					4	2	4							2	3		2		1	2
dead coral formation	4	3	3							5				2		2		1	3		1	3			
dead coral debris																									
DISEASED CORAL																									
Bleached Coral				4																					
Other Disease																									
UNKNOWNS																									
Unknowns																									

Fig. 4.2.139 Bairiki Transect 1-3 Substrate and Benthic Degradation

Definition of degraded state:

1 = least near pristine
2 = slightly degraded
3 = moderately degraded
4 = very degraded
5 = most totally degraded

notes:
- -colony with some live coral is 2-4
- -smaller or isolated coral colonies for the species are vulnerable, thus 2-3
- -coral colonies in proximity to COTs are vulnerable, thus 2-3
- -silt ranges from 2-5 depending on mild to heavy
- -crustose coralline algae are 1-2, fleshy coralline algae is 2-3
- -*Halimeda* sp. is 1-3, *Caulerpa* sp. is 2-3, other macroalgae 2-5
- -turf algae is 2-5, blue-green algae are 4-5, bleached coral 3-5
- -substrates are 1-2 if mild silt & coralline algae, 3-5 if heavy silt & turf or blue-greens
- -Zooanthids are 2-5 depending on colony size and condition, and invertebrates are 1-3

4.2.4.3 Transect 3 South-North by Depth

Seven photo quadrats are shown, one every 5m depth from a non-corrected depth of 35m to 5m alternating left and right along the proposed outfall route (figs. 4.2.140 to 4.2.146). Each quadrat covers 1m^2 of substrate. The four deepest quadrats are along the reef slope. The 15m quadrat is just seaward of the reef crest, and the 10m quadrat is on the reef crest. Finally, the 5m quadrat is just south of point 5 on the outer subtidal reef flat.

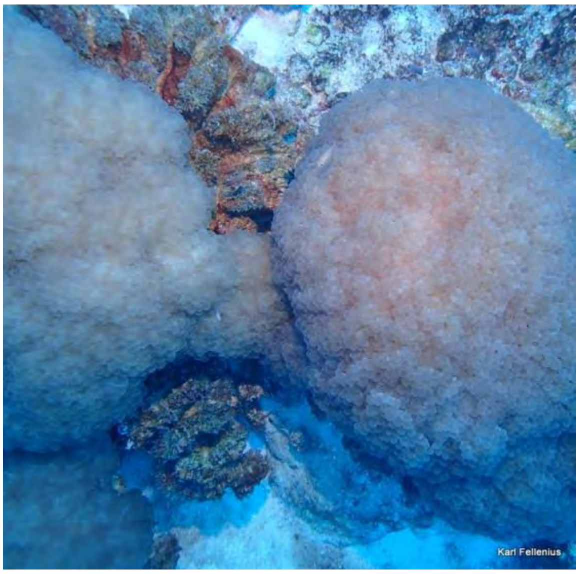


Fig. 4.2.140 transect 3 - 35m depth, South of point 24

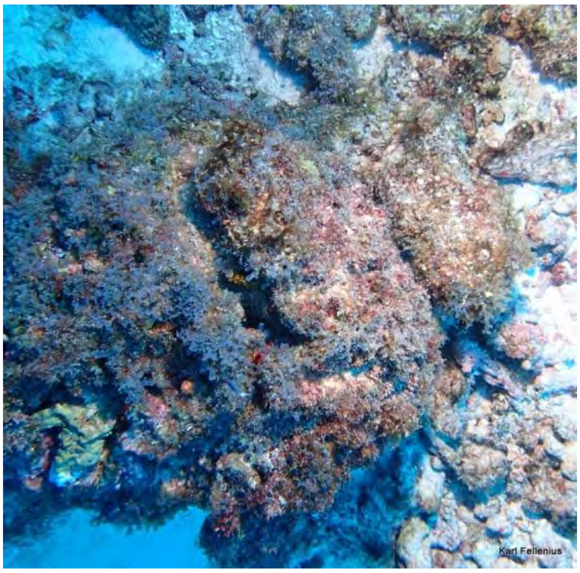


Fig. 4.2.141 transect 3 - 30m depth, South of point 23

Fig. 4.2.142 transect 3 - 25m depth, South of point 22

Fig. 4.2.143 transect 3 - 20m depth, North of point 22

Fig. 4.2.144 transect 3 - 15m depth, South of point 21

Fig. 4.2.145 transect 3 - 10m depth, at point 14

Fig. 4.2.146 transect 3 - 5m depth, South of point 5

Fig. 4.1.147 Bairiki reef flat, crest, and slope

Figure 4.2.146 re-displays the analysis for each photo quadrat for a number of marine life and substrate variables on a degradation scale of 1-5, where 5 is highly degraded.

Direction	W	Transect 1								E	S	Transect 2						N	S	Transect 3					N
Quadrat	W45	W35	W25	W15	W5	E5	E15	E25	E35	E45	S25	S15	S5	N5	N15	N25	N35	N45	2-35	2-30	2-25	2-20	2-15	2-10	2-5
Depth (m)	17	18	18.5	21.5	23.5	24.5	24.5	24	23.5	23	35	31	25	23.5	18.5	14.5	10.5	5.5	35	30	25	20	15	10	5
STONY CORAL																									
Acropora plumosa																									
Acropora valida																									
Acropora sp.																									
Blastmussa wellsi																							1		1
Favia sp.																									
Fungia sp.																									
Halomitra pileus																							2		
Heliopora coerulea																							4	2	2
Lepastrea sp.																									4
Leptoseris sp.																									
Lobophyllia sp.																									
Montipora sp.																									
Oxypora sp.																									
Pavona sp.																									
Plerogyra sinuosa				1		2					1					5		4	1			1			
Pocillopora sp.																						2	3		1
Porites rus																1	1					3	1	1	
Porites sp.					4																				
Turbinaria sp.																									
ALGAE																									
crustose coralline algae							2			2	1	2		1	2	1	1	1	1	1	2	2	2	1	2
Halimeda sp.																									
Caulerpa sp.																								2	
fleshy coralline algae				2	2		3		3		2			3	2			2	2	2		3	3	3	2
turf algae (microalgae)	4	3	3	4	5	3	3	4	5	4	3	3	5	2	3	2	3	2	2	4	2	3		2	2
Dictyota sp. macroalgae			5	3	4	4		3	5	4	4	3	4	3		4		3	2	5	2	3	4		
other macroalgae										5															
blue-green algae	5			5	5	4	5	5	5	5	4	4	5	4	5	3	5	5	4		5	4		4	
INVERTEBRATES																									
Palythoa sp. (zoanthid)											3								5						
other zooanthids																									
sponge					1																				
anemone																									
ascidian																									
crinoid																						1			
leather soft corals																									
gorgonian soft coral																									
sea cucumber																									
sea urchin																									
giant clam																									
oyster																									
COTs sea star																5		5			5				
other sea star																									
SUBSTRATE																									
mud																									
silt	2						3	3		2		2	3		3		2	3	2						
sand	2			1		1	2	3	2	2	2	2	2	2	3		3	4	2	2	2	2			
rubble	2			3	3	2	3	4				3		1	2	3	3	5	2		3	2			
debris						4		4				3	4		3										
rock	3	2	2	3	5					4	2	4							2	3		2		1	2
dead coral formation	4	3	3							5				2		2		1	3		1	3			
dead coral debris																									
DISEASED CORAL																									
Bleached Coral				4																					
Other Disease																									
UNKNOWNS																									
Unknowns																									

Fig. 4.2.146 Bairiki Transect 1-3 Substrate and Benthic Degradation

Definition of degraded state:

1 = least	near pristine	notes: -colony with some live coral is 2-4
2 =	slightly degraded	-smaller or isolated coral colonies for the species are vulnerable, thus 2-3
3 =	moderately degraded	-coral colonies in proximity to COTs are vulnerable, thus 2-3
4 =	very degraded	-silt ranges from 2-5 depending on mild to heavy
5 = most	totally degraded	-crustose coralline algae are 1-2, fleshy coralline algae is 2-3

-*Halimeda* sp. is 1-3, *Caulerpa* sp. is 2-3, other macroalgae 2-5
-turf algae is 2-5, blue-green algae are 4-5, bleached coral 3-5
-substrates are 1-2 if mild silt & coralline algae, 3-5 if heavy silt & turf or blue-greens
-Zooanthids are 2-5 depending on colony size and condition, and invertebrates are 1-3

4.3 Bikenibeu Outfall

Each section begins with a description of the chainage with photos referenced accordingly. Figure 4.3.1 shows the distribution of GPS positions taken along the existing and proposed outfall route.

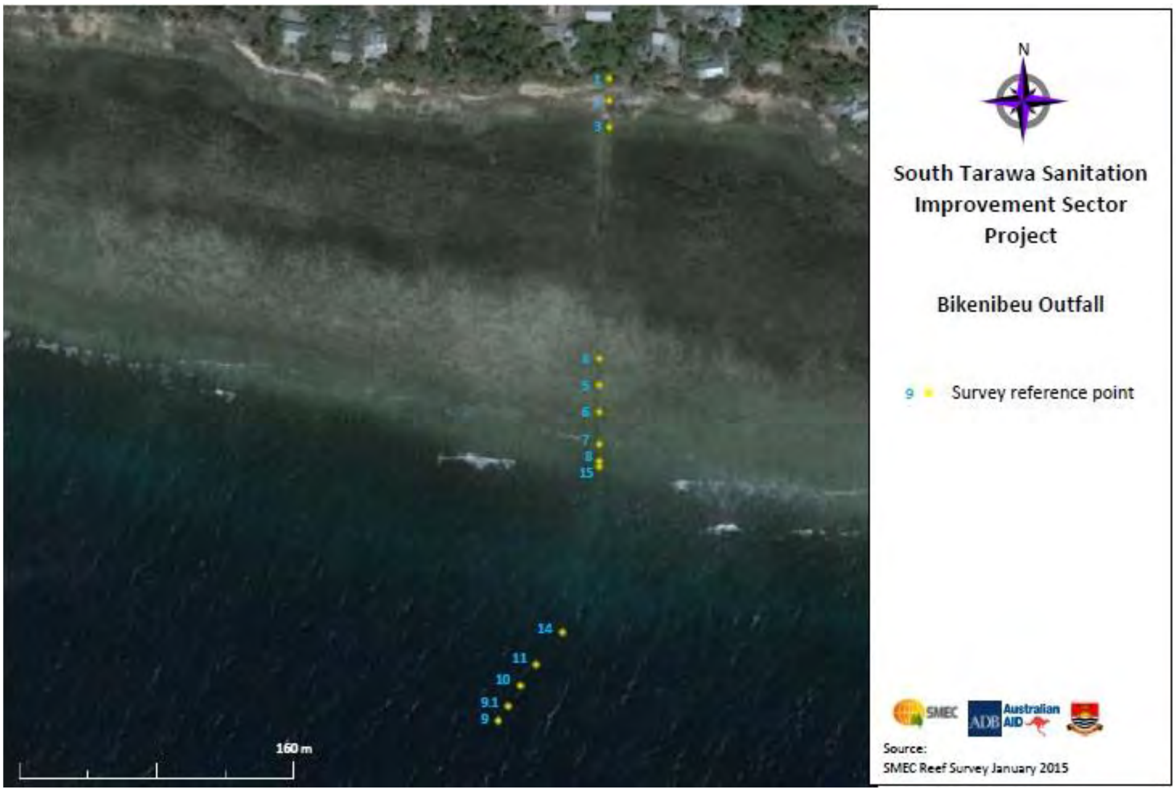


Fig. 4.3.1 Location of Existing and Proposed Bikenibeu Outfall Route

Figure 4.3.2 shows the pipeline route that was derived from the GPS points.

Fig. 4.3.2 Existing Outfall Pipe and Proposed Extension at Bikenibeu
(note: reference depths not corrected for 0 datum)

Figure 4.3.2 is the depth profile for the existing wastewater line and proposed extension from point 1 at the vent on the shoreline to point 9 at 33m depth on the reef slope. Total distance covered is 379m. Note that GPS points on the intertidal reef flat to end of pipe are all displayed as 0m.

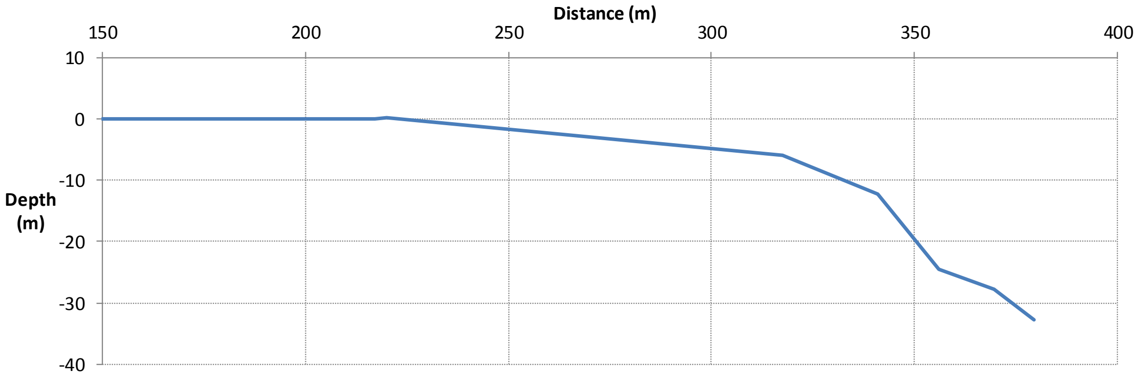


Fig. 4.3.2 Reef Depth Profile along the Existing Bikenibeu Outfall Route and Proposed Extension

4.3.1 Shoreline and Foreshore

Figures 4.3.3 and 4.3.4 of the vent location on the shoreline show point 1 as the 0 chainage point.

Fig. 4.3.3 Bikenibeu vent looking North

Fig. 4.3.4 Bikenibeu vent looking Southeast

4.3.2 Intertidal Reef Flat to End of Pipe

The total distance from the vent to the existing end of pipe is 220m (figure 4.3.5). This is 538m shorter than at Betio, and 16m longer than at Bairiki. The end of pipe is at a height of 28cm above 0 tide datum (LAT, BOM).

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)
Bikenibeu	vent	1	0.0	0.0
Bikenibeu	reef flat	2	12.2	12.2
Bikenibeu	reef flat	3	15.3	27.5
Bikenibeu	reef flat	4	132.1	159.6
Bikenibeu	reef flat	5	15.0	174.6
Bikenibeu	reef flat	6	15.4	189.9
Bikenibeu	reef flat	7	18.2	208.1
Bikenibeu	reef flat, near EOP	8	9.1	217.2
Bikenibeu	reef flat, EOP	15	3.0	220.1

Fig. 4.3.5 Intertidal Reef Flat Chainage

Figures 4.3.6 to 4.3.29 show the location and representative substrate and algae characteristics of the intertidal reef flat to the end of existing pipe. Quadrat photos are taken to the left and right of the transect line. Refer to video *Bikenibeu 2 S to N vid 33m (approx pt9) to 1m [disregard first 3min]*. Note that while sampling was done on average every 15m, there is 132m between point 3 and 4.

Approximately the first 20m of the inner intertidal reef flat is rubble and sand with no algae, followed by 30% cover of turf algae to the end of existing pipe. The odoriferous and fast-growing red macroalgae, *Hypnea* sp. starts at about 130m from the shoreline and persists at 25% cover for about 30m, dropping off to 5% at 12m before the end of existing pipe. From about 160m from the shoreline through to 3m before the existing end of pipe there is 10-40% cover of *Caulerpa* sp. sea grape algae, albeit with a few patches of cyanobacteria mat and 10% funnelweed macroalgae. The overriding point is that there is a dominance of fleshy and other undesirable algae across the intertidal reef flat, with no presence of any calcifying algae.


