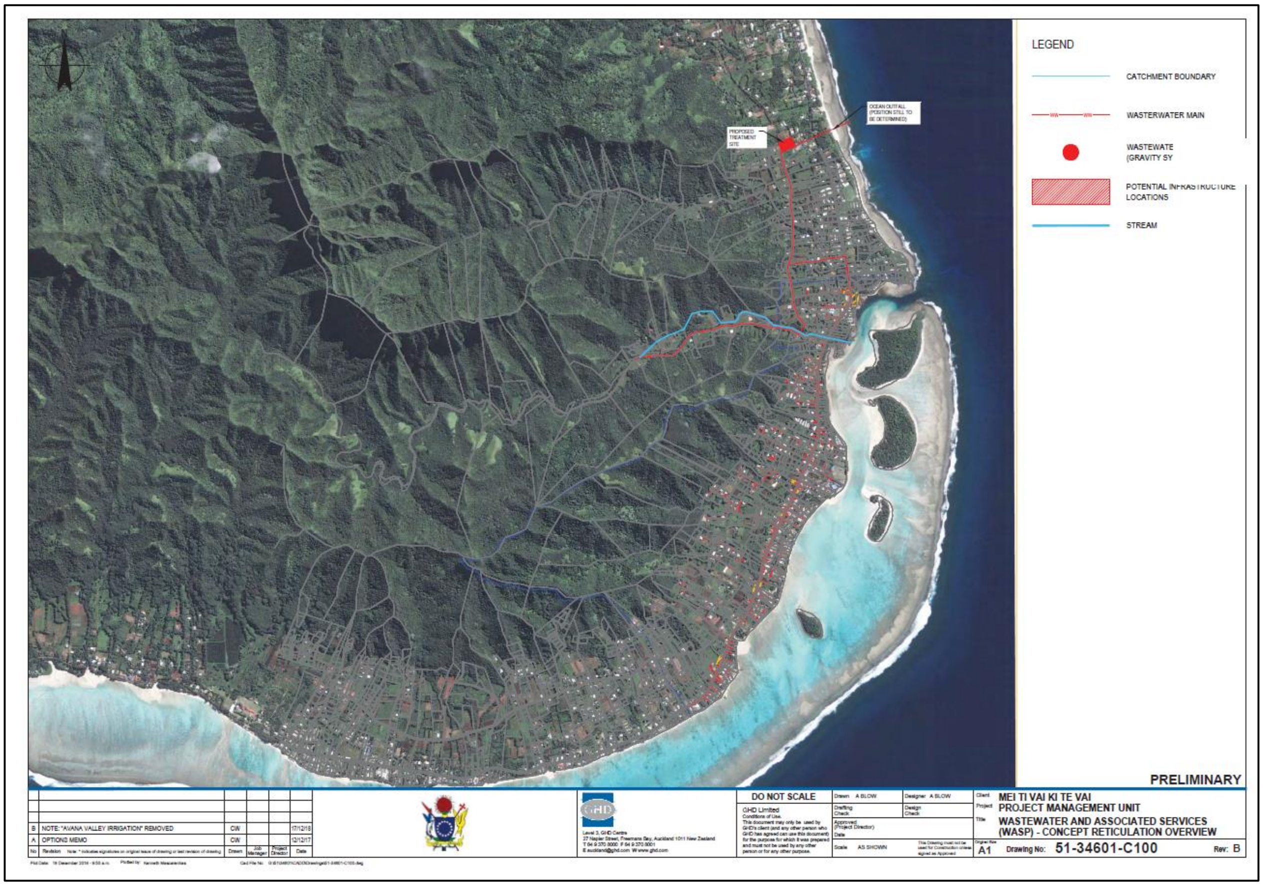
Reviewing the wastewater disposal options presented by GHD in "Mei Te Vai Ki Te Vai Muri Wastewater Concept Design Report (Hybrid Outfall)"



Source: GHD, 2018a

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I. INTRODUCTION

To date, we are yet to link the impacts noted in the marine environment on Rarotonga to nutrient loading because we lack information from consistent monitoring programs (e.g., water quality, reef health, reported hospital cases). For example, current water quality and health data do not permit a reliable link to the incidence of ciguatera fish poisoning (but see Rongo and van Woesik, 2013). Similarly, we are unable to link algal blooms in Muri to water quality data. In addition, it is not possible with the available data to differentiate between the contributions of climate variability and climate change as well as nutrient loading to explain the 'undesirable' changes (in today's tourism image) noted in algal communities within the Muri lagoon. We do, however, have anecdotal and local knowledge of the Muri lagoon environment to consider, where algal communities change with the season and bring with it marine delicacies in the process (e.g., *patito* that is harvested by locals; see Rongo and Dyer, 2014). Historically, residents of the Muri area have been known to utilize washed up algae along the shore for fertilizing their plantations. For these reasons, the justification of this sanitation project is ambiguous and we need to ask, why are we seemingly pushing hard for this project to go ahead?

The GHD report relied heavily on the findings of the Calibre Consulting review (2015) that based their conclusion on a sample size of 10 out of 199 household systems that WATSAN installed, which at 5% is barely statistically valid (Zar, 1999). This 2015 review discounted our local contractors and Cook Islands Government Ministries in being able to provide the same level of monitoring to the standards utilized in New Zealand (see Section 5.2.5 in Calibre Consulting, 2015), and basically formulated their recommendations on this, which is questionable as it already negates building local capacity as a solution. Subsequently, the GHD reports (2018 a,b) and other relevant reports point towards a reticulated system with an ocean outfall disposal option and a 10-year 'capacity building plan' (see GHD, 2018a Section 6), despite having limited or no information to support this conclusion; all other options have ostensibly been labeled either "outside the scope of this study" or "unacceptable" without much consideration (see GHD 2017 Section 3.3.5). In addition, local knowledge was not consulted in the oceanographic investigations in GHD 2018a. Considering the gaps identified, the Cook Islands Government **should proceed with much caution** regarding the recommendations and options presented in these reports. I will touch on the options presented in the GHD 2018a report, focusing mainly on the ocean outfall option and the potential concerns in the marine environment. I will also comment on and briefly discuss other options, which will need more detailed investigation if these options are considered.

II. OBJECTIVES

The purpose of this review is to provide information pertaining to the options discussed in the Mei Te Vai Ki Te Vai Muri Wastewater Concept Design Report: Hybrid Outfall (GHD, 2018a), and discuss the relevant research with emphasis on the ocean outfall option.

Background: my expertise is in the marine environment with over 25 years of experience monitoring Rarotonga's reefs, and around 10 years studying coral reef systems on Guam where ocean outfalls for wastewater disposal are utilized.

III. OPTIONS FOR WASTEWATER DISPOSAL

1. Land-based

Other options discussed in Section 4 of this report may provide viable solutions to the waste management problem in Muri. This section examines the land disposal option (Option 1) provided by GHD (2018a). This option may be considered if a centralized treatment system is decided upon (if all other options are not considered) as there is opportunity for nutrient uptake prior to wastewater entering waterways and into the marine environment. However, the challenge identified by GHD is the availability of land for both the treatment of wastewater and its disposal. As we have seen with Te Mato Vai, land acquisition will certainly be a challenge for this option. However, this may depend on the value of the land needed. For example, locals value wetlands less for development because of the difficulties in acquiring a permit (i.e., EIA), and therefore the willingness for landowners to offer these lands over other lands may be higher.

Wetlands have been proposed as an option for receiving wastewater, because these habitats act as bio-filters that can remove a range of pollutants (such as organic matter, nutrients, pathogens, heavy metals) from the water. Considering that secondary treatment is proposed, I assume that the use of wastewater should be safe for agricultural use. The Avatiu, Atupa, and Panama wetlands have a land area of more than 16 hectares (Figure 1). While a large portion of this area is no longer planted with taro, it hosts a diversity of wetland flora (e.g., water lilies) that are efficient at filtering polluted waters. Also, Panama was once used as the island's landfill, and would be a good location to consider because it is relatively remote. There are other wetlands around the island that can also be used for wastewater disposal. In fact, in Section 2.1 of the Review of Muri Waste Management Initiative Pilot for Rarotonga (Calibre Consulting, 2015), this solution of utilizing existing taro plantations and wetlands was already proposed in the ADB Final Report (ADB, 2009).

Figure 1. Google Earth image with yellow outline delineating the wetlands of Avatiu, Atupa, and Panama. The approximated area is 18.60 ha. This area is relatively remote and the density of development is low due to the former use of parts of this area as a dump site.

2. Ocean outfall

The crown-of-thorns starfish and reef state concerns

Coral reefs are important, structurally, for the protection of low-lying coastal areas from strong wave action and coastal erosion. Reefs also provide food, recreational opportunities, medicinal products, and are a major attraction for the tourism industry through lagoon tours, diving, and other marine-related activities. In the Cook Islands, the tourism industry generated ~NZD $125 million in 2017 (Cook Islands Statistics Office, 2019), which is ~26% of the Gross Domestic Product.

Coral reef ecosystems such as those found in Cook Islands' coastal zones are naturally nutrient-poor environments; altering this fact may compromise their existence. In comparison to New Zealand for example, New Zealand naturally has high background levels of nutrients (see satellite images of chlorophyll a data below; Figure 2) and hence supports marine life that can tolerate nutrient-rich environments (e.g., kelp forests with filter feeders such as oysters and mussels). Rarotonga's reefs have recovered to a relatively healthy state (percent coral cover > 25%; Rongo et al., 2016) following several reef disturbances in the last 20 years such as coral bleaching, cyclones, and most importantly the recent COTS outbreak from 1995 – 2001 (Table 1). One of the main concerns for the ocean outfall option is the direct input of nutrients from wastewater discharge onto the fore reefs around Rarotonga, and the risk of causing a Crown-of-Thorns starfish (COTS) outbreak (Figure 3).

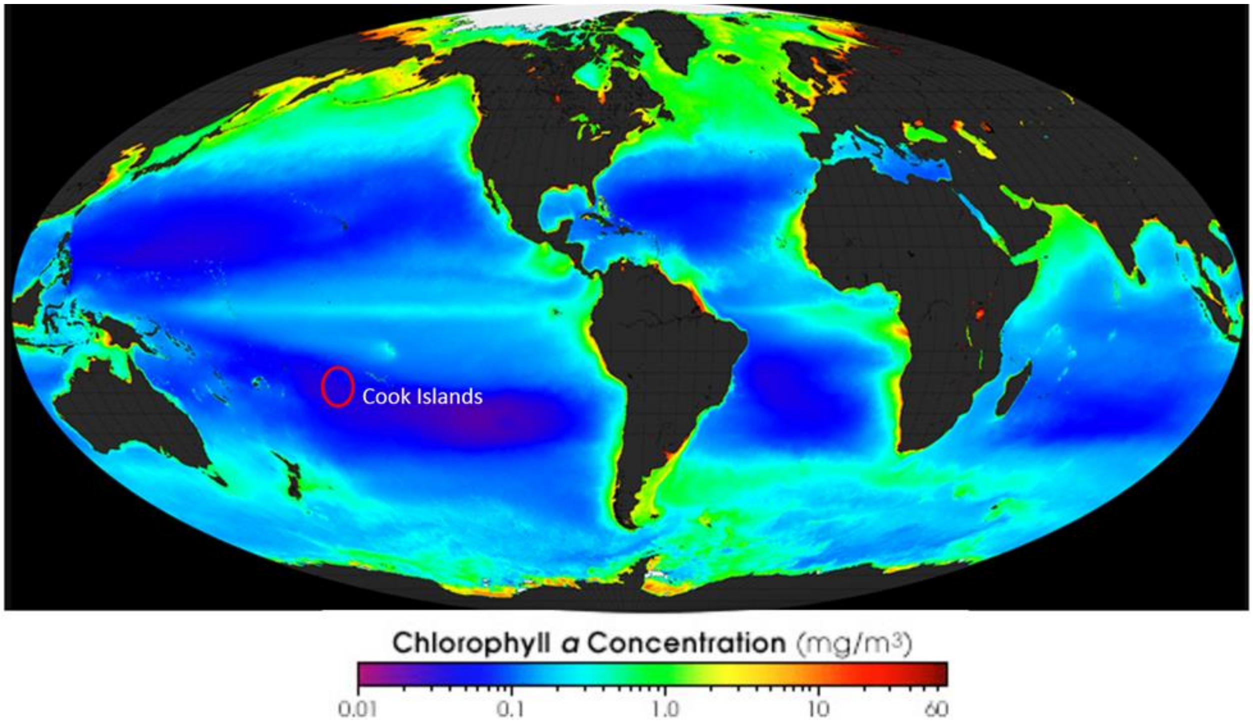

Figure 2. Global *chlorophyll-a* data taken from https://earthobservatory.nasa.gov/images/4097/global-chlorophyll, indicating the nutrient-poor region of the Cook Islands in contrast to New Zealand.