Fig. 4.3.6 Bikenibeu intertidal reef flat

Fig. 4.3.7 From Bikenibeu reef flat point 3 looking South


Fig. 4.3.8 Bikenibeu reef flat point 3, juvenile moray eel


Fig. 4.3.9 Bikenibeu reef flat point 3


Fig. 4.3.10 Bikenibeu intertidal reef flat

Fig. 4.3.11 From Bikenibeu reef flat point 4 looking South


Fig. 4.3.12 Bikenibeu reef flat point 4, macroalgae


Fig. 4.3.13 Bikenibeu reef flat point 4, brittle star

Fig. 4.3.14 Bikenibeu intertidal reef flat

Fig. 4.3.15 From Bikenibeu reef flat point 5 looking South

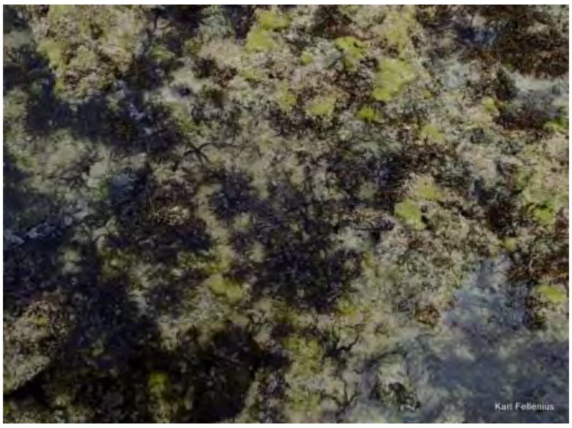


Fig. 4.3.16 Bikenibeu reef flat point 5, turf and macroalgae, and brittle stars

Fig. 4.3.17 Bikenibeu reef flat point 5, cyanobacteria mat algae (blue-green algae)

Fig. 4.3.18 Bikenibeu intertidal reef flat

Fig. 4.3.19 From Bikenibeu reef flat point 6 looking South

Fig. 4.3.20 Bikenibeu reef flat point 6, macroalgae

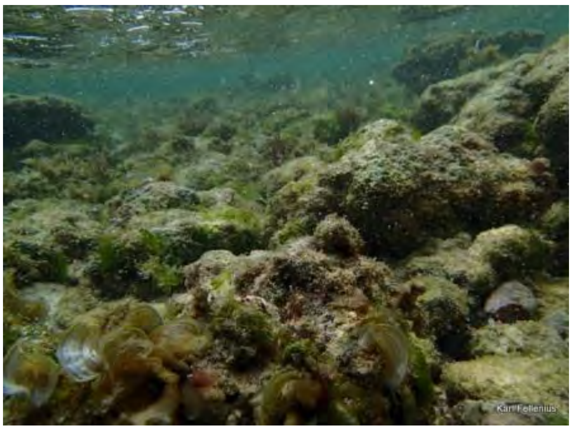


Fig. 4.3.21 Bikenibeu reef flat point 6, turf and funnelweed algae (*Padina* sp.)

Fig. 4.3.22 Bikenibeu intertidal reef flat

Fig. 4.3.23 From Bikenibeu reef flat point 7 looking South

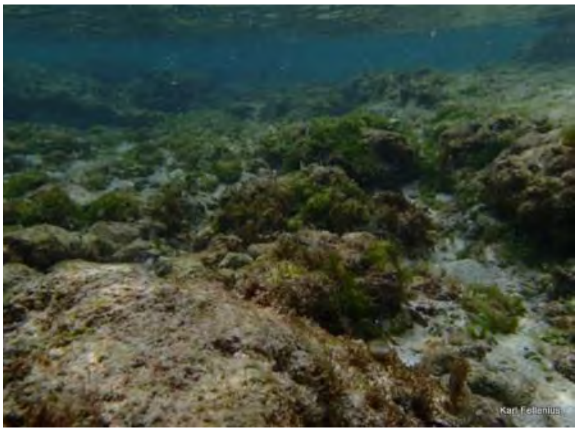


Fig. 4.3.24 Bikenibeu reef flat point 7, turf algae

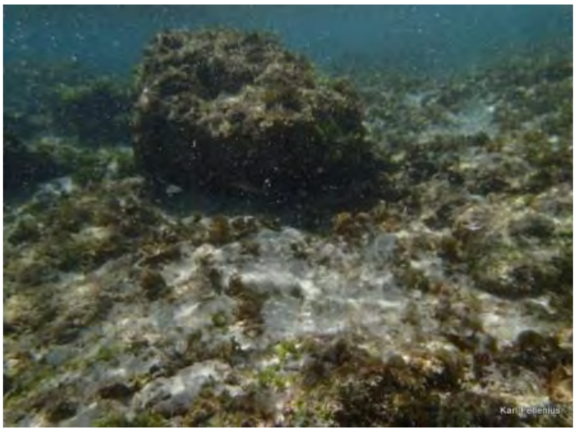


Fig. 4.3.25 Bikenibeu reef flat point 7,
turf and funnelweed algae (*Padina* sp.)

Fig. 4.3.26 Bikenibeu intertidal reef flat

Fig. 4.3.27 From Bikenibeu reef flat point 8 looking South

Fig. 4.3.28 Bikenibeu reef flat point 8,
sea grape algae (*Caulerpa* sp.)

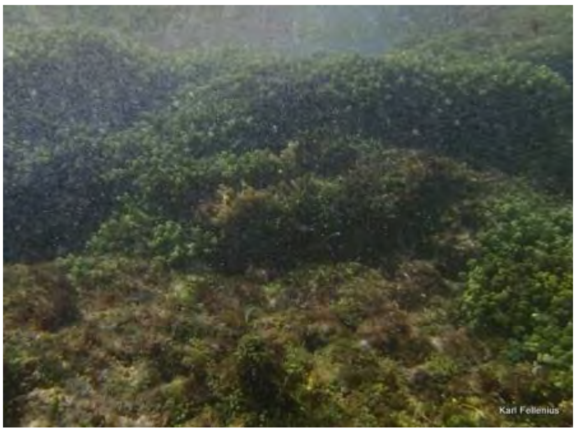


Fig. 4.3.29 Bikenibeu reef flat point 8,
turf and sea grape algae (*Caulerpa* sp.)

The area at the end of existing pipe during is shown in figures 4.3.30 and 4.2.31. Algae cover appears low right at the outfall because the energy of discharge at that point prevents it from attaching. The pipe itself appears in good condition except the portion that was attached from this point south has broken off. There are some CABs immediately north of the end of existing pipe, and these are discussed along with the excavation of the last section of pipe and removal of obstructions in section 4.3.3.

Fig. 4.3.30 Bikenibeu reef flat point 15,
turf and sea grape algae near end of existing pipe

Fig. 4.3.31 Bikenibeu reef flat point 15,
end of existing pipe

4.3.3 Subtidal Reef Flat beyond End of Existing Pipe

Figure 4.3.32 displays the coordinates of the GPS positions taken along the outfall route for the proposed extension south of the end of the existing pipe3

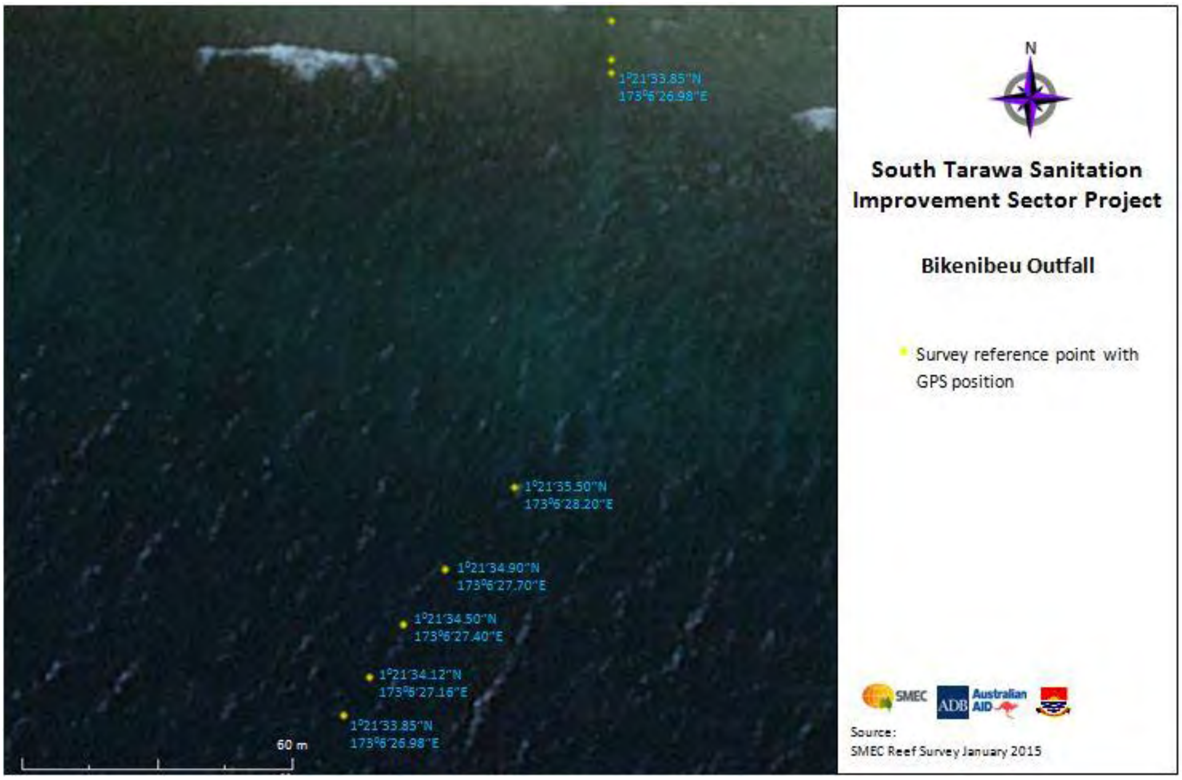


Fig. 4.3.32 GPS Position Coordinates of Proposed BikenibeuOutfall Route
(North reef flat positions not included)

Figure 4.2.33 re-displays the pipeline route that was derived from the GPS points.

Fig. 4.3.33 Existing Outfall Pipe and Proposed Extension at Bikenibeu
(note: reference depths not corrected for 0 datum)

The total distance from the vent to the end of the existing pipe (25) is 220m, at 570m shorter than at Betio and 16m shorter than at Bairiki (fig. 4.3.34).

There is another 80m of subtidal reef flat before the reef begins to crest, 85m shorter than at Betio and 50m shorter than at Bairiki. Point 14 at the end of the broken pipe is 15m into the crest at a depth of 5.9m below 0 tide datum.

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)	Depth (m)
Bikenibeu	reef flat subtidal, EOP	15	3.0	220.1	0.28
Bikenibeu	reef crest, broken EOP	14	97.3	317.4	-5.91

Fig 4.3.34 Bikenibeu Reef Flat Chainage

Figure 4.3.35 shows the proposed outfall route and the various features and obstructions found along the length of the proposed extension. In contrast with Betio and Bairiki, there are fewer obstructions. However, significant coral obstructions are concentrated on the reef crest.

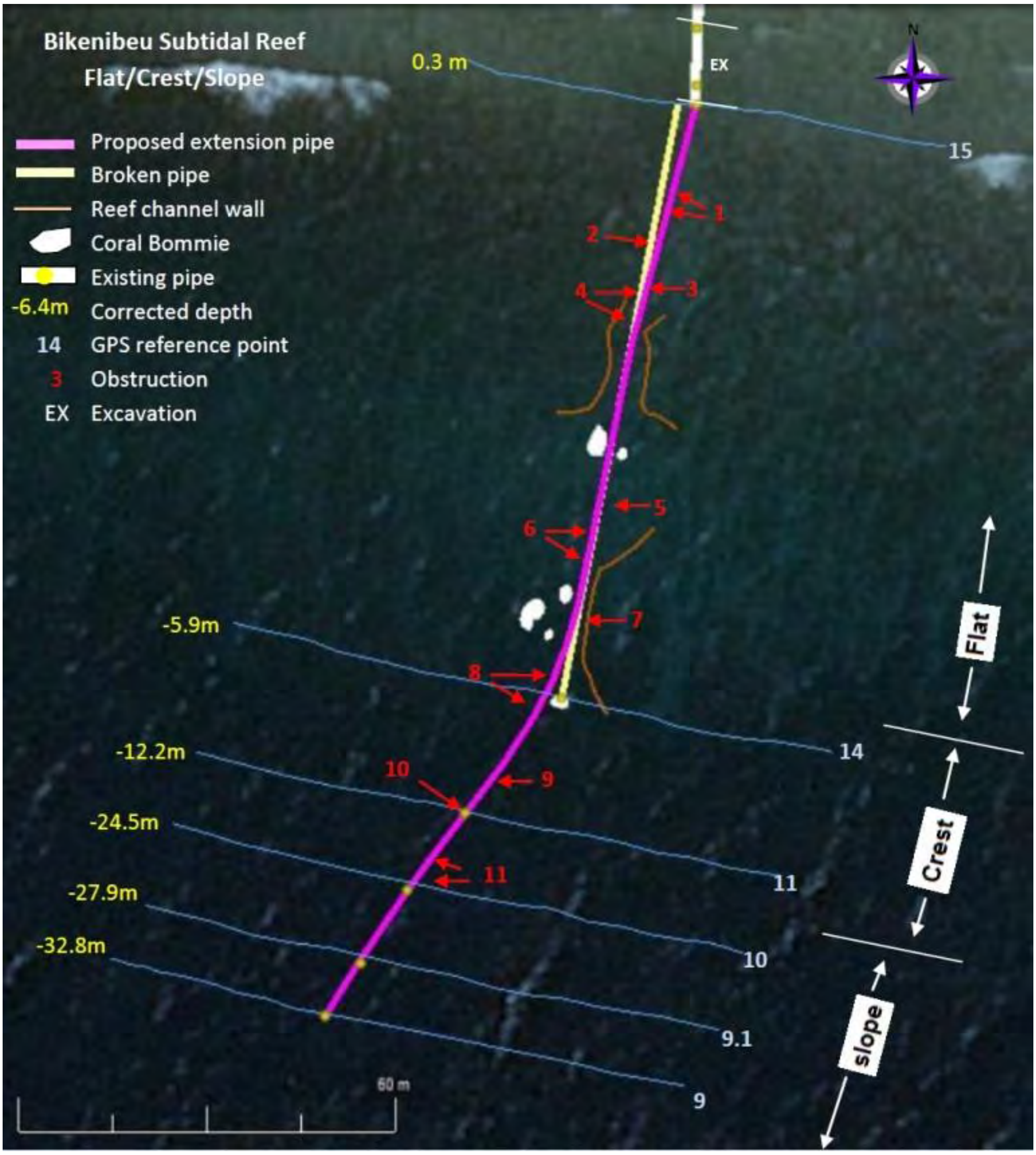


Fig. 4.3.35 Features and Obstructions along the Existing and Proposed Bikenibeu Outfall Route (digitized by SMEC)

In this section refer to video *Bikenibeu 2 S to N vid 33m (approx pt9) to 1m [disregard first 3min]* and *Bikenibeu 1 - N to S vid 4m (6m N of Pt14) to 36m (pt9)*. Note that video 2 runs south to north, opposite to the north to south sequence of discussion of excavation and obstructions.

The existing outfall pipe needs to be cut approximately 13m north of the end of the end of the existing pipe, and the trench excavated. A few small CABs are strewn along this length, and along with some small and a few large rocks (up to 0.7m diameter) need to be removed (figs. 4.3.36 to 4.3.39, reference from 6:00 to 6:53 in Bikenibeu video 2).