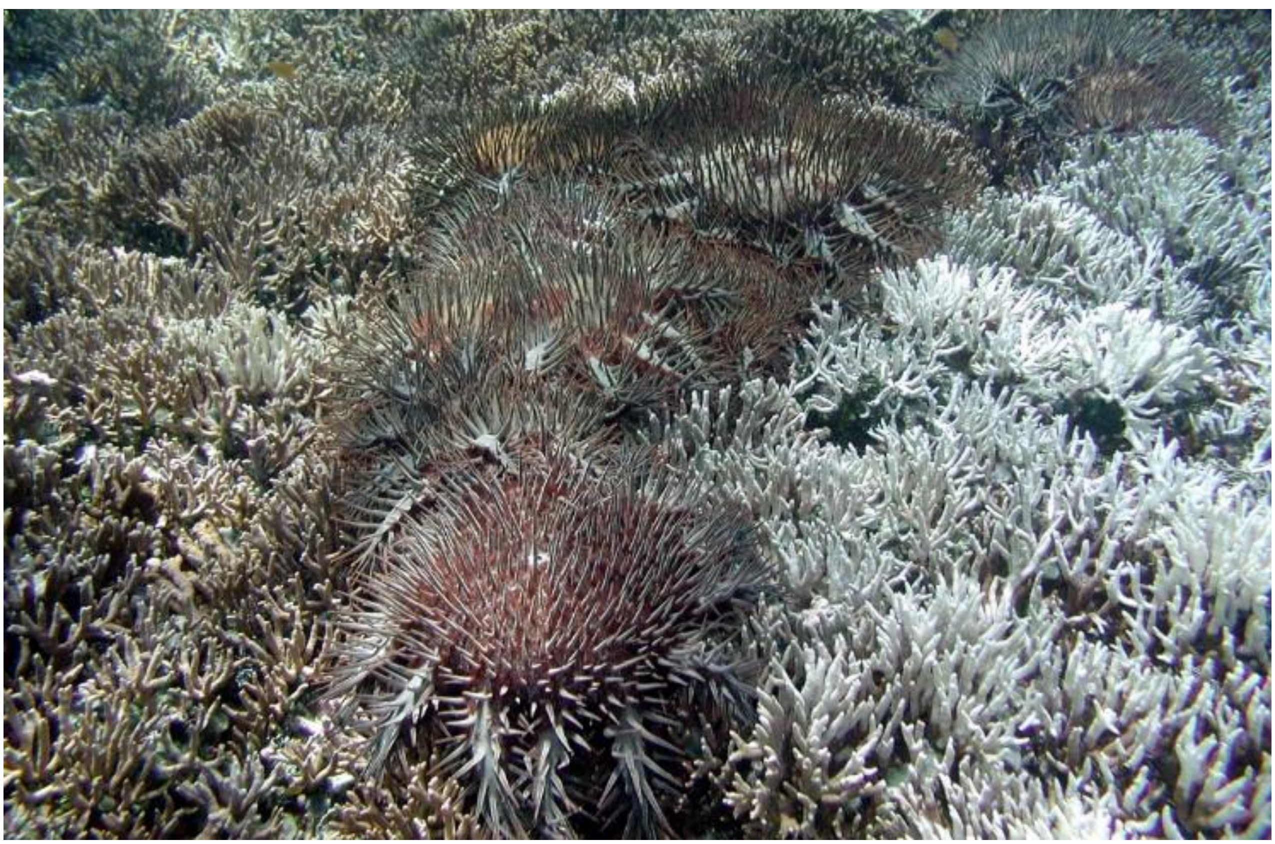
Figure 3. Crown-of-thorns starfish (COTS; *Acanthaster planci*) outbreak in Japan. The white area on the right of the photo indicates corals killed by the COTS while they fed towards the left. Photo by: Dr Robert van Woesik.

Table 1. Taken from Rongo and van Woesik (2013). Natural disturbances (including cyclones, crown-of-thorns starfish outbreaks, and coral bleaching) impacting Rarotonga, Cook Islands, between 1970 and 2011. Cyclone and wind data taken from Asian Development Bank (2005), de Scally et al. (2006), Baldi et al. (2009), and New Zealand's National Institute of Water and Atmospheric Research database (www.cliflo.niwa.co.nz). Cyclone, storm, and gale refer to Category 3 systems, and major cyclones refer to Category 4 and 5 systems. Wind speeds reported here are those noted for Rarotonga. *Acanthaster planci* outbreak data and coral bleaching information were taken from Devaney and Randall (1973), Goreau and Hayes (1995), Lyon (2003), Rongo et al. (2006, 2009a), and Rongo and van Woesik (2011). Severity factor is based on the damage noted in Rarotonga from 1994 to 2011, with 5 being the most severe. SST refers to sea surface temperature.

Year	Natural disturbance	Severity factor	Description of impact
1970	*Acanthaster planci* outbreak begins; Cyclone (Dolly)		*Dolly*: high winds damaged ~40% of Rarotonga's export banana crop; information on wave damage not available
1971	*A. planci* outbreak		
1972	*A. planci* outbreak; Cyclone (Agatha)		Extensive damage from *A. planci* outbreak noted in lagoon areas on the northwestern exposure; *Agatha*: wind speeds up to 134 km/h that damaged ~75% of Rarotonga's export banana crop; information on wave damage not available
1973	*A. planci* outbreak		
1974	*A. planci* outbreak		
1975	*A. planci* outbreak		
1976	*A. planci* outbreak ends; Storm (Kim)		Lagoon coral cover declined from *A. planci* outbreak; *Kim*: wind speeds up to 135 km/h, causing some fishing vessel damage
1978	Cyclone (Charles)		*Charles*: wind speeds up to 135 km/h; wave height of 11 m; reported to have caused damage to the wharf
1987	Major cyclone (Sally)		*Sally*: wind speeds up to 156 km/h and wave height of 12 m
1989	Gale (unnamed)		*Gale*: wind speeds up to 105 km/h; no information on swells
1991	Cyclone (Val); Coral bleaching		*Val*: wind speeds up to 74 km/h and wave height of 14 m; severe bleaching of lagoon corals from extreme low tides
1992	Cyclone (Gene)		*Gene*: wind speeds up to 115 km/h; flooding and big swells with coastal damage on western exposure
1993	Cyclone (Nisha)		*Nisha*: wind speeds up to 74 km/h; big swells
1994	Coral bleaching	1	Coral bleaching from high SSTs impacted corals on fore reef slopes on the northern to western exposure
1995	*A. planci* outbreak begins	3	Large numbers noted on the northern fore reef exposure
1996	*A. planci* outbreak	4	Extensive damage of fore reef slopes on the northern exposure
1997	Cyclone (Pam); *A. planci* outbreak	5	*Pam*: wind speeds up to 150 km/h; wave height of 14 m; record rainfall of 107 mm in 6 h; *A. planci* damage on the northeastern exposure
1998	*A. planci* outbreak; Coral bleaching	3	*A. planci* damage on eastern and southeastern exposure; coral bleaching of lagoon corals from extreme low tides
1999	*A. planci* outbreak	2	Extensive damage of fore reef slopes on the southern exposure
2000	*A. planci* outbreak	2	Extensive damage of fore reef slopes on the southwestern and western exposure
2001	*A. planci* outbreak ends; Storms (Oma, Trina)	4	*A. planci* outbreak significantly reduced fore reef coral cover; *Oma*: wind speeds up to 130 km/h and heavy rain; *Trina*: wind speeds up to 102 km/h with big swells
2002		0	
2003	Major cyclone (Dovi); Titikaveka Irritant Syndrome (TIS)	5	*Dovi*: wind speeds up to 66 km/h and wave height of 17 m; strong swell/surge along coastal areas; *TIS*: harmful algal bloom causing eye and respiratory irritation in residents
2004	Major cyclone (Heta)	5	*Heta*: wind speeds up to 72 km/h and wave height of 17.4 m; major coastal damage
2005	Major cyclones (Meena, Nancy, Olaf, Percy); Gale (Rae)	5	Severe coastal damage from the four major cyclones; *Meena*: wind speeds up to 161 km/h and wave height of 17 m; *Nancy*: wind speeds up to 165 km/h and wave height of 22 m; *Olaf*: wind speeds up to 95 km/h and wave height of 16 m; *Percy*: wind speeds up to 76 km/h and wave height of 19 m; *Rae*: wind speeds up to 75 km/h
2006	Coral bleaching	1	Coral bleaching of lagoon corals observed in Ngatangiia on the southeastern exposure from extreme low tides
2007		0	
2008		0	
2009	Coral bleaching	1	Minor bleaching observed on reef flats on the northern exposure from extreme low tides
2010		0	
2011		0	