Fig. 4.3.36 From Bikenibeu 5m North of end of existing pipe, looking South, corrected height +0.4m

Fig. 4.3.37 From Bikenibeu 9m North of end of existing pipe, looking South, corrected height +0.4m

Fig. 4.3.38 From Bikenibeu end of existing pipe, looking Northeast, corrected height +0.3m

Fig. 4.3.39 From Bikenibeu end of existing pipe, looking South, corrected height +0.3m

The entire length of the broken pipe from point 15 to 14 (97m) and its still-attached 10 CABs need to be removed (reference from 2:48 to 5:30 in Bikenibeu video 2).

There is no significant coral or other marine life in this heavily-silted area. A table of substrate and benthic categories and their frequency percentages is averaged across the subtidal reef flat and presented at the end of this section. The close visual inspection discussion includes highlights of the substrate and marine life including coral and algae, as a lead-up to the summary provided in the table.

The 97m of substrate between points 15 and 14 (end of broken pipe) is silt, rubble, debris, rock, and minor coral at a slope of 4°.There are about 60% cover of turf algae, but no coralline algae.

Obstruction 1: There are 5 loose rocks up to 1m in diameter for a 7m stretch that need to be removed (reference from 4.46 to 5:05 in Bikenibeu video 2). Some levelling is required for 2 solid rock areas. One of the loose rocks is shown in figure 4.3.40 (reference at 4:50 in Bikenibeu video 2). [dive team estimate 2hrs.]

Obstruction 2: There is miscellaneous debris and 1 loose rock 1.2m in diameter for a 4m stretch that need to be removed (video capture fig. 4.3.41 and reference from 4.32 to 4:42 in Bikenibeu video 2). Some levelling is required for 1 solid rock area. [dive team estimate 1.5hrs.]

Fig. 4.3.40 From Bikenibeu 15m South of end of existing pipe, looking South, corrected depth 0.6m

Fig. 4.3.41 From Bikenibeu 22m to 18m South of end of existing pipe, looking North, corrected depth 1.0m

Obstruction 3: Levelling and infilling is required over a 3m stretch (video capture fig. 4.3.42 and reference from 4.12 to 4:19 in Bikenibeu video 2). Note that the broken pipe has moved to the right away from the proposed outfall route [dive team estimate 2hrs.]

Fig. 4.3.42 Bikenibeu subtidal reef flat, crest, and slope

Fig. 4.3.43 From Bikenibeu 28m South of end of existing pipe, looking North, route along ⬇ corrected depth 1.9m

Obstruction 4: Levelling and infilling is required over a 6m stretch (video capture fig. 4.3.42, fig. 4.3.45, and reference from 3:58 to 4:10 in Bikenibeu video 2). Note that the broken pipe has moved to the right away from the proposed outfall route, and that the figures show the route from different directions. [dive team estimate 3hrs.]

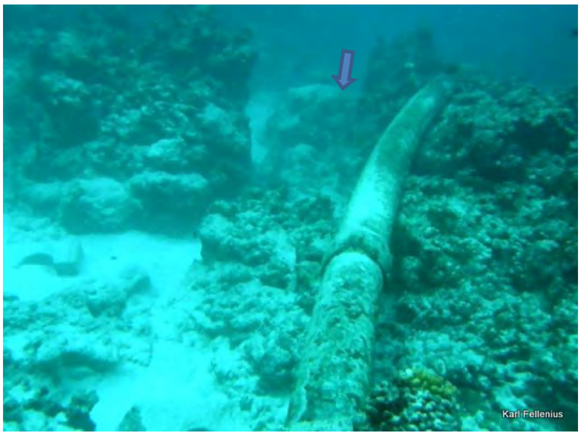


Fig. 4.3.44 From Bikenibeu 34m South of end of existing pipe, looking North, route along ⬇ corrected depth 1.7m

Fig. 4.3.45 From Bikenibeu 26m South of end of existing pipe, looking South, route along ⬆ corrected depth 1.9m

Coral cover approaches 5% for the area of obstructions 3 and 4, and to the south for the remaining 50m of the subtidal reef flat. There remains significant debris and silt, but rubble cover is declining and sand in the channel is increasing. No other marine life except turf algae.

Obstruction 5: The 2m side of a large coral bommie needs to be shaved by 0.5m (video capture fig. 4.3.46, and reference from 3:49 in Bikenibeu video 2).There is no coral in the affected area. [dive team estimate 3hrs.]

Obstruction 6: Levelling, infilling, and debris removal is needed along a 6m stretch (video capture fig. 4.3.47, and reference from 3:29 to 3:46 in Bikenibeu video 2).There is some minor *P. rus* and *Pocillopora* sp. in the affected area, and the latter can be relocated. [dive team estimate 2hrs.]

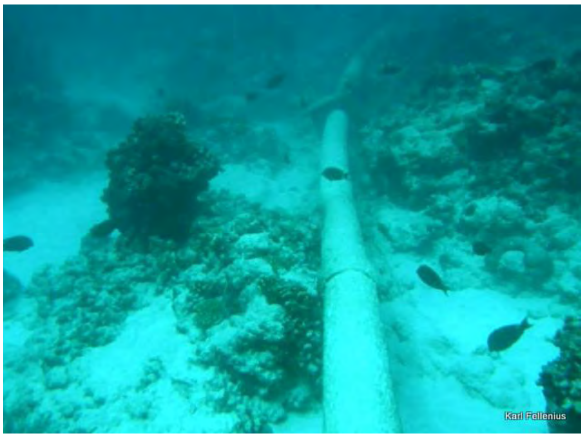


Fig. 4.3.46 From Bikenibeu 27m North of point 14, looking North, corrected depth 1.6m

Fig. 4.3.47 From Bikenibeu 25m North of point 14, looking South, route along broken pipe, corrected depth 1.3m

NOTE: Based on estimates on viewing video 2, obstruction 4 is 26-34m south of point 15, and obstruction 5 is 27-29m north of point 14. There is only 3m between them. This means that the chainage from point 15 (end of existing pipe) to 14 (end of broken pipe) should be about 66m, not the 97m as measured by SMEC during the survey. The 97m may be in error. The total chainage for Bikenibeu then becomes 348m, not the SMEC total of 379m. This is somewhat closer to the 315m estimate listed in the TOR in appendix C.

Figure 4.3.48 shows a series of three CABs just over half-way along the subtidal reef flat (reference at 3:16 in Bikenibeu video 2).One of the CABs has a patch of the same common zooanthid *Palythoa* sp. that is present in the spur-and-groove channels at Betio. The amount of silt and algae in this area is less, with 40% turf algae and coral cover increases to about 10%, dominated by *p. rus*.

Fig. 4.3.48 From Bikenibeu 19m North of point 14, looking South, corrected depth 3.8m

Fig. 4.3.49 From Bikenibeu 15m North of point 14, looking South, corrected depth 3.8m

Obstruction 7: Levelling is needed along a 3m stretch of a low relief coral bommie (video capture fig. 4.3.50, and reference from 3:05 to 3:11 in Bikenibeu video 2 and 0:00 to 0:08 in video 1). Immediately south at 2:58 in the video are 3 CABs that need to be removed. The affected surface of the bommie is covered in *P. rus* and very little of it can be relocated. [dive team estimate 2hrs.]

Fig. 4.3.50 From Bikenibeu 10m North of point 14, looking North, corrected depth 3.6m

Fig. 4.3.51 From Bikenibeu 10m North of point 14, looking South, route along ⬆ corrected depth 3.6m

Obstruction 7 is precisely 10m north of point 14, where the proposed outfall route turns slightly right (west-southwest) over the reef crest (reference at 0:14 in Bikenibeu video 1). Figure 4.3.53 shows the end of the broken pipe at point 14, and the coral rise of P. rus and *H. coerulea* that prevent this from being a viable route.

Fig. 4.3.52 Bikenibeu subtidal reef flat, crest, and slope

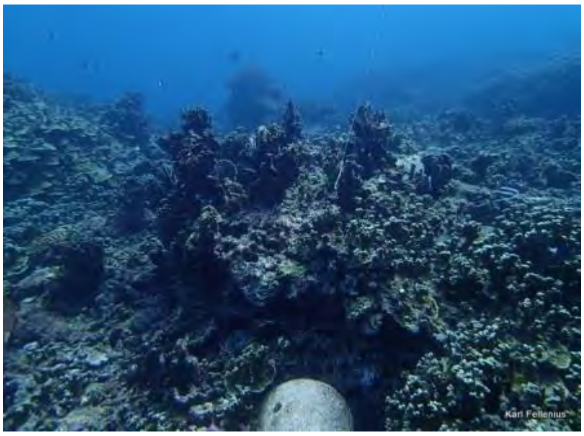


Fig. 4.3.53 From Bikenibeu point 14, looking South, corrected depth 5.9m

Figure 4.3.54 gives the average percent cover for substrate and benthic categories on the subtidal reef flat. The 60% cover for undesirable algae is the same as for the Betio reef flat, and slightly more than at Bairiki. There is less than half the coral cover than for both the other reef flats. In contrast with Bairiki, the Bikenibeu subtidal reef flat has slightly more turf algae but no coralline algae. It also no *Acropora* sp. table corals, a dominance of *P. rus*, more rock and significantly more silt. Limited zooanthids are present, and in contrast with Betio are located further out.

Total Substrate		Stony Coral Growth Form		Algae		Invertebrates	
% cover		% cover within *		% cover on substrate**			Incidence
mud	0	massive	0	crustose coralline algae	0	sponge	0
silt	25	submassive	95	*Halimeda* sp.	0	anemone	0
sand	15	encrusting	5	*Caulerpa* sp.	0	ascidian	0
rubble	10	table	0	**algae+silt+sand+coral = 100	0	gorgonian soft coral	0
debris	15	digitate	0			sea cucumber	0
rock	20	branching	0			sea urchin	0
dead coral formation	5	foliose	0	fleshy coralline algae		giant clam	0
dead coral debris	4	mushroom	0	turf algae (microalgae)	60	oyster	0
live stony coral	5*	fire	0	other macroalgae	0	COTs sea star	0
zoanthid corallimorph	1			blue-green algae***	0	other sea star	0
soft coral	0				60		
	100		100	***filamentous & mat cyanobacteria			

Fig. 4.2.54 Bikenibeu Subtidal Reef Flat Substrate and Benthic Categories

In contrast with Betio and similar to Bairiki, there is a baseline comparison for Bikenibeu in the survey by Lovell (2000, p15). Coral cover at 3m depth was 6.5% made up with one-third *Acropora* sp. table corals and two-thirds submassive *Pocillopora* sp. Coral cover today is about half, with no table corals. Algae cover at that time was 12%, with coralline algae at one-third and microalgae at two-thirds. Today there are no coralline algae and 60% turf microalgae.

4.3.4 Reef Crest and Slope

Figure 4.3.55 re-displays the coordinates of the GPS positions taken along the outfall route for the proposed extension south of the end of the existing pipe.

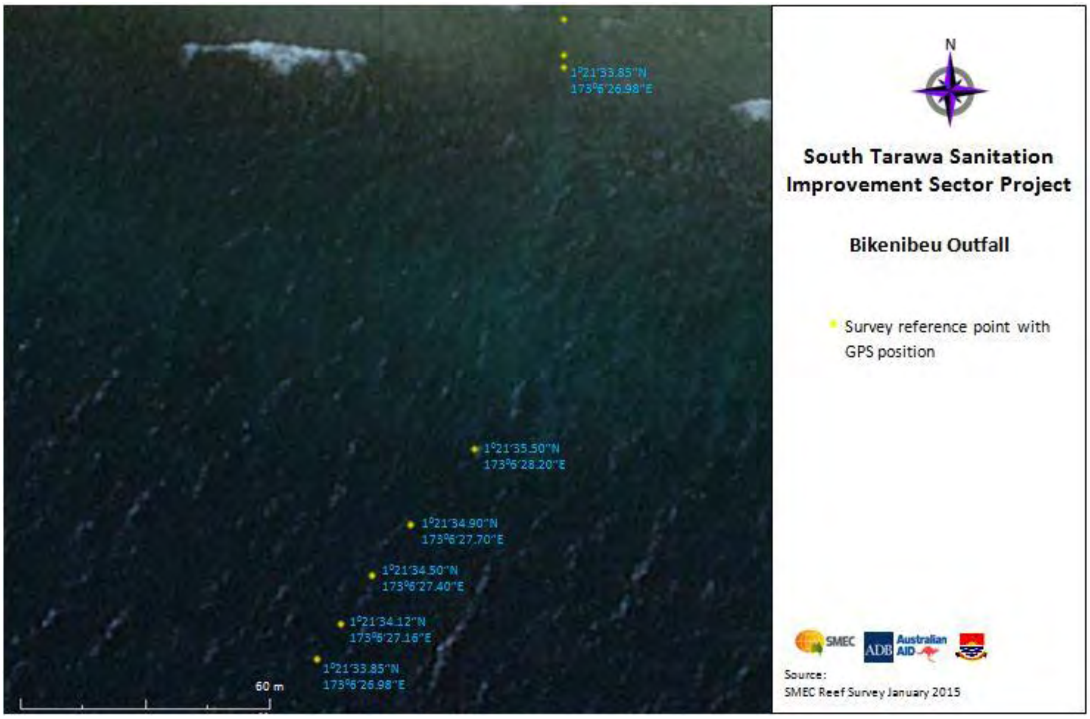


Fig. 4.3.55 GPS Position Coordinates of Proposed BikenibeuOutfall Route
(North reef flat positions not included)

Figure 4.3.56 re-displays the pipeline route that was derived from the GPS points.

Fig. 4.3.56 Existing Outfall Pipe and Proposed Extension at Bikenibeu
(note: reference depths not corrected for 0 datum)

The total distance from the vent to the deepest survey point 9 at 33m is 379m (figure 4.2.83). Compared with the subtidal reef flat, the reef crest and slope are narrower covering only a distance of 62m. This is 4m shorter than at Betio, and 35m shorter than at Bairiki. The reef crest at 40m wide however, is about twice the distance of the same stretch at Betio and Bairiki.

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)	depth (m)
Bikenibeu	reef crest	11	23.6	341.0	-12.18
Bikenibeu	reef slope	10	14.9	355.9	-24.46
Bikenibeu	reef slope	9.1	13.7	369.6	-27.86
Bikenibeu	reef slope	9	9.9	379.4	-32.75

Fig. 4.3.57 Reef Crest-Slope Chainage, Distance, and Depth

In this section refer to videos: *Bikenibeu 1 - N to S vid 4m (6m N of Pt14) to 36m (pt9), Bikenibeu 2 - S to N vid 33m (approx pt9) to 1m [disregard first 3min],* and *Bikenibeu 3 - 5m 360 deg EOP broken (pt14).*

The 24m of substrate between points 14 and 11 is debris and 60% coral cover at a slope of 15°, with higher coral cover on the upper crest than the lower crest. Coral is represented by a diversity of growth forms and genus types, although *P. rus* is dominant. There are about 5% cover of turf algae, 5% fleshy coralline algae, and 15% of the more desirable crustose coralline algae.

Figures 4.3.59 through 4.3.63 show the reef crest environment between points 14 and 11. They do not specify the proposed outfall route, which is to the right beyond figure 4.3.61. The figures emphasize that the upper reef crest has significantly high coral cover at over 80% with modest rugosity limiting the options of a viable route across the reef.