In the 1970s, Devaney & Randall (1973) documented the first reported COTS outbreak on Rarotonga during a Pacific-wide outbreak (Sapp, 1999), where 80,974 COTS were removed from Rarotonga's reefs (see Birkeland, 1982). This outbreak lasted seven years (from 1968 – 1974), and destroyed corals on the fore reef and the lagoon habitats of Rarotonga; reefs recovered in less than 10 years to pre-COTS conditions (Rongo et al., 2009). A second major COTS outbreak from 1995 to 2001 also lasted seven years, and the Cook Islands Ministry of Marine Resources carried out a massive eradication effort around Rarotonga as a result. Unlike the earlier outbreak, more information about the latter outbreak on reef state was available. We noted that COTS were limited to fore reef communities, and coral cover was reduced from more than 40% prior to 1995 to less than 5% in 2006 (Rongo et al., 2006). During this outbreak, most large coral colonies were killed off especially the large platy, branching, and encrusting corals (e.g., Acroporids, Montiporids); most of the corals that survived were the small massive and encrusting colonies (e.g., *Favia* spp., *Leptastrea* spp., and *Leptoria phrygia*). Subsequent to this outbreak, reefs around Rarotonga remained in a degraded state for over a decade (Rongo et al., 2009).

A widely supported hypothesis for the cause of COTS outbreaks is the 'larval starvation hypothesis' which argues that nutrient-limited survival of the pelagic planktotrophic larvae of COTS controls population outbreaks (Birkeland 1982; Lucas 1982; Ayukai et al., 1997; Brodie et al. 2005; Fabricius et al., 2010; Baird et al., 2013). In other words, increased food availability will increase larval survivorship of COTS that can lead to outbreaks. Furthermore, a recent study suggested that in addition to nutrient loading, increased temperatures as forecasted by climate change models may shorten the COTS developmental time by 30%, which may increase the probability of survival by 240% (Uthicke et al., 2015).

Basically, discharging large amounts of nutrients to the fore reefs will increase larval survivorship of COTS, which may again decimate the coral reefs of Rarotonga. In the recent COTS outbreak, Rarotonga's reefs struggled to recover and given the added factor of climate change impacts worsening today, reefs would be further hindered from recovery if another outbreak were to occur. With a consistent supply of nutrients offshore from an ocean outfall, COTS may become chronic instead of episodic, further compromising reef recovery after a major reef disturbance. In addition, the consistent supply of nutrients may also facilitate a shift towards an algal-dominated reef after a major disturbance (e.g., COTS outbreak or cyclone damage), making it harder to return to a coral-dominated state. Increasing algal coverage on fore reefs would also provide more habitat and refuge for microscopic plant cells (dinoflagellates) that cause fish poisoning (i.e., ciguatera). Ciguatera poisoning was a major problem on Rarotonga from the late 1980s into the 2000s (Rongo et al, 2009; Rongo and van Woesik, 2011, 2012, 2013); while the incidence of ciguatera poisoning has declined over the last decade as reefs continue to recover, a shift back into an algal-dominated reef would likely cause a ciguatera outbreak when conditions are optimal.

Other potential impacts to the marine environment

The most common response to wastewater discharge has been an increase in benthic algae and filter-feeding invertebrates such as bryozoans, sponges and tunicates, with a corresponding decrease in the diversity and abundance of corals (e.g., Walker and Ormond, 1982, see also Pastorok and Bilyard, 1985). Nutrient enrichment (i.e., phosphates) can also reduce calcification rates by 50% (e.g., Kinsey and Davies 1979), a problem that would worsen with the impact of ocean acidification. In contrast, a study in Australia (i.e., Wooldridge, 2009) showed that reducing DIN concentrations by 50 to 80% will increase the thermal tolerance of corals by 2 - 2.5 ºC. Interestingly, Bay et al. (2017) found that corals on Rarotonga are unique because they have the genetic make-up that can help them cope with increased temperatures associated with climate change. In support, the recent mass bleaching event of 2016/17 where over 80% of corals around Rarotonga bleached showed a 100% recovery (T. Rongo, pers. comm.). Therefore, the need to protect our reefs is even more critical considering the impacts of climate change and the survival of coral reefs into the future.

We also need to understand that sewage is a convergence of many other potentially toxic and distinct stressors which include inorganic nutrients, pathogens, suspended solids, heavy metals, antibiotics, hormones from contraceptives, sediments, and other toxins (Wear & Thurber, 2015) that can have detrimental effects on marine life depending on the level of treatment before discharge. For example, coral species found around the sewage outfalls on Guam – where both primary and secondary treatments are implemented – were more prevalent to disease (Raymundo et al., 2011; see also Redding et al., 2013; Figure 4).

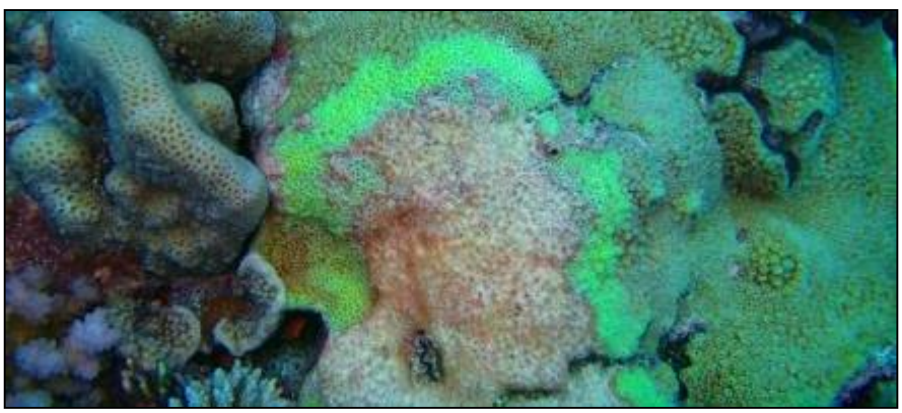

Figure 4. Coral disease indicated by the yellow band affecting the live coral, with coral on the inner part of the band killed by the disease. Coral disease has been linked to human activities (e.g., Ward & Lafferty, 2004).

Oceanographic investigation and local knowledge

Understanding ocean currents is key for determining the impacts of any development in the marine environment. For example, Holden (1992) has been referenced in proposed projects in the marine environment on Rarotonga (e.g., the fuel pipeline proposal on the Panama fore reef). The Blacka et al. report (see Appendix H in GHD, 2018a) – commissioned to conduct a current study on the eastern exposure of Rarotonga around the Muri area – builds upon Holden's work and suggested a predominant northwestward to westward current running parallel to the coast from Avana northward.

Today, local knowledge is recognized as an important source of information to guide, complement, and verify scientific information as evident in climate change literature (e.g., Williams and Hardison, 2013; Rongo and Dyer, 2014). For example, the predominant currents identified by Holden and Blacka et al. was verified by local knowledge from fishermen who have had decades of experience fishing around Rarotonga. However, local knowledge also suggested that the predominant current is sometimes interrupted by an opposite flow, especially more frequently during the summer months (local fishers Peter Toto and Tangaina Patia, pers. comm.). Other information provided by local fishers include the following:

- Wind is not always a good predictor of currents on Rarotonga because currents often run counter to the wind direction.
- Within the course of a day, currents change direction every 6 hours corresponding to tidal changes.
- "*Offshore currents always find its way back to land*" (Peter Toto, pers. comm.); for example, an anecdotal account was given of a deceased person who was taken out to sea in the Nikao area and returned to Avarua by the currents. These oceanographic behaviors of nearshore currents are also supported by the pioneering work of Swearer et al. (1999) and Jones et al. (1999) with regards to reefs self-seeding. Ebert & Russell (1988) attributed such current behaviors to coastal bathymetry and complexity such as headlands where eddies are created on their leeward side, which can play a role in larval retention. Similar effects are also evident along the fore reef slopes of Rarotonga, where extended reef slopes known locally as "*toro*" (Figure 5) are areas where currents are temporarily pushed outward on the side of the prevailing current, while eddying occurs on the leeward side of the *toro*. It is likely that these bathymetric features will influence the distribution of wastewater in the nearshore environment. Areas where eddying occurs facilitates the return of marine larvae and particulate matter to reefs; for this reason, these areas also tend to have high biodiversity.

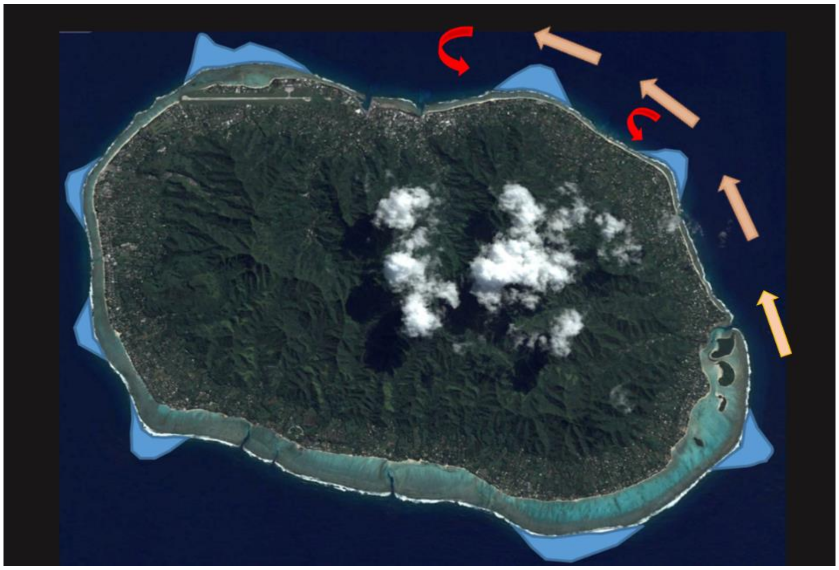

Figure 5. Extended reef slopes/shelves (light blue) known to locals as "*toro*" are areas where currents are pushed outward but also where eddies occur. Note: these extended reef slopes are not to scale, and are only to indicate their approximate location based on local knowledge. Orange arrows indicate the predominant current flow, while the red curved arrows indicate areas where eddies have been noted by local fishers along the coast.

The parallel current flow along the coast indicated in the Blacka et al. study (see Appendix H in GHD, 2018a) may suggest that nutrients will be transported down-current and the size of reef area affected may be determined by the strength of the current. At a current speed of 0.3 to 0.4 m/s (as indicated in the GHD, 2018a), it would take around 7.9 to 5.9 hours respectively for wastewater discharged from Muri to reach Avarua, a distance of 8+ km. The Avarua area has been suggested to be where eddying occurs (Holden, 1992 and local knowledge); this is also the most important 'sink' for marine biodiversity on Rarotonga (Rongo et al., 2009) and the location of numerous dive and fishing spots frequently visited by tourist and locals alike. With the predominant current, it is likely that any wastewater discharge along the Muri coastline via an ocean outfall will end up in Avarua.

There are other important oceanographic features (e.g., areas where eddying occurs) that needs to be examined to fully understand how wastewater would be distributed on reef communities. Also, the duration of the Blacka et al. study was only over a few days, and there is a need to conduct investigations over a minimum period of one year to capture all possible current flows under different conditions, seasons, etc. Perhaps an Acoustic Doppler Current Profiler anchored to the reef is needed to properly understand the currents of the area.

The effect of nutrients originating from Muri may be supported by data obtained from the long-term reef monitoring surveys conducted over the last 10 years (Rongo et al., 2006; 2009; Rongo, 2011; Rongo and van Woesik, 2013; Rongo et al., 2015; 2017). Avana (Motutapu) and Upper Tupapa (Kiikii) have been monitored since 2000; Tokerau Jim and Paradise Inn was added in 2011 (Figure 6). Algal species composition at these sites show some degree of similarity with a gradient effect. Algal communities along this exposure are dominated by two species, *Amphiroa* *foliacea* and *Asparagopsis taxiformis;* dense mats of these species were only observed at the Avana site (to the south of the Avana passage) and rarely seen past Motu Koromiri. However, their distribution, especially *Asparagopsis taxiformis*, extends towards the embayments in Matavera and Tupapa to the north, even reaching the Paradise Inn site in Avarua. Both species are chemically defended and unpalatable to grazers. Any additional nutrient inputs into the marine environment in Muri, especially with the ocean outfall option, may exacerbate the growth of unpalatable algal communities already present along this coast that may outcompete corals.