Fig. 4.3.58 Bikenibeu subtidal reef flat, crest, and slope

Fig. 4.3.59 Bikenibeu vicinity of point 14, anemone with Orangefin anemonefish - *Amphiprion chrysopterus* corrected depth 7.5m

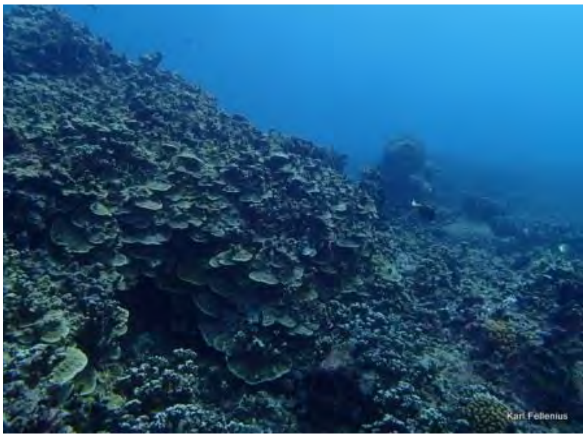


Fig. 4.3.60 From Bikenibeu vicinity of point 14, looking East, corrected depth 6.5m

Fig. 4.3.61 From Bikenibeu vicinity of point 14, looking South, route to the right beyond rise, corrected depth 6.5m

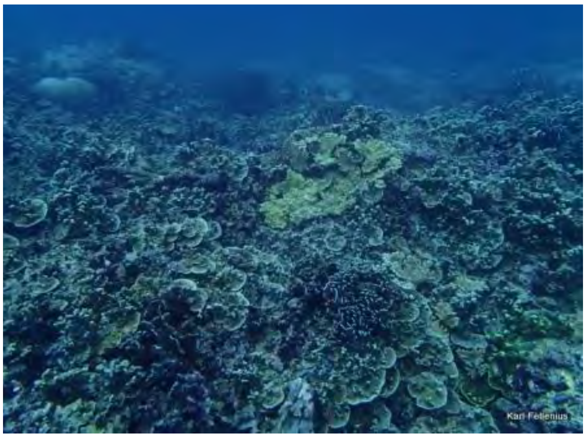


Fig. 4.3.62 From Bikenibeu vicinity of point 14, looking South, corrected depth 11.0m

Fig. 4.3.63 From Bikenibeu vicinity of point 14, looking West, Fire coral - *Millepora* sp., route in background, corrected depth 8.5m

Figure 4.3.64 re-displays the proposed route and the various features and obstructions found along the length of the proposed extension pipe.

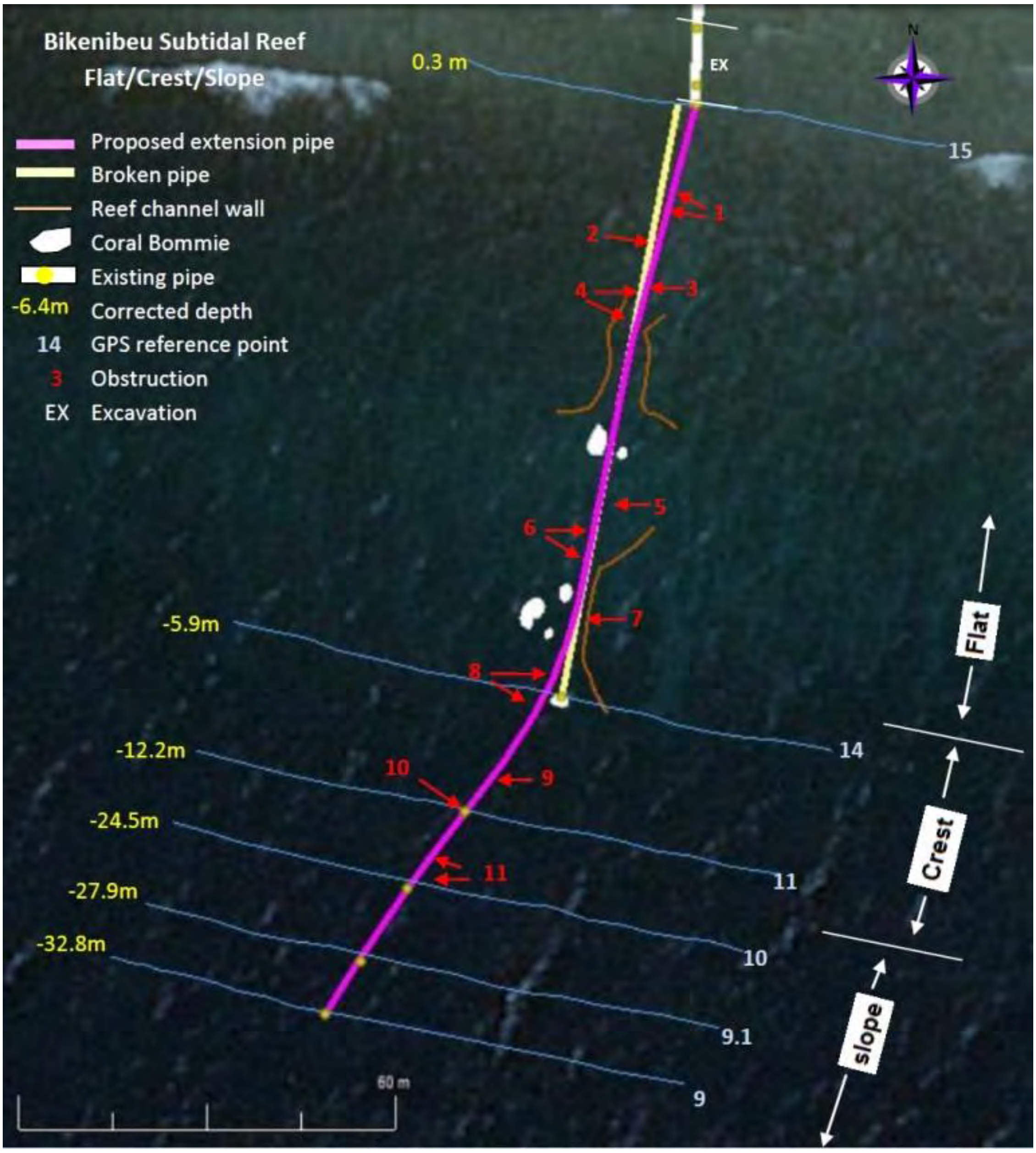


Fig. 4.3.64 Features and Obstructions along the Existing and Proposed Bikenibeu Outfall Route (digitized by SMEC)

Bikenibeu video 3 is a 360° view taken from 2m north of the end of the broken pipe at point 14. At exactly 0:12, 0:39, and 1:20 it shows a direction of 210° to be the outfall route across the reef crest. Bikenibeu video 1 from 0:14 to 0:35 shows the 8m stretch of concentrated coral along that direction that makes up obstruction 8 below. The 3m long sand and rubble patch from 0:22 to 0:26, combined with the lack of significant obstacles south of 0:35 are the reasons for the proposed route in this location. Note that video 1 from 0:26 to 0:35 veers left by 1m away from the proposed route.

<u>Obstruction 8</u>: Removal and partial relocation of coral 1.2m wide and 0.8m high along a 5m stretch (video capture fig. 4.3.65 and fig. 4.3.66, and reference from 0:14 to 0:35 in Bikenibeu video 1). Within the sand and rubble patch identified above there is a 0.3m edge of a coral bommie that also needs to be removed (video capture fig. 4.3.67 and fig. 4.3.68, and reference Bikenibeu video 1 at 0:22 and video 2 at 2:32). The affected corals are almost entirely *P. rus* with some *H. coerulea* and *Pocillopora* sp. Some additional 0.3m diameter solid rock and miscellaneous debris to be removed as well [dive team estimate 6hrs. at 6m depth]

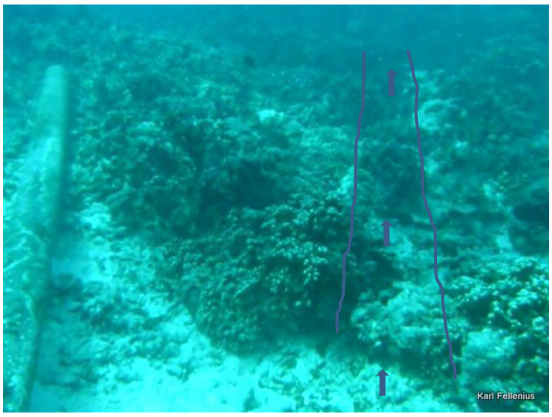


Fig. 4.3.65 From Bikenibeu 3m North of point 14, looking South, route along ⬆ corrected depth 5.5m

Fig. 4.3.66 From Bikenibeu 2m North of point 14, looking South, route along ⬆ corrected depth 5.6m

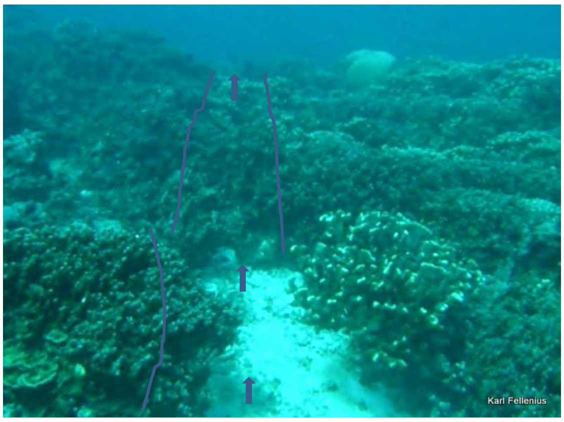


Fig. 4.3.67 From Bikenibeu 4m West of point 14, looking South, route along ⬆ corrected depth 5.8m

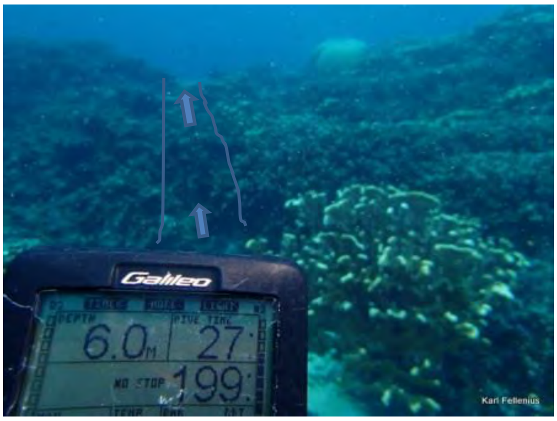


Fig. 4.3.68 From Bikenibeu 4m West of point 14, looking South, route along ⬆ corrected depth 5.8m

Fig. 4.3.69 From Bikenibeu 8m Southwest of point 14, looking South, route along ⬆ corrected depth 5.8m

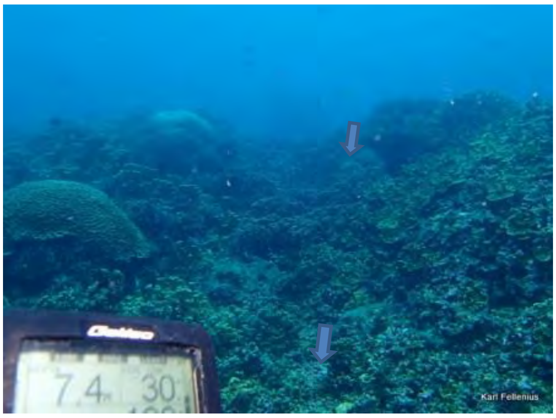


Fig. 4.3.70 From Bikenibeu 11m Southwest of point 14, looking North, route along ⬆ corrected depth 7.2m

Figures 4.3.69 and 4.3.70 are of the reef crest directly south of the obstruction (reference from 0:35 to 0:44 in Bikenibeu video 1). They show there to be no obstructions and that the outfall pipe can sit on top of the low relief reef, which is less than 20% coral cover dominated by *P. rus*.

Obstruction 9: Removal and relocation of up to half a dozen mostly *Pocillopora* sp. coral colonies 0.2-0.4m diameter along a 10m stretch ending 6m north of point 11 (fig. 4.3.72 and reference from 0:54 to 1:14 in Bikenibeu video 1). [dive team estimate 2hrs. at 8m depth]

Fig. 4.3.71 Bikenibeu subtidal reef flat, crest, and slope


Fig. 4.3.72 From Bikenibeu 6m North of point 11, corrected depth 9.0m

The 15m of substrate between points 11 and 10 is debris and 15% coral cover at a slope of 40°. Coral cover is mainly massive *P. sinuosa*, some massive *Lobophyllia* sp. and submassive *P. rus* and *H. coerulea*. Minor *Pocillopora* sp. and encrusting *Porites* sp. are also present but no *Acropora* sp. The debris is mainly dead and scattered *P. sinuosa* colonies. There are about 5% turf algae, 5% fleshy coralline algae, 20% of the more desirable crustose coralline algae. The upper slope at point 11 is shown in figures 4.3.73 and 4.3.74 (video reference from 2:02 to 3:02 in Bikenibeu video 1).


Fig. 4.3.73 At Bikenibeu point 11, looking West, *Millepora* - *Heliopora* - *Pocillopora* sp., corrected depth 12.2m

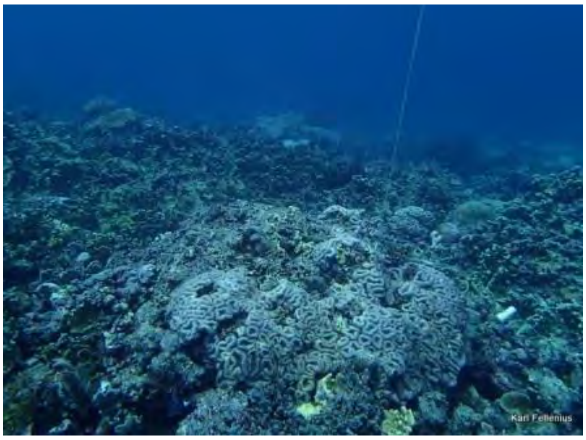


Fig. 4.3.74 At Bikenibeu point 11, looking South, *Lobophyllia* sp., corrected depth 12.2m

Obstruction 10: Levelling of debris and possible removal and relocation of small coral colonies along a 4m stretch ending at point 11 (video capture fig. 4.3.75 and fig. 4.3.76, reference from 1:19 to 1:27 in Bikenibeu video 1). [dive team estimate 1hr. at 12m depth]

Fig. 4.3.75 At Bikenibeu 2m North of point 11, looking South, corrected depth 12.0m

Fig. 4.3.76 At Bikenibeu point 11, looking North, corrected depth 12.2m

From a few meters south of point 11 to just north of point 10 the *P. sinuosa* is relatively concentrated. The relief is not as high as it is on the upper slope at Bairiki, and the outfall pipe can likely be placed on top of the live bubble coral field. However, it is recommended that some effort be placed on relocation of the affected colonies.

<u>Obstruction 11</u>: The middle slope north of point 10 has numerous patches of debris and up to a dozen 0.8-1.2m diameter *P. sinuosa* colonies that should be relocated. (figs. 4.3.77 and 4.3.78, reference from 2:23 to 2:55 in Bikenibeu video 1). [dive team estimate 4.5hrs. at 20m depth]

Fig. 4.3.77 From Bikenibeu 7m South of point 11, looking South, corrected depth 18.5m

Fig. 4.3.78 At Bikenibeu 12 m South of point 11, looking South, corrected depth 22.5m

The 14m of substrate between points 10 and 9.1 is largely sand, silt, rubble, and debris at a slope of 14°. Coral cover is reduced to 5%. Blue-green, turf, and fleshy coralline algae are present at 5% each, although there is still 15% crustose coralline algae. The upper and middle slopes are shown in figures 4.3.79 and 4.3.80 (video reference from 2:57 to 3:19 in Bikenibeu video 1).

Fig. 4.3.79 From Bikenibeu point 10, looking South, corrected depth 24.5m

Fig. 4.3.80 From Bikenibeu point 9.1, looking South, corrected depth 27.9m

The 10m of substrate between points 9.1 and 9 is debris and 80% coral cover at a slope of 26°. Coral cover is almost exclusively massive *P. sinuosa*. The debris is mainly dead and scattered *P. sinuosa* colonies. Crustose coralline algae is back up to 20%. The lower slope at point 9 is shown in figures 4.3.81 and 4.3.82 (video reference from 3:19 to 3:50 in Bikenibeu video 1).