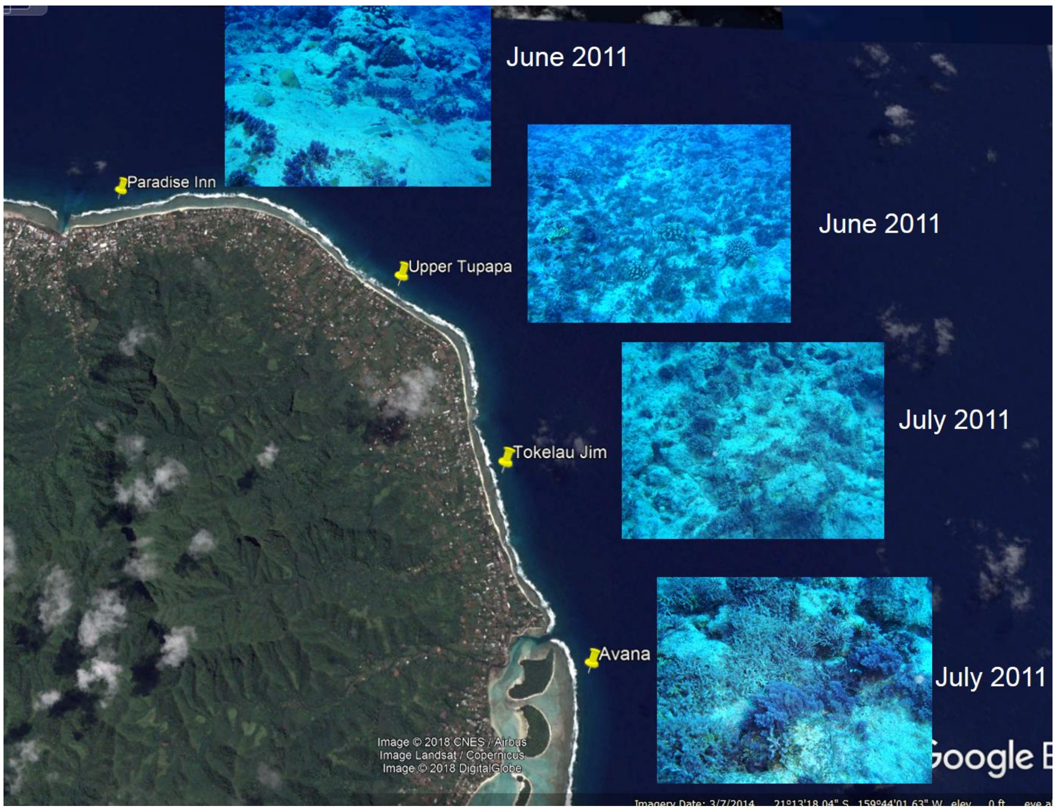

Figure 6. Google Earth image indicating sites monitored by Dr Teina Rongo in 2011. Photo inserts indicate the algal communities at each side (taken by Teina Rongo), which show some degree of similarity with a gradient effect.

GHD investigators noted that the parallel nearshore current may provide the justification to support the ocean outfall option because the concern was more about the effluent coming back to shore. On the contrary, it can be argued that a parallel current will not only disperse nutrients and other pollutants to down-current locations, but will be taken up by reef communities along this coast potentially impacting marine life (e.g., den Haan et al., 2016).

I also note that investigations supporting this option (GHD, 2018a) failed to gather local knowledge from fishers and other stakeholders to fully understand the risks of an ocean outfall. For example, < 500 m offshore from the area proposed for the outfall as well as several locations down-current from this area (between Avana and Avarua), are important fishing spots for the *mangā* (deep-water snake mackerel, *Promethichthys prometheus*) (Peter Toto, Ministry of Marine Resources Officer Sonny Tatuava, pers. comm), a favorite fish consumed by locals. In fact, the probable outfall locations identified in GHD 2017 (see Appendix D, Figure 5) are areas (harbours and man-made channels as well as natural channels) where *mangā* fishing is conducted, because *mangā* tend to aggregate around areas of freshwater effluent. This stretch of coast also hosts several dive sites that are used regularly by dive operators. Surely, the dive industry would be impacted if tourists discover that a wastewater outfall is located up-current from these dive sites.

These algal species were also noted on the western exposure (coverage less than Avana fore reef) – south of the Edgewater Resort and other tourist accommodations in the area as well as the stream that drains the Landfill and the current sewage treatment plant in Arorangi (Figure 7). A dual pond treatment facility is used, and landfill leachate also discharges to these ponds; this facility is expected to treat all septage generated on Rarotonga to around 2023 (see ADB, 2009; point 187). The treated effluent that discharges into the nearby stream, flowing eventually to the lagoon some 1.6 km away, was noted to be high in nitrogen with possibly other contaminants of both organic and metal in origin (see ADB, 2009; point 187). Considering the distance between the treatment site and lagoon, there may be opportunity for the nutrients to be taken up on land under normal conditions (outside of flood events) before discharge to the ocean.

Whether these algal species can be used as bio-indicators of specific land-based pollutants are unknown, however, it may be useful to investigate this especially for wastewater effluent. Bio-indicators on the reef (e.g., coral and algal cover and disease prevalence on reefs) will be key in monitoring the distribution and impacts of wastewater discharge if an ocean outfall proceeds.

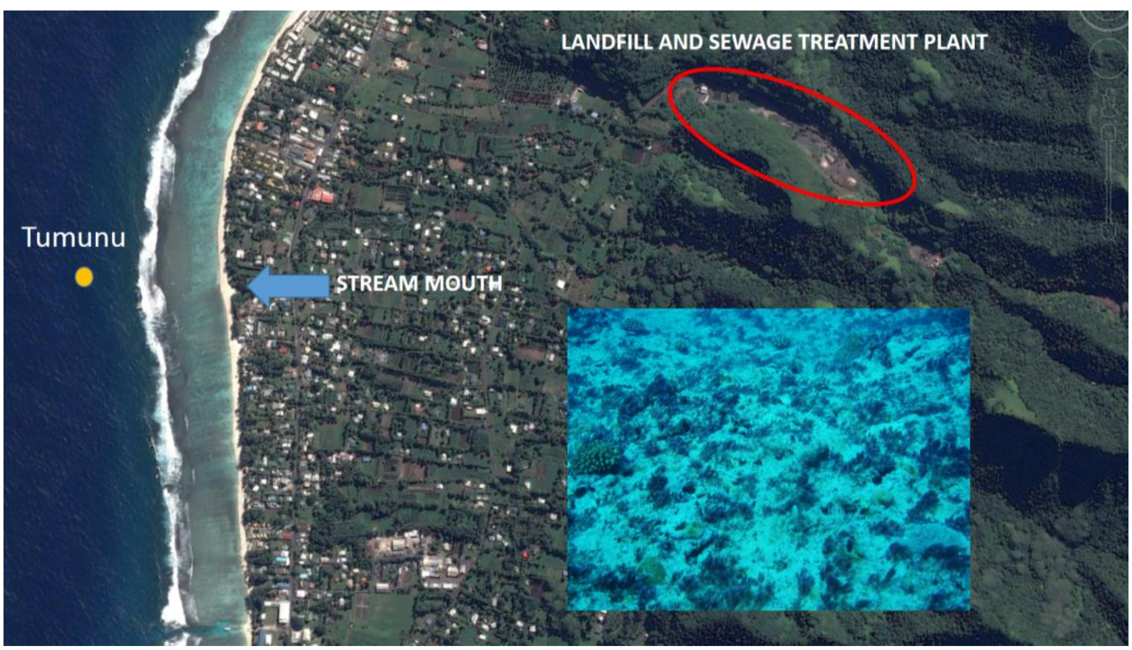

Figure 7. Google Earth image with red oval delineating the site of the landfill and sewage treatment plant. Blue arrow indicates the stream mouth that drains the catchment of the landfill and other water bodies in the area. Yellow dot marks Tumunu site, that has been surveyed since 2000. The insert is a picture of Tumunu's reef benthos surveyed in 2011, indicating patches of the algae *Asparagopsis taxiformis*.

Summary

The oceanographic information presented in GHD's report (see Appendix H in GHD, 2018a) is insufficient to support the ocean outfall option. Given the gaps identified in the GHD report (i.e., lack of local knowledge) and concerns raised regarding the potential risks to the nearshore reef communities (e.g., COTS outbreak, marine disease, compromising reef resilience, and facilitating a shift towards the undesirable algal-dominated reef state) and people's livelihood (e.g., fishing, dive tours among others), the ocean outfall option **should not be considered**. The fore reef habitats around Rarotonga serve as refuge for marine biodiversity that help replenish lagoon populations. Therefore, nutrient inputs into this environment may cause more problems for the lagoon – the very environment we are exploring solutions to protect. In fact, the ocean outfall option removes responsibility of good stewardship of our environment, and allows room for more development without consideration of the environmental consequences because the sewage problem will be "taken care of" and wastewater will be disposed into the ocean – "out of sight, out of mind" – further encouraging more wasteful practices as well.

I am not aware of any success story regarding coral reef communities near an ocean outfall. Scientific literature has shown negative impacts of wastewater disposal into the marine environment (e.g., Kaneohe Bay in Hawaii, Smith et al., 1981; Guam, Redding et al., 2013). In addition, sewage overflow from treatment plants close to the coast are also of concern (e.g., Hawaii News Now, 2018a,b). For the Cook Islands, the ocean outfall option may further compromise our image as an eco-friendly destination for tourism considering the negative publicity surrounding the purse seine fishing issue and the prospect of deep sea mining in a supposedly conservation-focused ocean space – the Marae Moana. Furthermore, water is a limited resource on Rarotonga; discharging this resource to the ocean would be a wasted opportunity to recycle water and nutrients especially for agricultural purposes.

3. Hybrid Option 2B

As discussed above in Option 2, the ocean outfall is not acceptable and therefore this hybrid option not viable. The Sogi ocean outfall of Samoa was mentioned by GHD as an example for us to consider (see Appendix B in GHD, 2018a), but refer to this article for concerns raised: http://www.samoaobserver.ws/en/03_11_2016/local/13476/Waste--water-threatens-town-plan.htm

4. Other options to consider

In my recent communications with local service providers regarding the WATSAN pilot project and about sanitation on Rarotonga in general, it was noted that managing our sanitation issues **"should have been a local approach by locals, 'assisted' by a consultant for capacity building based on local knowledge and a positive local drive to a solution".** Options provided in this section can be used in combination to reduce nutrient enrichment and their impact to the marine environment. These are cheaper, workable alternatives to the options presented by GHD, which can 1) reduce our reliance on overseas consultants and contractors who offer multi-million dollar solutions that are not necessarily suited to the Cook Islands context, 2) build capacity of our Ministries, NGOs, private sector, etc., and 3) engage the wider community to participate in the solutions which is key to promoting ownership, good stewardship, and awareness of the issues:

a. **<u>Household onsite treatment systems</u>** - The Calibre review (2015) discussed the failures of the WATSAN pilot project and identified some important areas where improvements can be made. However, based on limited information (e.g., insufficient lagoon water quality data), the review seemed reluctant to give the project a chance to improve on the lessons learned. Instead, a completely new solution of a centralized reticulated system was offered that focused on taking the responsibility away from homeowners and local service providers. A centralized system would also remove the education and awareness component (i.e., impacts of sewage and wastewater on the environment) because this solution requires minimal involvement from users – "*out of sight, out of mind*".

   An alternative to the centralized system would be to relook at the WATSAN pilot project and make improvements, starting with the problems identified in the Calibre review (2015). A critical part of the project would be the monitoring component (discussed more in Part b of this Section), which could be outsourced to independent organizations (e.g., environmental NGOs).

b. **<u>Consistent monitoring programs</u>** – A gap identified when it comes to marine-related problems is the lack of data from consistent monitoring programs to help make informed decisions. There is a tendency for monitoring to be reactive – we start only after a problem occurs. Also, there has been the lack of testing facilities on the island, as mentioned in the WMI review (Calibre Consulting, 2015). I believe we now have private facilities and Ministries that can carry out water quality testing on Rarotonga (e.g., CIMTech, Cook Islands Ministry of Health and Ministry of Marine Resources), and funding should be made available to upgrade and maintain these facilities and build local capacity to conduct testing. For the purpose of monitoring lagoon health, water quality data on nitrogen, phosphorus and enterococci concentrations (as indicators of sewage effluent) along with other parameters (i.e., Dissolved Oxygen, temperature, pH, chlorophyll a, suspended solids) needs to be collected fortnightly. Other information needed are rainfall (from rain gauges in the area), irradiance, wind, and the Southern Oscillation Index. In addition, marine benthic surveys (i.e., coverage and species composition of algae) also need to be conducted quarterly to get a clear understanding of the biological changes within Muri lagoon in response to water quality and climate variations. After all, it was the algal problem that instigated the proposed sanitation solutions in the first place. Funding should also be allocated to support the coral reef monitoring program for Rarotonga and Aitutaki (and potentially extend this to the Pa Enua) as well as coastal mapping to understand long-term changes. We can consider giving the responsibility of biological monitoring and coastal mapping to NGOs and the private sector respectively who already have the capacity – instead of Government ministries – to ensure data is consistent, independent and transparent. Unfortunately, Government ministries have a poor track record regarding monitoring programs because of staff turnover where capacity is lost, especially when HOMS change over and dictate the direction of their Ministries towards areas of their interests at the expense of other areas.

c. **Ecotoilet options** - The most important factor contributing to nutrient loading is water, which acts as the medium in transporting nutrients from one point to another. Yet, water is a limited resource on Rarotonga. A very dry spell (drought) is defined as 15 days or more with no rain (Thompson, 1986); in the last few months of 2018, many households around Rarotonga were without water as a result of prolonged drought periods associated with a moderate El Niño which brings cool and dry conditions to Rarotonga. In the Cook Islands, it is estimated that the daily average use of water is around 260 liters per capita per day (http://www.pacificwater.org/pages.cfm/country-information/cook-islands.html), and a third of this amount may be attributed to toilet flushing alone based on a New Zealand example (http://www.learnz.org.nz/water172/bg-standard-f/water-use). A waterless system (Figure 10; see also http://www.ecoloogroup.com/) was mentioned in the wastewater options report (GHD, 2017), but disregarded because it was deemed unacceptable to the wider community based on the Beca's report (Beca International Consultants, 2012). Yet, in 2018, there has been an increase in waterless systems installed in Rarotonga and in the Pa Enua (e.g., by PTS Plumbing, a local contractor; private homeowners), and is gaining acceptance from the general public and business community (e.g., Discover Ecocentre in Arorangi). Waterless systems will not only reduce our use of water, but also eliminate the transportation of nutrients to the ocean. Awareness programs promoting these waterless systems and the benefits on our environment need to be disseminated to the wider community to continue to change mindsets. Similarly, such promotion would enhance the Cook Islands' image as a green, environmentally-conscious destination, which would benefit our tourism sector and align with our Marae Moana objectives. Perhaps Government can consider subsidies, similar to the water tank subsidy scheme, to encourage households to change over to this type of system.