Fig. 4.3.81 From Bikenibeu 3m South of point 9.1, looking South, corrected depth 29.0m

Fig. 4.3.82 From Bikenibeu 3m North of point 9, looking South, corrected depth 31.5m

Beyond point 9 below a depth of 33m it appears that coral cover of *P. sinuosa* is once again reduced, but only to 40%.

Note that terminating the outfall 2m south of point 10 (reference 3:00 in video 1) is warranted because it achieves a 25m depth (corrected), and keeps the diffuser and the immediate area of discharge away from the *P. sinuosa* that is both shallower and deeper but not in the debris field in the middle. If the diffuser is 10m long and ends at this precise location, it would be 10m north of the deeper *P sinuosa*. This is not significant, but it is better than terminating it in the deeper coral patch, which would necessitate further obstruction work, damage coral from both removal of obstructions and from more concentrated effluent plume discharge, and therefore not yield the perceived benefits that a deeper outfall might suggest.

Depth (m)	Time (hours)
1-9	23.5
10-14	1.0
15-19	0.0
20-24	4.5
25-29	0.0
30-34	0.0
Total	29.0

Fig. 4.3.83 Bikenibeu Obstruction Time Underwater

Figure 4.3.83 lists that the total estimated underwater time to rectify the obstructions noted for Bairiki is 29 hours. At 5 hours underwater per day +10% contingency it totals 6.5 days of diving. Dives need to be from deep to shallow so the first few days would focus on the reef slope in the morning and the reef flat in the afternoons. Subsequent days would focus on the reef crest in the mornings and reef flat in the afternoons. The last days would be only on the reef flat. This does not include the time needed for marking the alignment of the route with stakes and lines (est. 2d), guiding the placement of the pipeline (est. 1d) or the time needed for adjusting the CABs (est. 1.5d). With 10% contingency it totals 11.5 days of diving.

With 13 days at Betio, 16.5 days at Bairiki, and 11.5 days at Bikenibeu the total underwater time needed for rectifying obstructions and laying the new outfall pipes is estimated at 41 days. At 6 days of diving per week, this requires the work to be done over 7 weeks. Alternatively it can be done in stages, with 2 weeks at Betio, 3 weeks at Bairiki, and 2 weeks at Bikenibeu.

Figure 4.3.84 and 4.3.85 give the average percent cover for substrate and benthic categories on the reef crest and reef slope, respectively. Combined they have significantly less undesirable algae than on the subtidal reef flat and the coral cover is almost 10 fold at about 50%. In contrast with the reef crest at Betio, Bikenibeu has 5 fold more coral, some crustose coralline algae, significantly less silt and turf algae, and almost no rubble or debris. In contrast with Bairiki, it has twice the coral cover, much less turf algae, but no table corals.

Total Substrate		Stony Coral Growth Form		Algae		Invertebrates	
% cover		% cover within *		% cover on substrate**			Incidence
mud	0	massive	5	crustose coralline algae	15	sponge	0
silt	2	submassive	85	*Halimeda* sp.	0	anemone	0
sand	2	encrusting	10	*Caulerpa* sp.	0	ascidian	0
rubble	2	table	0	**algae+silt+sand+coral = 100	15	gorgonian soft coral	0
debris	2	digitate	0			sea cucumber	0
rock	5	branching	0			sea urchin	0
dead coral formation	0	foliose	0	fleshy coralline algae	5	giant clam	0
dead coral debris	1	mushroom	0	turf algae (microalgae)	5	oyster	0
live stony coral	60*	fire	5	other macroalgae	0	COTs sea star	0
zoanthid corallimorph	1			blue-green algae***	0	other sea star	0
soft coral	0				10		
	100		100	***filamentous & mat cyanobacteria			

Fig. 4.3.84 Bikenibeu Reef Crest Substrate and Benthic Categories

The Bikenibeu reef slope by comparison has the same type of massive coral as Betio and Bairiki, but with significantly higher cover. In contrast with Bairiki, no recent COTs predation on *P. sinuosa* was found and therefore there was minimal dead coral formations and debris. Furthermore, it has no blue-green algae, minimal turf algae, and less fleshy coralline algae than both Betio and Bairiki. The reason for this is a relatively healthy supply of crustose coralline algae, which is absent at the other two locations.

Total Substrate		Stony Coral Growth Form		Algae		Invertebrates	
% cover		% cover within *		% cover on substrate**			Incidence
mud	0	massive	80	crustose coralline algae	20	sponge	4
silt	10	submassive	10	*Halimeda* sp.	0	anemone	0
sand	15	encrusting	5	*Caulerpa* sp.	0	ascidian	0
rubble	10	table	5	**algae+silt+sand+coral = 100	20	gorgonian soft coral	0
debris	10	digitate	0			sea cucumber	0
rock	5	branching	0			sea urchin	0
dead coral formation	2	foliose	0	fleshy coralline algae	5	giant clam	0
dead coral debris	2	mushroom	0	turf algae (microalgae)	3	oyster	0
live stony coral	45*	fire	0	other macroalgae	0	COTs sea star	0
zoanthid corallimorph	1			blue-green algae***	2	other sea star	0
soft coral	0				10		
	100		100	***filamentous & mat cyanobacteria			

Fig. 4.3.85 Bikenibeu Reef Slope Substrate and Benthic Categories

Lovell (2000, p16) reported coral cover at 10m depth at that time to be 28% with *Acropora* sp. alone at over 5%. While coral cover today is double that, it has little diversity across species and no *Acropora* sp. A 2011 marine survey at the Temaiku subdivision in Bikenibeu put the coral cover at 58% at 10m and 37% at 25m depth (KIR PWU 2013, BEIA p26).

4.3.4.1 Transect 1 West-East

Ten photo quadrats are shown along a 100m west-east transect with the mid-point at 50m on the proposed outfall route at a corrected depth of 24m (figs. 4.3.86 to 4.3.95). Five quadrats are taken west of the mid-point, and five are taken east. Depths along the transect direction vary due west and east of the mid-point. Each quadrat ideally covers 1m^2 of substrate at 10m distance intervals.

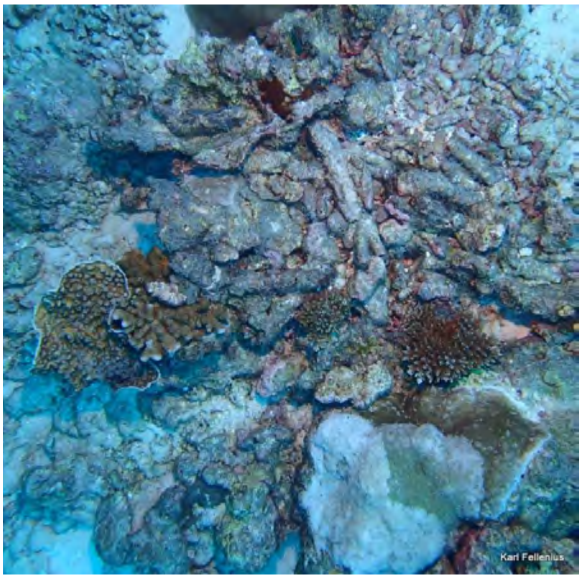


Fig. 4.3.86 transect 1 - 45m West of route, 24m depth

Fig. 4.3.87 transect 1 - 35m West of route, 24m depth

Fig. 4.3.88 transect 1 - 25m West of route, 24m depth

Fig. 4.3.89 transect 1 - 15m West of route, 24m depth

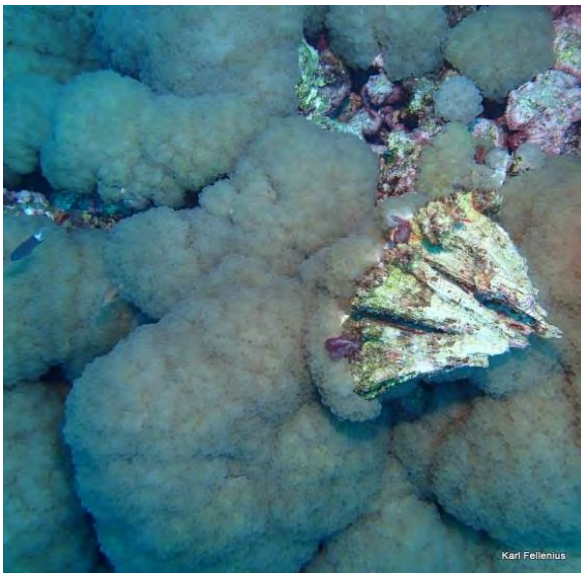


Fig. 4.3.90 transect 1 - 5m West of route, 24m depth

Fig. 4.3.91 transect 1 - 5m East of route, 24m depth

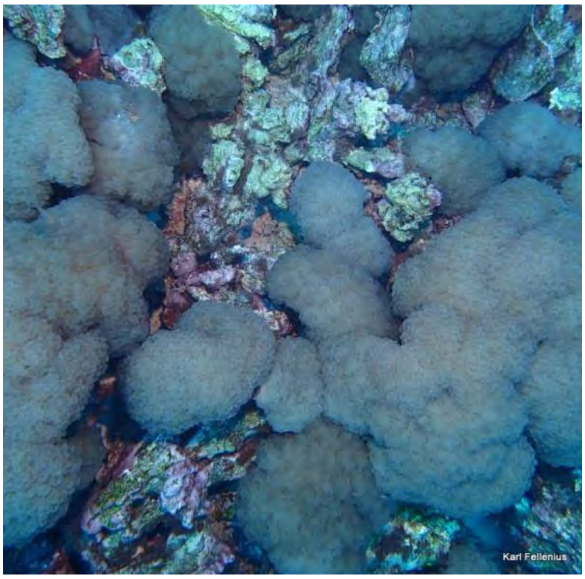


Fig. 4.3.92 transect 1 - 15m East of route, 24m depth

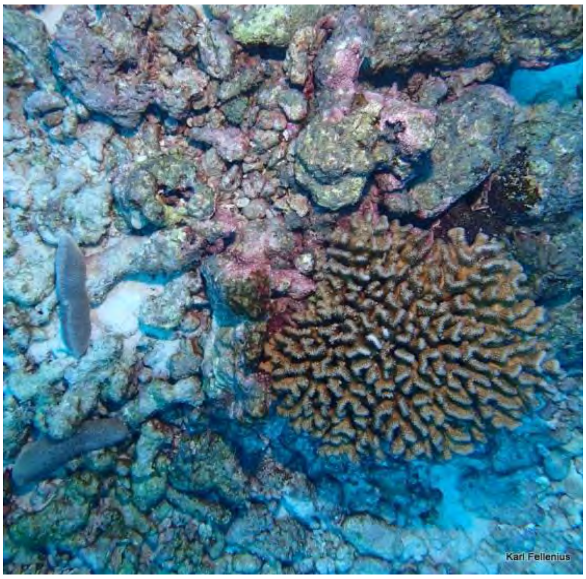


Fig. 4.3.93 transect 1 - 25m East of route, 24m depth

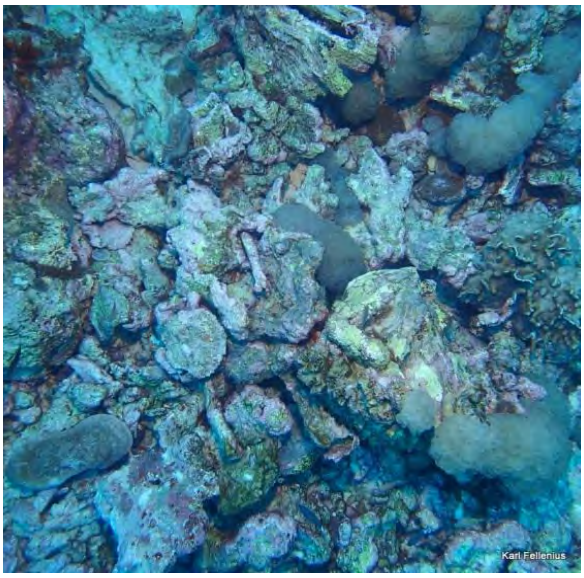


Fig. 4.3.94 transect 1 - 35m East of route, 24m depth

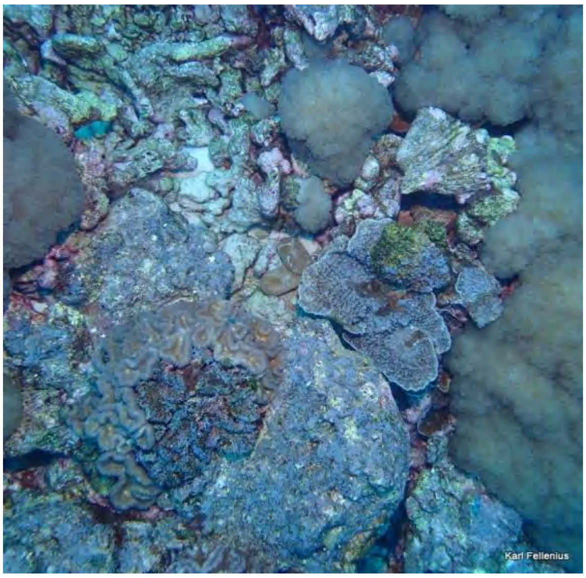


Fig. 4.3.95 transect 1 - 45m East of route, 24m depth

Figure 4.3.96 presents the analysis for each photo quadrat in transect 1 for a number of marine life and substrate variables on a degradation scale of 1-5, where 5 is highly degraded. Transect 2 and 3 are included, although accompanying photos are in the next section.

Direction	W	Transect 1								E	S	Transect 2							N	S	Transect 3					N
Quadrat	W45	W35	W25	W15	W5	E5	E15	E25	E35	E45	S25	S15	S5	N5	N15	N25	N35	N45	3-35	3-30	3-25	3-20	3-15	3-10	3-5
Depth (m)	17	18	18.5	21.5	23.5	24.5	24.5	24	23.5	23	35	31	25	23.5	18.5	14.5	10.5	5.5	35	30	25	20	15	10	5
STONY CORAL																									
Acropora plumosa													2												
Acropora valida	1																								
Acropora sp.	5																								
Blastmussa wellsi																									
Favia sp.																									
Fungia sp.				1			2	1	2	1															
Halomitra pileus						1																			
Heliopora coerulea				1		1			2						1	1		3							
Lepastrea sp.																									
Leptoseris sp.															3	2									
Lobophyllia sp.		3						4	5	3													2	2	
Montipora sp.	5			4												4		2							
Oxypora sp.	1									4															
Pavona sp.			4																						
Plerogyra sinuosa		1	1	1	1	1	1		2	1			1		1	1			1	3					
Pocillopora sp.	1							1							1			1				1			4
Porites rus															1	1		1				2	1	1	1
Porites sp.				2			4									3									
Psammocora sp.							4																		
Turbinaria sp.																									
ALGAE																									
crustose coralline algae	1	1	1	1	1	1	1	1	1	1	1	2			1	1	1	1	1	1	2	1	2	2	1
Halimeda sp.		3																							
Caulerpa sp.																									
fleshy coralline algae	2	2	2	2	2	2	2	2	2	2	2	2			2	2	2	2	2	2	2	2	2	2	2
turf algae (microalgae)	2				2		2	2				3							2	2	2	2		2	
Dictyota sp. macroalgae				3		2	2	2		4					2		2	2							
other macroalgae																									
blue-green algae					4							5		5						4	4	4			
INVERTEBRATES																									
Palythoa sp. (zoanthid)				3				4				4		5							2			4	
other zooanthids						3																			
sponge	3																		3	2		2			
anemone																									
ascidian																									
crinoid															1			1							
leather soft corals																									
gorgonian soft coral																									
sea cucumber																									
sea urchin																									
giant clam																									
oyster																									
COTs sea star																									
other sea star																									
SUBSTRATE																									
mud																									
silt								2				2		5					2		3				
sand	2			1				1				2		3					2	2	2	1			
rubble	2		1	1	1	1		2	1	1		3		4					3	3	3				
debris					2	2	2		2		1	2							2	2	3				
rock	2		1	3				3		4					1		1	1		4		1	2		2
dead coral formation		2																							
dead coral debris									2	2										2				2	
DISEASED CORAL																									
Bleached Coral	4												2												
Other Disease																									
UNKNOWNS																									
Unknowns																									

Fig. 4.3.96 Bikenibeu Transect 1-3 Substrate and Benthic Degradation

Definition of degraded state:

1 = least	near pristine	notes:	-colony with some live coral is 2-4
2 =	slightly degraded		-smaller or isolated coral colonies for the species are vulnerable, thus 2-3
3 =	moderately degraded		-coral colonies in proximity to COTs are vulnerable, thus 2-3
4 =	very degraded		-silt ranges from 2-5 depending on mild to heavy
5 = most	totally degraded		-crustose coralline algae are 1-2, fleshy coralline algae is 2-3
			-*Halimeda* sp. is 1-3, *Caulerpa* sp. is 2-3, other macroalgae 2-5
			-turf algae is 2-5, blue-green algae are 4-5, bleached coral 3-5
			-substrates are 1-2 if mild silt & coralline algae, 3-5 if heavy silt & turf or blue-greens
			-Zooanthids are 2-5 depending on colony size and condition, and invertebrates are 1-3

4.3.4.2 Transect 2 South-North by Distance

Eight photo quadrats are shown along a 70m south-north transect with the "mid-point" (MP) at 25m north of point 9 on the proposed outfall route at a corrected depth of 24m (figs. 4.3.97 to 4.3.104). The transect length is less than 100m because no quadrats were taken deeper than the 35m maximum diving depth of the survey (2m deeper than point 9). It ends at 6m depth on the subtidal reef flat north of point 14 a full 45m north of the "mid-point." Three quadrats are taken south of the mid-point, and five are taken north. Each quadrat ideally covers 1m^2 of substrate at 10m distance intervals.

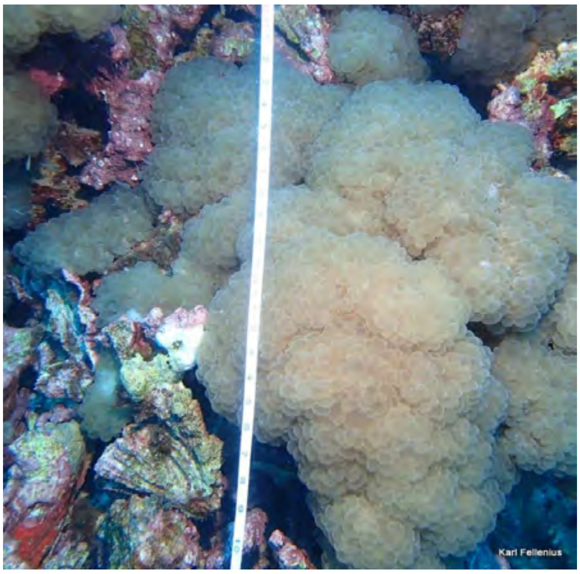


Fig. 4.3.97 transect 2 - 25m South of MP, 35m depth

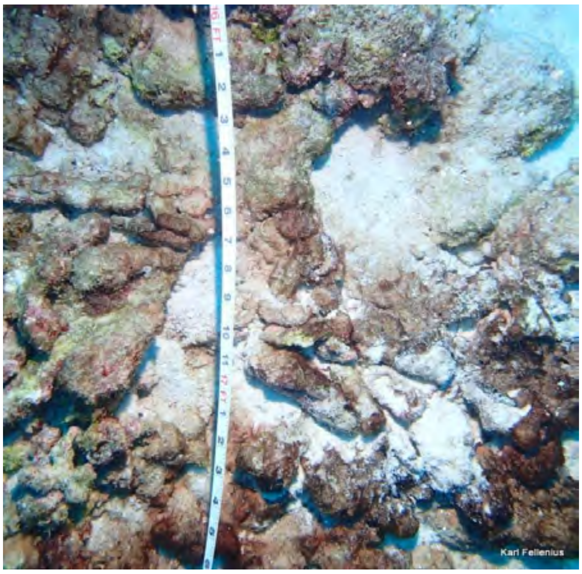


Fig. 4.3.98 transect 2 - 15m South of MP, 29m depth

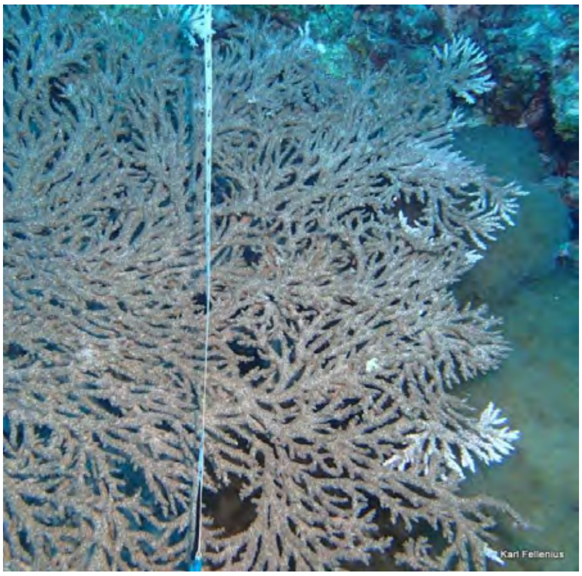


Fig. 4.3.99 transect 2 - 5m South of MP, 26m depth

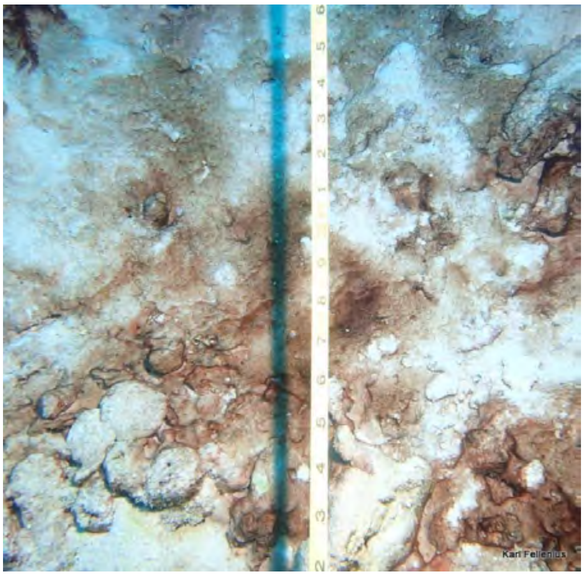


Fig. 4.3.100 transect 2 - 5m North of MP, 22m depth

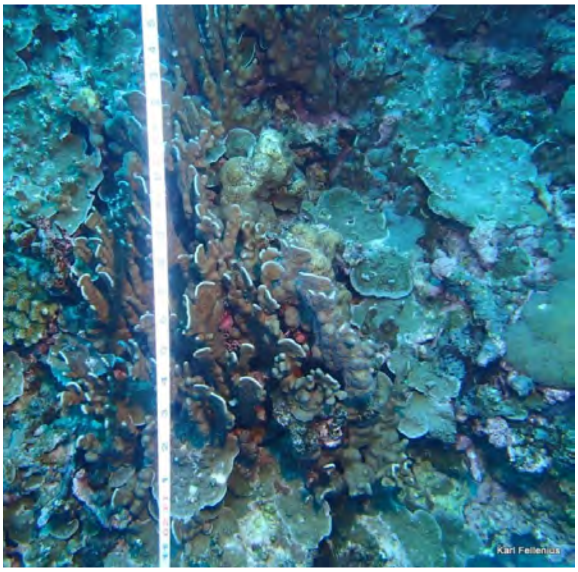


Fig. 4.3.101 transect 2 - 15m North of MP, 12m depth

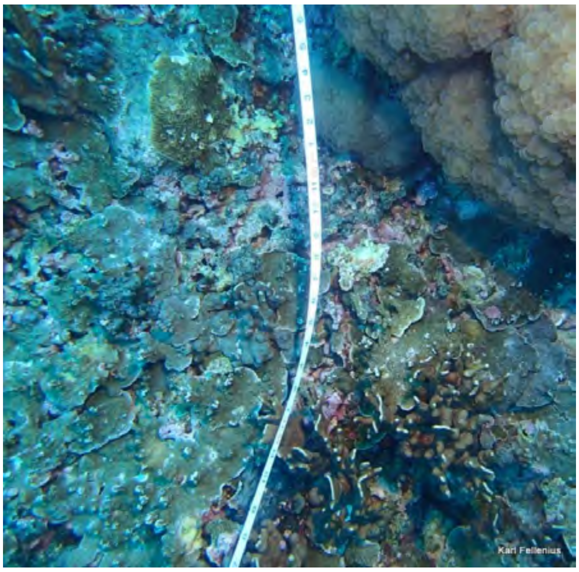


Fig. 4.3.102 transect 2 - 25m North of MP, 10m depth

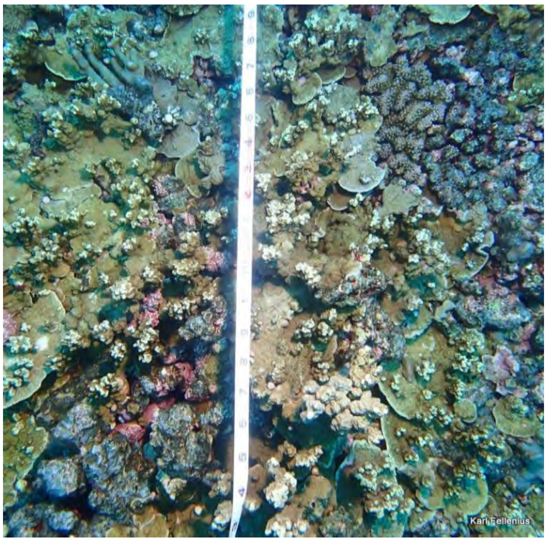


Fig. 4.3.103 transect 2 - 35m North of MP, 7m depth

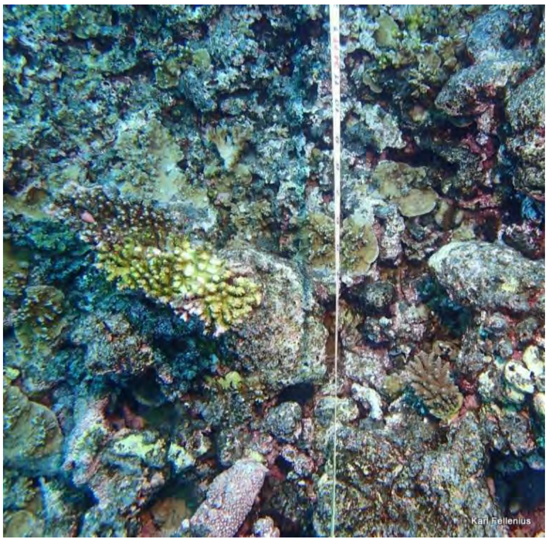


Fig. 4.3.104 transect 2 - 45m North of MP, 6m depth

Figure 4.3.105 re-displays the analysis for each photo quadrat.

Direction	W	Transect 1								E	S	Transect 2						N	S	Transect 3					N
Quadrat	W45	W35	W25	W15	W5	E5	E15	E25	E35	E45	S25	S15	S5	N5	N15	N25	N35	N45	3-35	3-30	3-25	3-20	3-15	3-10	3-5
Depth (m)	17	18	18.5	21.5	23.5	24.5	24.5	24	23.5	23	35	31	25	23.5	18.5	14.5	10.5	5.5	35	30	25	20	15	10	5
STONY CORAL																									
Acropora plumosa													2												
Acropora valida	1																								
Acropora sp.	5																								
Blastmussa wellsi																									
Favia sp.																									
Fungia sp.				1			2	1	2	1															
Halomitra pileus						1																			
Heliopora coerulea				1		1			2						1	1		3							
Lepastrea sp.																									
Leptoseris sp.															3	2									
Lobophyllia sp.		3						4	5	3													2	2	
Montipora sp.	5			4												4		2							
Oxypora sp.	1									4															
Pavona sp.			4																						
Plerogyra sinuosa		1	1	1	1	1	1		2	1			1		1	1			1	3					
Pocillopora sp.	1							1							1			1				1			4
Porites rus															1	1		1				2	1	1	1
Porites sp.				2			4									3									
Psammocora sp.							4																		
Turbinaria sp.																									
ALGAE																									
crustose coralline algae	1	1	1	1	1	1	1	1	1	1	1	2			1	1	1	1	1	1	2	1	2	2	1
Halimeda sp.		3																							
Caulerpa sp.																									
fleshy coralline algae	2	2	2	2	2	2	2	2	2	2	2	2			2	2	2	2	2	2	2	2	2	2	2
turf algae (microalgae)	2				2		2	2				3							2	2	2	2		2	
Dictyota sp. macroalgae				3		2	2	2		4					2		2	2							
other macroalgae																									
blue-green algae					4							5		5						4	4	4			
INVERTEBRATES																									
Palythoa sp. (zoanthid)				3				4				4		5							2			4	
other zooanthids						3																			
sponge	3																		3	2		2			
anemone																									
ascidian																									
crinoid															1			1							
leather soft corals																									
gorgonian soft coral																									
sea cucumber																									
sea urchin																									
giant clam																									
oyster																									
COTs sea star																									
other sea star																									
SUBSTRATE																									
mud																									
silt								2				2		5					2		3				
sand	2			1				1				2		3					2	2	2	1			
rubble	2		1	1	1	1		2	1	1		3		4					3	3	3				
debris					2	2	2		2		1	2							2	2	3				
rock	2		1	3				3		4					1		1	1		4		1	2		2
dead coral formation		2																							
dead coral debris									2	2										2				2	
DISEASED CORAL																									
Bleached Coral	4												2												
Other Disease																									
UNKNOWNS																									
Unknowns																									

Fig. 4.3.105 Bikenibeu Transect 1-3 Substrate and Benthic Degradation

Definition of degraded state:

1 = least	near pristine	notes:	-colony with some live coral is 2-4
2 =	slightly degraded		-smaller or isolated coral colonies for the species are vulnerable, thus 2-3
3 =	moderately degraded		-coral colonies in proximity to COTs are vulnerable, thus 2-3
4 =	very degraded		-silt ranges from 2-5 depending on mild to heavy
5 = most	totally degraded		-crustose coralline algae are 1-2, fleshy coralline algae is 2-3
			-*Halimeda* sp. is 1-3, *Caulerpa* sp. is 2-3, other macroalgae 2-5
			-turf algae is 2-5, blue-green algae are 4-5, bleached coral 3-5
			-substrates are 1-2 if mild silt & coralline algae, 3-5 if heavy silt & turf or blue-greens
			-Zooanthids are 2-5 depending on colony size and condition, and invertebrates are 1-3

4.3.4.3 Transect 3 South-North by Depth

Seven photo quadrats are shown, one every 5m depth from a non-corrected depth of 35m to 5m alternating left and right along the proposed outfall route (figs. 4.3.106 to 4.3.112). Each quadrat covers $1m^2$ of substrate. The four deepest quadrats are along the reef slope. The 15m quadrat is just seaward of the reef crest, and the 10m quadrat is on the reef crest. Finally, the 5m quadrat is just north of point 14 on the upper reef crest.