Figure 10. Ecoloo option that may be a very important alternative to flush toilet systems mainly used in Rarotonga, especially with the wastewater issues our island is currently experiencing. http://www.ecoloogroup.com/ecoloo.html

d. **Public awareness** - Public awareness is perhaps one of the most important components of any project in the Cook Islands, yet receives minimal funding allocations. ADB (2009) identified that the issue of sanitation in the Cook Islands received limited public awareness. Thus the sector suffers from poor public or even official awareness of the nature of the health and environmental risks associated with the lack of proper sanitation facilities. There is a need for an extensive awareness campaign about health and hygiene at all levels, which will generate support for sanitation services and appropriate levels of funding. We need to be creative in ways of delivering awareness not only for solutions but also for changing mindsets. Perhaps the approach can be community groups (e.g., NGOs, church youth groups, sports groups, schools, Cook Islanders studying) utilizing small grants programs – focused around the issues of sanitation – to actively participate in solutions that promote awareness (e.g., tree planting programs, short documentaries, reef studies, art exhibitions, etc.). For example, one of the GEF Small Grants Programme's priority areas for 2019 is on waste management: https://www.thegef.org/topics/gefsgp

e. **<u>Tree planting</u>** - If you examine the terrestrial flora of Ngatangiia, you will find that most of the trees are introduced ornamentals, such as various palms including coconut trees where most have shallow root systems. Native coastal trees like Tamanu (*Calophyllum inophyllum*), Utu (*Barringtonia asiatica*), Pukatea (*Pisonia grandis*), and Puka (*Hernandia nymphaeifolia)* that have been deforested along most of the coast of Rarotonga (but still found along Panama road), are deep-rooted that can likely penetrate the shallow nutrient-rich groundwater of Muri. These trees will also help protect the coast from erosion and high seas. For example, Palmerston hosts the last healthy *Tamanu* forest in the Cook Islands that are protecting the island from coastal erosion and cyclones as well as possibly reducing nutrient loading into the lagoon. Currently, NGO Kōrero o te 'Ōrau in partnership with Manava Ora o te Ivi Maori, have started school holiday programs – funded by the Ridge to Reef Project under the Cook Islands National Environment Service and implemented by the Ministry of Agriculture – and one of the activities is to reforest Rarotonga's coast with native trees (Figure 8). Utilizing the expertise of the Ministry of Agriculture and collaborating with NGO groups, schools, church groups, etc. to implement this approach may be more effective and beneficial because the community is actively participating in solutions that foster awareness and ownership of the issues of sanitation.

Figure 8. School holiday programme run in October 2018, where children planted around 20 native trees along the coast of the Nikao cemetary/RSA area to combat coastal erosion. Pictured here is a Tamanu tree (photo by Nana Tokari).

f. **<u>Coastal Protection Units</u>** – One factor not examined by GHD because of the lack of historical scientific data – though local knowledge has noted this over time – is the shallowing of Muri lagoon. This is not unique to Rarotonga and has been observed throughout the Cook Islands (see Rongo and Dyer, 2014), which is likely attributed to several factors: 1) increased storm activities in the last 30 years due to a shift in climate variability (e.g., positive Pacific Decadal Oscillation), 2) global sea level rise, and 3) man-made changes along the coast (e.g., increased use of sea walls). These changes have likely transported large amounts of sand into lagoons or out to the ocean. Shallowing may have led to elevated lagoon temperatures during the day (e.g., ADP, 2009), which combined with nutrient loading may cause changes to algal community composition. Today, we are seeing algal species that were not common before, while some that used to be common have disappeared or become rare (Rongo and Dyer, 2014). A potential solution is to try and restore some of the coast by slowly removing sand from the lagoon using Coastal Protection Units designed by Don Dorell (e.g., at the western end of the Rarotonga runway; Figure 9). These units are already in use around Rarotonga and proven to work by not only dissipating energy of waves, but most importantly accumulating sand along the coast. Other systems may be available, but the underlying idea is to deepen Muri lagoon by removing sand without using the destructive practice of dredging. This should restore some of the beaches in Muri (note: Muri beach was wider and horse racing was one of the activities carried out there), and can also reduce the area of stagnant waters where seaweeds are growing (Figure 10). Following the beach restoration, reforestation of this coast (see Option a) to retain the sand could be considered. This approach can be developed and implemented locally. This approach to climate change adaptation that can perhaps qualify as a project under the Green Climate Fund scheme.

Figure 9. *Left*: Coastal Protection Units (CPU) designed by Don Dorell, deployed at the western end of the Rarotonga runway. *Right:* CPU deployed in Vaimaanga, which may be suited for use in the Muri lagoon.

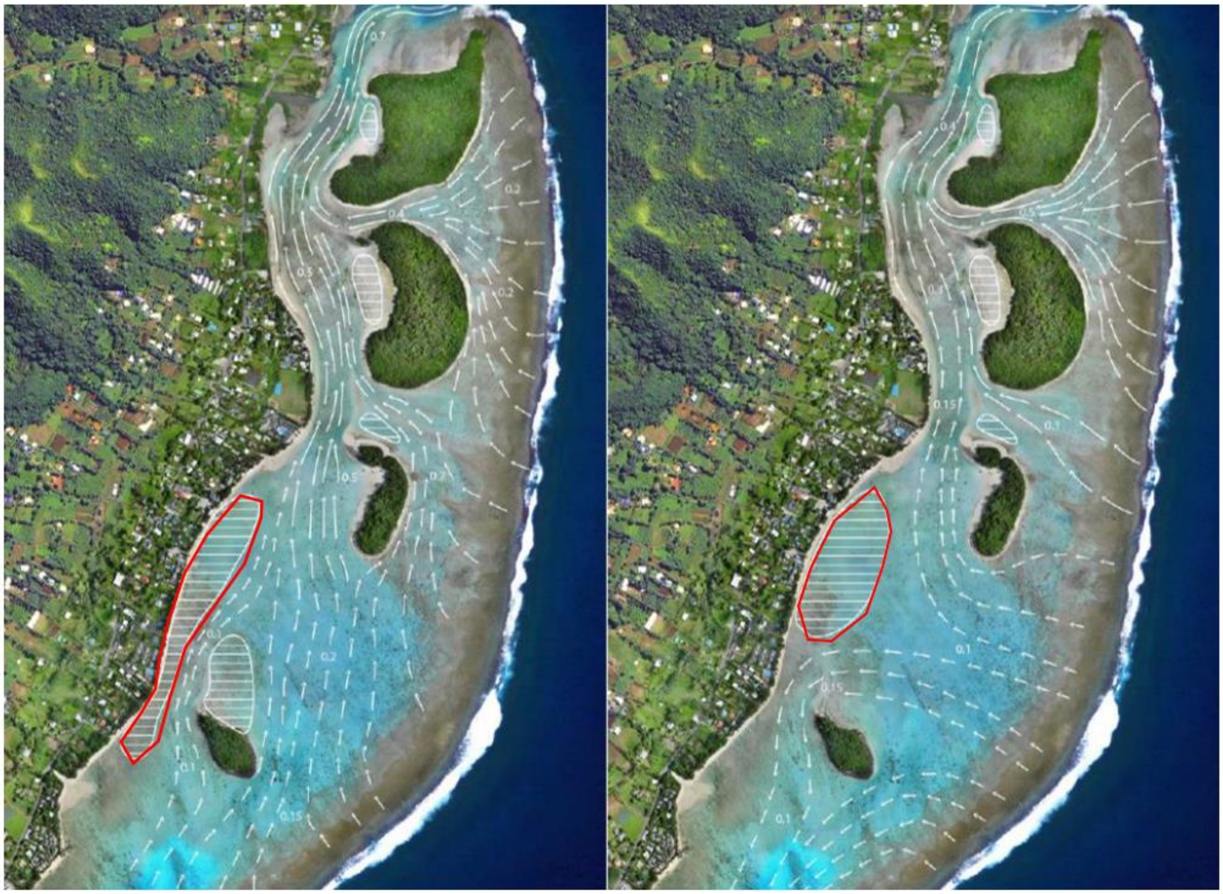

Figure 10. Taken from GHD, 2018b. Red area delineated are stagnant zones identified where large algal mats have grown.

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