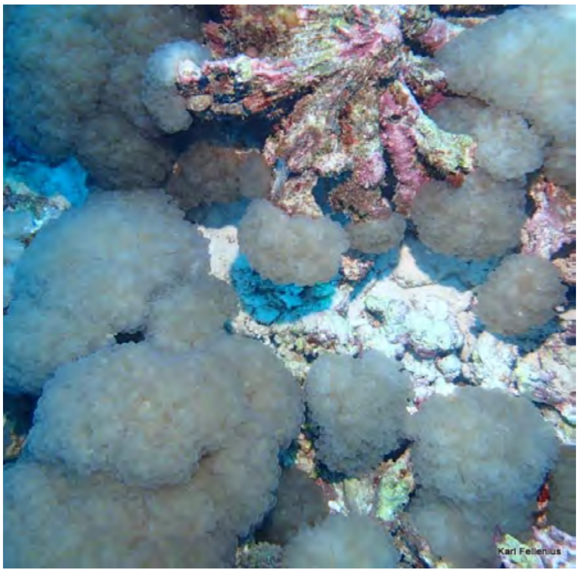


Fig. 4.3.106 transect 3 - 35m depth, South of point 9

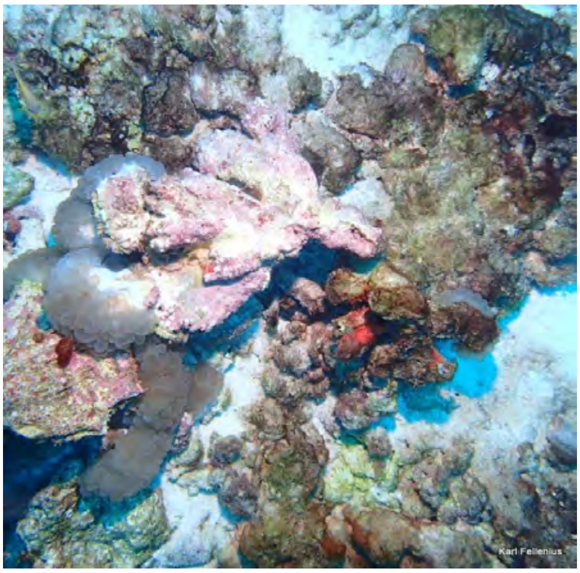


Fig. 4.3.107 transect 3 - 30m depth, South of point 9.1

Fig. 4.3.108 transect 3 - 25m depth, South of point 10

Fig. 4.3.109 transect 3 - 20m depth, North of point 10

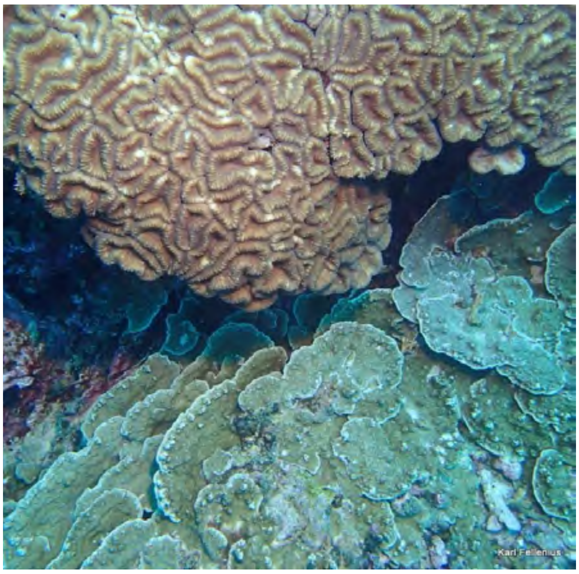


Fig. 4.3.110 transect 3 - 15m depth, South of point 11

Fig. 4.3.111 transect 3 - 10m depth, North of point 11

Fig. 4.3.112 transect 3 - 5m depth, North of point 14

Fig. 4.3.113 Bikenibei reef flat, crest, and slope

Figure 4.3.114 re-displays the analysis for each photo quadrat for a number of marine life and substrate variables on a degradation scale of 1-5, where 5 is highly degraded.

Direction	W	Transect 1								E	S	Transect 2							N	S	Transect 3					N
Quadrat	W45	W35	W25	W15	W5	E5	E15	E25	E35	E45	S25	S15	S5	N5	N15	N25	N35	N45	3-35	3-30	3-25	3-20	3-15	3-10	3-5
Depth (m)	17	18	18.5	21.5	23.5	24.5	24.5	24	23.5	23	35	31	25	23.5	18.5	14.5	10.5	5.5	35	30	25	20	15	10	5
STONY CORAL																									
Acropora plumosa													2												
Acropora valida	1																								
Acropora sp.	5																								
Blastmussa wellsi																									
Favia sp.																									
Fungia sp.				1			2	1	2	1															
Halomitra pileus						1																			
Heliopora coerulea				1		1			2						1	1		3							
Lepastrea sp.																									
Leptoseris sp.															3	2									
Lobophyllia sp.		3						4	5	3													2	2	
Montipora sp.	5			4												4		2							
Oxypora sp.	1									4															
Pavona sp.			4																						
Plerogyra sinuosa		1	1	1	1	1	1		2	1			1		1	1			1	3					
Pocillopora sp.	1							1							1			1				1			4
Porites rus															1	1		1				2	1	1	1
Porites sp.				2			4									3									
Psammocora sp.							4																		
Turbinaria sp.																									
ALGAE																									
crustose coralline algae	1	1	1	1	1	1	1	1	1	1	1	2			1	1	1	1	1	1	2	1	2	2	1
Halimeda sp.		3																							
Caulerpa sp.																									
fleshy coralline algae	2	2	2	2	2	2	2	2	2	2	2	2			2	2	2	2	2	2	2	2	2	2	2
turf algae (microalgae)	2				2		2	2				3							2	2	2	2		2	
Dictyota sp. macroalgae				3		2	2	2		4					2		2	2							
other macroalgae																									
blue-green algae					4							5		5						4	4	4			
INVERTEBRATES																									
Palythoa sp. (zoanthid)				3				4				4		5							2			4	
other zooanthids						3																			
sponge	3																		3	2		2			
anemone																									
ascidian																									
crinoid															1			1							
leather soft corals																									
gorgonian soft coral																									
sea cucumber																									
sea urchin																									
giant clam																									
oyster																									
COTs sea star																									
other sea star																									
SUBSTRATE																									
mud																									
silt								2				2		5					2		3				
sand	2			1				1				2		3					2	2	2	1			
rubble	2		1	1	1	1		2	1	1		3		4					3	3	3				
debris					2	2	2		2		1	2							2	2	3				
rock	2		1	3				3		4					1		1	1		4		1	2		2
dead coral formation		2																							
dead coral debris									2	2										2				2	
DISEASED CORAL																									
Bleached Coral	4												2												
Other Disease																									
UNKNOWNS																									
Unknowns																									

Fig. 4.3.114 Bikenibeu Transect 1-3 Substrate and Benthic Degradation

Definition of degraded state:

1 = least	near pristine	notes:	-colony with some live coral is 2-4
2 =	slightly degraded		-smaller or isolated coral colonies for the species are vulnerable, thus 2-3
3 =	moderately degraded		-coral colonies in proximity to COTs are vulnerable, thus 2-3
4 =	very degraded		-silt ranges from 2-5 depending on mild to heavy
5 = most	totally degraded		-crustose coralline algae are 1-2, fleshy coralline algae is 2-3
			-*Halimeda* sp. is 1-3, *Caulerpa* sp. is 2-3, other macroalgae 2-5
			-turf algae is 2-5, blue-green algae are 4-5, bleached coral 3-5
			-substrates are 1-2 if mild silt & coralline algae, 3-5 if heavy silt & turf or blue-greens
			-Zooanthids are 2-5 depending on colony size and condition, and invertebrates are 1-3

4.4 Coastal Processes

Coral reef islands are naturally dynamic features, with its shorelines moving as a result of changes to the physical and biological environment. Reef islands are made up of sediment that is generated by the breakdown of living material on the adjacent reef. Coastal processes are physical and biological mechanisms that operate along a coastline, bringing about various combinations of sediment transport, erosion, and deposition. Human use of South Tarawa requires space and produces waste, which affects these natural processes and changes the location and relative proportions of erosion and accretion that would otherwise be present if it was an unpopulated area. The incremental contribution that the proposed replacement or rehabilitation of the sewage outfall infrastructure in South Tarawa would have on coastal processes is the focus of this section. Physical and biological processes are described and discussed in the context of the status quo situation, impacts during construction, and impacts post-construction (fig. 4.4.1).

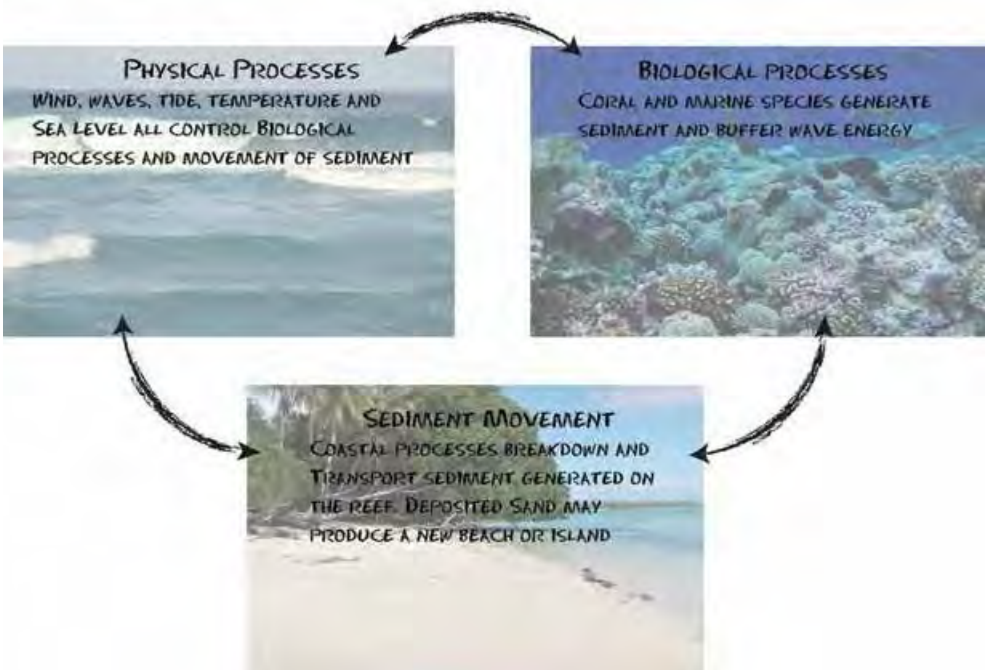


Fig. 4.4.1 Coastal Processes on Coral Atolls
(from Ford 2013, p2)

4.4.1 Physical

Some of the physical coastal processes include wind, waves, currents, tides, temperature, and sea level. They continually drive the sediment produced via biological processes and result in sediment movement that builds and erodes islands. Marine deposition on geological timescales and terrestrial deposition from episodic flooding are the overriding large-scale processes that determine where sediment accumulates over time. Tides allow higher waves to reach the island at high tide. Island morphology shows that the highest elevation of an atoll island is on the ocean side berm (ridge), which is made up of coarse coral sediment and larger shingles (fig. 4.4.2). Lagoon shorelines are exposed to smaller waves, resulting in smaller berms made up of fine sediment.

Fig. 4.4.2 Berm-building on Coral Atolls
(from Ford 2013, p4)

The proposed replacement or rehabilitation of the outfalls on the ocean side of South Tarawa will not affect any of the physical processes described because they are too small to act as a barrier. Works however, need to take place under relatively calm conditions so that additional trenching before infilling does not provide an artificial conduit for loss of sand from the beach.

4.4.2 Biological

The shells and skeletons of many reef plants and animal are calcium carbonate and when this is broken down it forms sediment, rich in nutrients. Reef structure provides the greatest control on the South Tarawa shoreline. This is because reef width and elevation combined with its coral rugosity determine how much wave energy reaches the shoreline. The tropical coral reef crest in particular is responsible for an average of 86% of the attenuation of the wave energy as it approaches the shoreline (Ferrario *et al*. 2014, p4). Under stable sea level conditions, a healthy coral reef will continue to generate sediment that may be added to the island. Conversely, an unhealthy reef may not be able to sustain a continuous supply of sediment. Notwithstanding the impacts of coral bleaching and acidification, a healthy reef may also be able to grow upwards as sea level rises, contributing to adaptation and resilience to the effects of climate change (Ford 2013, p2).

As described in the marine life assessment sections of this report, the biological processes on the reef flat, crest, and slope at all three outfalls are significantly degraded due to the developed shorelines and nearshore herbivore fishing pressure in South Tarawa. Therefore, physical processes are likely more eroding rather than depositing sediment from biological processes over time. Coastal protection services from the ecosystem are slowly diminishing via bioerosion. Nutrient loading from surface run-off and sewage discharge is the primary local point source cause for the reduced ability of the reef to calcify as it becomes more algae-dominated than coral. Betio however, has the lowest risk of coastal protection loss because it has a wider reef flat than the other two outfall areas.

With respect to the proposed replacement or rehabilitation of the outfalls, the works will improve the biological process of reef-building. The proposed 30m discharge will change the poor status quo discharge in the shallows and reduce the nutrient load on the more productive portions of the reef. The sewage will be pumped further away on the lower slope where the effects on the reef will be minimal by comparison. The works however, need to take place under relatively calm conditions so that additional sediment produced during excavation does not adversely affect existing coral.

5 Recommendations

The detailed recommendations for the close visual inspection and marine life surveys are contained within the obstructions descriptions for each outfall. The marine life transect analysis gave a detailed snapshot of degradation, which was consistent with those recommendations. This section only summarizes the number and type of obstructions in the context of overall marine life conditions, but does not repeat what is already in the text of the report. It does however, re-state the recommended outfall diffuser depths and locations.

5.1 Betio Outfall

There are several ecological concerns and recommendations.

5.1.1 Ecological Concerns

Betio has heavy sedimentation, low coral, and significant rubble and debris. Even with the extension of the outfall pipe the area will take a long time to produce the conditions needed for adequate coral growth to support even a modest coral reef ecosystem.

5.1.2 Recommendations

There is significant excavation needed in the shallow reef flat where the extended trench meets the proposed route. The reason is due to there being too many obstructions along the existing route for it to be a viable option. The proposed route to the west of the existing route goes through a spur-and-groove channel. There are 25 obstructions along the proposed outfall route. All of these can be removed by a dive team, and are made of coral, rock, and debris. The vast majority are on the subtidal reef flat. The estimated underwater time needed for rectifying obstructions is 7.5 days, for a total underwater installation time of 13 days. Numerous obstructions require coral to be relocated.

Terminating the outfall within 2m south of point 7 is warranted because it achieves the desired 30m depth, and keeps the diffuser and the immediate area of discharge away from the *H. coerulea* that is on the upper reef slope. If the diffuser is 10m long and ends at this location, it would be 47m south of the shallower *H. coerulea*. It is expected but not confirmed via surveying, that the reef conditions on the slope are similar 25m east and west of the outfall location based on the visibility at the time.

5.2 Bairiki Outfall

There are several ecological concerns and recommendations.

5.2.1 Ecological Concerns

Bairiki has moderate sedimentation, low to medium coral, and medium amounts of rubble and debris. The extension of the outfall pipe will benefit the area almost immediately. By re-directing the nutrient load, some stress is removed from existing coral, especially on the reef crest where there is high coral cover. The Crown-of Thorns infestation continues, and it is likely that it is related to the shallow status quo discharge.

5.2.2 Recommendations

There is excavation needed in the shallow reef flat where the proposed route meets the existing route. There are 48 obstructions along the proposed outfall route. All of these can be removed by a dive team, and are made of coral, rock, and debris. The vast majority are on the subtidal reef flat. The estimated underwater time needed for rectifying obstructions is 11 days, for a total underwater installation time of 16.5 days. Numerous obstructions require coral to be relocated.

Note that terminating the outfall 3m south of point 23 is warranted because it achieves the desired 30m depth, and keeps the diffuser and the immediate area of discharge away from the *P. sinuosa* that is both shallower and deeper but not in the debris field in the middle. If the diffuser is 10m long and ends at this precise location, it would be 5m north of the deeper *P sinuosa*. This is not significant, but it is better than terminating it in the deeper coral patch, which would necessitate further obstruction work, damage coral from both the removal of obstructions and from more concentrated effluent plume discharge, and therefore not yield the perceived benefits that a deeper outfall might suggest.

If the design allows for it, it would be even better from an environmental standpoint for the diffuser to terminate 7m north of point at 25m depth (corrected) because it gives a longer buffer down to the deeper coral patch. Moreover, it would eliminate some of the deeper obstruction removal work needed.

5.3 Bikenibeu Outfall

There are several ecological concerns and recommendations.

5.3.1 Ecological Concerns

Bikenibeu has low to moderate sedimentation, medium to high coral, and low to medium amounts of rubble and debris. The extension of the outfall pipe will benefit the area almost immediately. By re-directing the nutrient load, some stress is removed from existing coral, especially on the reef crest, upper slope, and lower slope where there is high coral cover.

5.3.2 Recommendations

There is excavation needed in the shallow reef flat where the proposed route meets the existing route. There are 11 obstructions along the proposed outfall route. All of these can be removed by a dive team, and are made of coral, rock, and debris. The vast majority are on the subtidal reef flat. The estimated underwater time needed for rectifying obstructions is 6.5 days, for a total underwater installation time of 11 days. Numerous obstructions require coral to be relocated.

Note that terminating the outfall 2m south of point 10 is warranted because it achieves a 25m depth, and keeps the diffuser and the immediate area of discharge away from the *P. sinuosa* that is both shallower and deeper but not in the debris field in the middle. If the diffuser is 10m long and ends at this precise location, it would be 10m north of the deeper *P sinuosa*. This is not significant, but it is better than terminating it in the deeper coral patch, which would necessitate further obstruction work, damage coral from both the removal of obstructions and from more concentrated effluent plume discharge, and therefore not yield the perceived benefits that a deeper outfall might suggest.

<u>End Note</u>: This additional marine survey was recommended based on the Basic Environmental Impact Assessment Report (KIR PWU 2013, BEIA p33). The BEIA states that the PPTA dive team in 2011 assessed the marine life condition at the proposed outfall locations and there was virtually no coral at 30m. There was some coral at Bikenibeu, but mostly rubble (p.33). Based on this report, the authors think that Bikenibeu was obviously not properly assessed at that time. Moreover, the BEIA states that the presence of *Halimeda* sp. in an algae assemblage found at that time indicates nutrient enrichment. This is incorrect, and the lack of *Halimeda* sp. found and reported on in this report is precisely the opposite, that it is not present because of nutrient enrichment.

6 Conclusion

This report included findings and recommendations from marine surveys carried out by University of Hawai'i Sea Grant and College of the Marshall Islands during January 19-25, 2015 at the existing and proposed sewer outfalls on South Tarawa in Kiribati. The purpose was to determine the optimal siting of proposed new sewage outfalls for the locations of Betio, Bairiki, and Bikenibeu via reconnaissance and a close visual inspection and marine life survey for the proposed outfalls routes. The proponent for the project is the Kiribati Ministry of Public Works and Utilities.

It found that the existing discharge of sewage at the edge of the intertidal reef flat is producing excessive sedimentation along with nutrient enrichment that is significantly contributing to the degradation of the coral reefs along South Tarawa. The report detailed precise routing for the proposed outfall extensions, and determined that minimal disturbance of existing coral reef habitat will ensue if obstructions removal and relocation is done by hand. This is especially obvious with the moderate to high coral cover on the reef flat at Bairiki and Bikenibeu. Further to Lovell (2000) it is noted that most of the affected corals are uncommon corals - *Heliopora coerulea* (blue coral) and *Plerogyra sinuosa* (bubble coral) – but they are relatively common in South Tarawa.

With 13 days at Betio, 16.5 days at Bairiki, and 11.5 days at Bikenibeu the total underwater time needed for rectifying obstructions and laying the new outfall pipes is estimated at 41 days.

7 Citation References

Asian Development Bank. 2011. *Initial Environmental Evaluation*. South Tarawa Sanitation Sector Improvement Project. 79p.

Ferrario, F., M.W Beck, C. D. Storlazzi, F. Micheli, C. C. Shepard, and L. Airoldi. 2014. The Effectiveness of Coral Reefs for Coastal Hazard Risk Reduction and Adaptation. *Nature Communications*. 5(3794): 1-9.

Ford, M.R. and Coastal Consultants NZ. 2013. *A Landowner's Guide to Coastal Protection*. Honolulu: UH Hawaii Sea Grant. 17 p.

Houke, P. 2015. *Personal Communication*. March 2, 2015 Correspondence.

IUCN. 2006. *Global Invasive Species Database: Hypnea musciformis*. National Biological Information Infrastructure & World Conservation Union/ Invasive Species Specialist Group. http://www.issg.org/database/species/ecology.asp?si=728&fr=1&sts=&lang=EN

Kiribati Ministry of Public Works and Utilities. 2013. *Basic Environmental Impact Assessment*. South Tarawa Sanitation Sector Improvement Project, Sewer System and Ocean Outfalls Rehabilitation Subprojects. South Tarawa: KIR PWU. 77p. http://www.mfed.gov.ki/wp-content/uploads/2014/02/Combined-Contract-Vol-4-for-ICB01-BEIA-and-RAP-pages-1-50.pdf

Lovell, E. 2000. *Coral Reef Benthic Surveys of Tarawa and Abiang Atolls, Republic of Kiribati*. SOPAC Technical Report 310. 89p. http://ict.sopac.org/VirLib/TR0310.pdf

Ocean Outfalls Advisor, SMEC. 2014. *Specification for Diving Survey of Locations for Ocean Outfalls on South Tarawa*. South Tarawa Sanitation Sector Improvement Project. 10p.

Ocean Outfalls Advisor, SMEC. 2015. *Personal Communication*. January 21, 2015. South Tarawa, Kiribati.

NOAA Coral Watch. 2014. *Four-Month Coral Bleaching Thermal Stress Outlook*. http://coralreefwatch.noaa.gov/satellite/bleachingoutlook_cfs/outlook_cfs.php

International Environmental Expert, SMEC. 2015. *Coral and Other Benthic Survey Design*. Guidance via email correspondence from Ocean Outfalls Advisor on January16, 2015.

The following are not cited, but are for reference:

Donner, S. 2007. *Coral Reef Benthic Monitoring: Final Report/Workshop Report*. Kiribati Adaptation Project. Vancouver: University of British Columbia. 29p. http://www.climate.gov.ki/wp-content/uploads/2013/05/Coral-Reef-Monitoring.pdf

Houke, P., D. Benavente, J. Iguel, S. Johnson, and R. Okano. 2014. Coral Reef Disturbance and Recovery Dynamics Differ across Gradients of Localized Stressors in the Mariana Islands. *Plos One*. 9(8): 1-15

Tonganibeia, K. 2005. *Impacts assessment of Betio, Bairiki and Bikenibeu Sewage Outfalls on Coral Reef*. Report prepared for PMO and Steering Committee, SAPHE.

8 Appendix A: Outfall Pipeline Chainage and Depth

Figures 8.1 to 8.3 summarize the chainage and corrected depths for 0 tide datum for the existing outfalls and proposed extensions for Betio, Bairiki, and Bikenibeu.

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)	Depth (m)
Betio	vent	37	0.0	0.0	0.00
Betio	reef flat, intertidal	36	13.6	13.6	0.00
Betio	reef flat, intertidal	34	26.9	40.5	0.00
Betio	reef flat, intertidal	33	27.1	67.6	0.00
Betio	reef flat, intertidal	32	35.1	102.7	0.00
Betio	reef flat, intertidal	31	26.3	129.0	0.00
Betio	reef flat, intertidal	1	30.0	159.0	0.00
Betio	reef flat, intertidal	2	32.3	191.3	0.00
Betio	reef flat, intertidal	3	32.0	223.3	0.00
Betio	reef flat, intertidal	4	30.2	253.5	0.00
Betio	reef flat, intertidal	6	28.7	282.2	0.00
Betio	reef flat, intertidal	7	28.4	310.6	0.00
Betio	reef flat, intertidal	8	28.7	339.3	0.00
Betio	reef flat, intertidal	9	29.0	368.3	0.00
Betio	reef flat, intertidal	10	31.3	399.6	0.00
Betio	reef flat, intertidal	11	29.4	429.0	0.00
Betio	reef flat, intertidal	13	31.5	460.5	0.00
Betio	reef flat, intertidal	14	30.0	490.5	0.00
Betio	reef flat, intertidal	16	29.4	519.9	0.00
Betio	reef flat, intertidal	17	31.5	551.4	0.00
Betio	reef flat, intertidal	18	29.0	580.4	0.00
Betio	reef flat, intertidal	19	31.4	611.8	0.00
Betio	reef flat, intertidal	21	26.4	638.2	0.00
Betio	reef flat, intertidal	23	35.0	673.2	0.00
Betio	reef flat, intertidal	24	29.0	702.2	0.00
Betio	reef flat, intertidal	26	13.2	715.4	0.00
Betio	reef flat, intertidal	BETCOLD(27)	16.0	731.4	0.00
Betio	reef flat, intertidal	01	102.4	828.4	0.72
Betio	reef flat, intertidal	2	22.5	850.0	-0.65
Betio	reef flat, subtidal	17	33.5	883.5	-2.28
Betio	reef flat, subtidal	21	10.5	894.0	-2.88
Betio	reef flat subtidal-crest	23	25.8	919.8	-4.58
Betio	reef crest	14	26.4	946.2	-9.85
Betio	reef slope	11	28.7	974.9	-23.92
Betio	reef slope	7	4.0	978.9	-29.00
Betio	reef slope	6	21.3	1000.2	-33.92

Fig. 8.1 Betio Chainage, Distance, and Depth

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)	Depth (m)
Bairiki	vent	1	0.0	0.0	0.00
Bairiki	reef flat, intertidal	2	17.2	17.2	0.00
Bairiki	reef flat, intertidal	3	12.0	29.2	0.00
Bairiki	reef flat, intertidal	4	15.9	45.1	0.00
Bairiki	reef flat, intertidal	5	15.9	61.0	0.00
Bairiki	reef flat, intertidal	6	28.6	89.6	0.00
Bairiki	reef flat, intertidal	7	15.4	105.0	0.00
Bairiki	reef flat, intertidal	8	16.2	121.2	0.00
Bairiki	reef flat, intertidal	9	16.8	138.0	0.00
Bairiki	reef flat, intertidal	12	15.2	153.2	0.00
Bairiki	reef flat, intertidal	13	15.6	168.8	0.00
Bairiki	reef flat, intertidal	14	16.5	185.3	0.00
Bairiki	reef flat, intertidal	15	13.0	198.3	0.00
Bairiki	reef flat, intertidal	16	16.1	214.4	0.00
Bairiki	reef flat, near EOP	17	15.8	230.3	0.00
Bairiki	reef flat subtidal, EOP	25	5.8	236.1	0.10
Bairiki	reef flat, subtidal	18	6.4	242.5	0.59
Bairiki	reef flat, EOP broken	19	59.5	302.0	-2.63
Bairiki	reef flat, subtidal	20	30.4	332.4	-2.99
Bairiki	reef flat, small bommie	5	9.6	342.0	-3.91
Bairiki	reef flat, small bommie	6	23.5	365.5	-5.28
Bairiki	reef flat, S channel	7	19.8	385.3	-7.33
Bairiki	reef crest, large bommie	14	6.7	392.0	-9.92
Bairiki	reef crest	21	9.6	401.6	-13.13
Bairiki	reef slope	22	40.7	442.2	-22.80
Bairiki	reef slope	23	30.5	472.7	-26.91
Bairiki	reef slope	24	16.2	488.9	-34.04

Fig. 8.2 Bairiki Chainage, Distance, and Depth

Outfall Location	Marine Zone	GPS Point	Chainage (m)	Accum. Distance (m)	Depth (m)
Bikenibeu	vent	1	0.0	0.0	0.00
Bikenibeu	reef flat, intertidal	2	12.2	12.2	0.00
Bikenibeu	reef flat, intertidal	3	15.3	27.5	0.00
Bikenibeu	reef flat, intertidal	4	132.1	159.6	0.00
Bikenibeu	reef flat, intertidal	5	15.0	174.6	0.00
Bikenibeu	reef flat, intertidal	6	15.4	189.9	0.00
Bikenibeu	reef flat, intertidal	7	18.2	208.1	0.00
Bikenibeu	reef flat, near EOP	8	9.1	217.2	0.00
Bikenibeu	reef flat subtidal, EOP	15	3.0	220.1	0.28
Bikenibeu	reef flat, broken EOP	14	97.3	317.4	-5.91
Bikenibeu	reef crest	11	23.6	341.0	-12.18
Bikenibeu	reef slope	10	14.9	355.9	-24.46
Bikenibeu	reef slope	9.1	13.7	369.6	-27.86
Bikenibeu	reef slope	9	9.9	379.4	-32.75

Fig. 8.3 Bikenibeu Chainage, Distance, and Depth

9 Appendix B: Water Temperatures

Figure 9.1 shows the recorded water temperatures, depths, times, and profiles for all the dives conducted during the marine surveys at Bikenibeu, Bairiki, and Betio Jan 19-25, 2015. The average temperature was 29.8 degrees Celsius for an average dive depth of 12m.

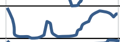
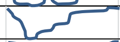
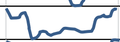
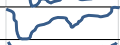
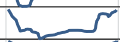
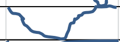
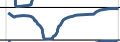
Date	Ocean Outfall Location	Ave Temp (°C)	Ave Depth (m)	Max Depth (m)	Dive Time (min)	Dive Profile	Time In	Time Out	High Tide	Low Tide
19-Jan	Bikenibeu	30	14.1	36.6	49		13:15	14:04	1555 +273cm	0935 +84cm
19-Jan	Bikenibeu	30	9.3	34.2	31		15:07	15:38	1555 +273cm	0935 +84cm
19-Jan	Bikenibeu	31	1.2	1.9	5		16:34	16:39	1555 +273cm	0935 +84cm
20-Jan	Bairiki	30	13.6	35.3	59		13:32	14:31	1636 +285cm	1017 +73cm
20-Jan	Bairiki	30	16.4	37.1	28		15:11	15:39	1636 +285cm	1017 +73cm
20-Jan	Bairiki	30	1.7	2.7	4		14:12	14:16	1636 +285cm	1017 +73cm
21-Jan	Betio	30	19.3	35.8	42		14:22	15:04	1717 +291cm	1100 +66cm
21-Jan	Betio	30	8.1	35.4	35		15:32	16:07	1717 +291cm	1100 +66cm
22-Jan	Bikenibeu	30	18.9	36.3	42		10:23	11:05	1759 +289cm	1142 +65cm
22-Jan	Bairiki	30	10.7	26.8	45		12:06	12:51	1759 +289cm	1142 +65cm
23-Jan	Bairiki	29	20.2	35.2	42		9:20	10:02	1840 +280cm	1225 +71cm
23-Jan	Bairiki	30	17.6	27.4	37		11:14	11:51	1840 +280cm	1225 +71cm
24-Jan	Betio	30	4.6	15.8	42		12:46	13:28	1921 +264cm	1308 +82cm
24-Jan	Betio	29	17.1	35.4	42		14:08	14:50	1921 +264cm	1308 +82cm
24-Jan	Betio	30	2.0	3.6	3		14:59	15:02	1921 +264cm	1308 +82cm
24-Jan	Betio	30	11.7	35.7	26		15:23	15:49	1921 +264cm	1308 +82cm
25-Jan	Betio	29	17.6	35.7	23		12:24	12:47	--	1354 +99cm
	Average of all dives	29.8	12.0	27.7	33					

Fig. 9.1 Water Temperatures Recorded during Dive Surveys