Interdisciplinary Assessment of the Muri Lagoon

Final Report

Consolidating the Sanitation Development Upgrade for the Cook Islands Government

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Final Report

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Abbreviations

The following abbreviations are used in this document.

ABNJ	Areas Beyond National Jurisdiction
AEE	Assessment of Environmental Effect
AWS	Automated Weather Station
CCD	Climate Change Department
CFP	Ciguatera Food Poisoning
CH-a	Chlorophyll - a
CIG	Cook Islands Government
CNL	Central National Laboratory
COTS	Crown of Thorns starfish
DIN	Dissolved Inorganic Nitrogen
DPSIR	Driver; Pressure; State; Impact; Response
DO	Dissolved oxygen
DRP	Dissolved Reactive Phosphorus
EEZ	Economic Exclusive Zone
EBSA	Ecologically and Biologically Significant Areas
EIA	Environmental Impact Assessment
FADs	Fish Aggregating Devices
GDP	Gross Domestic Product
ICI	Infrastructure Cook Islands
IMF	Integrated Monitoring Framework
IMP	Integrated Monitoring Programme
IRD	Institute of Research and Developments
ISO	International Standardization Organization
JCU	James Cook University
KEF	Key Ecological Features

MCS	Monitoring, Control, and Surveillance
MFEM	Ministry of Finance and Economic Management
MNES	Matters of National Environmental Significance
MMR	Ministry of Marine Resources
MoA	Ministry of Agriculture
MoT	Ministry of Transport
MSP	Marine Sector Policy
MTCKTV	Mei Te Vai Ki Te Vai
N	Nitrogen
NO_3-N	Phosphate related nutrients
NES	National Environment Service
NH_3-N	Nitrate related nutrients
NH_4-N (NH_4)	Ammonia related nutrients (Ammonia)
NSDP	National Sustainable Development Plan (2016-2020) " Te Kaveinga Nui"
OIP	Oceans and islands Programme
OPM	Office of the Prime Minister
P	Phosphorus
PPT	Parts per thousand
PSSAs	Particularly Sensitive Sea Areas
RAPCA	Rapid Coastal Assessment
R2R	Ridge to Reef
SOP	Standard Operating Procedures
SPC	The Pacific Community (originally SOPAC)
SPREP	Secretariat of the Pacific Regional Environment Programme
SPRFMO	South Pacific Regional Fisheries Management Organisation
TN	Total Nitrogen
TP	Total Phosphorus

UAVs	Unmanned Aerial Vehicle
UoNSW	University of New South Wales
VMS	Vessel Monitoring System
WATSAN	Infrastructure Cook Islands' Water, Waste and Sanitation Unit
WMI	Waste Management and Sanitation Improvement
WHO	World Health Organisation

EXECUTIVE SUMMARY

The global objective of this consultancy assignment (commissioned to AECOM) is to undertake a multidisciplinary review of key parameters impacting on the health and quality of the marine ecosystems at Muri Lagoon. The assignment was designed to assist MMR, using available datasets, to provide a professional opinion on the cause of seaweed growth in the Muri Lagoon.

The Final Report is structured to address this key aspect, plus all other required aspects of the project and hence as adopted to use of the following headers. Brief findings and recommendations are presented under each of these respective headers.

KEY OBSERVATIONS

The importance of a number of geological (hydrogeology and presence of "motus"), oceanographic (sea temperature/salinity/currents), climatic (wind direction and rainfall) and anthropogenic parameters (nutrient input) all contribute to the understanding of what causes the extent, formulation and magnitude of seaweed outbreaks within Muri Lagoon. Regional climatic cycles (El Nino and La Nina) appear to also be influencing factors in providing the ambient conditions for seaweed growth over longer timescales.

Clear answers cannot be provided to exactly determine the cause of seaweed outbreaks, as there remains a series of outstanding datasets (stream and monitoring/groundwater analyses) that are still pending from the MTVKTV project during the second quarter of 2017. Despite this, based on available datasets reviewed, it appears that the "risk period" for increased seaweed outbreaks falls between December and February each year when sea temperatures and rainfall is highest and salinity levels are at their lowest. In addition, nutrient loading into the Lagoon from the Muri catchment remains significant especially during high rainfall events, meaning that a sewage reticulation intervention alone, whilst beneficial, will not prevent future seaweed outbreaks in Muri. The additional data is vital to help formulate more accurate intervention strategies for Muri Lagoon.

PART A: TECHNICAL FINDINGS

Regarding the assessment of water quality data, lagoon flushing is deemed of paramount importance to help regulate sea temperature and salinity within the Lagoon (seaweed growth appears to be linked climatic factors, lagoon sedimentation thus reducing flushing and nutrient enrichment through streams). Nutrient inputs (phosphates and nitrates) have not been laboratory analysed by MMR since August 2014 and such data is urgently required in order to assist in confirming this theory.

Regarding the assessment of marine biodiversity data, new coastal habitat of maps need to be produced with immediate effect using a combination of drone technology, supporting imagery and ground truthing interpretation. In addition, improved knowledge on suspended sediment analysis, regular invertebrates (sea cucumbers), coral and seaweed species surveys should be included within MMR monitoring procedures for Muri and further afield. Introducing a "coral gardens" feasibility project is proposed.

Regarding the assessment of coastal hydrodynamics, pending coastal hydrodynamic model results (due by June 2018 through work by the University of New South Wales) should assist in improving

our understanding of natural flushing rates through the Lagoon and what impact (if any) enhanced flushing times (created by boulder or channel clearance related activities) would have on sedimentation, salinity and sea temperatures.

Regarding bacterial measurements, a series of "spiked" datasets (bacteria) have been captured by MMR and modifications to the current monitoring protocol for such situations arising are recommended to confirm or refute the measurements collated. The introduction of new E.coli testing is proposed to help improve understanding and communication of land derived bacterial inputs to the lagoon. Regarding the assessment of ciguatera outbreaks, a new "risk assessment" procedure should be initiated by MMR to help communicate "risk periods" for possible ciguatera poisoning. Research suggests that periods up to 3 months after a significant cyclone event (impacting of reef rugosity and rubble extent) appears to be a peak time for possible cases to be recorded. Updates to Ministry of Health (MoH) recording templates (questionnaires) are proposed based on international best practice (protocol being MMR to detect health issues who then report this to MoH).

Regarding current MMR field monitoring procedures, field monitoring programmes should seek to embrace a "zonal" approach, capturing water quality and sediment information within the inner, outer and reef crest areas as far as possible. A number of improvement proposals are presented, including the recommendation to initiate a tablet/mobile based data collection approach (and supporting software) which may be promoted to provide a platform for integrated field data collection through any web browser in the future (which may be expanded to the outer islands in time).

PART B: PROPOSED RECOMMENDATIONS

Regarding proposed Intervention Measures to Rehabilitate Muri Lagoon, a number of possibilities are put forward, though efforts to cost these are not included in the absence of additional environmental monitoring data from MTVKTV which may influence the priorities of such actions. Efforts to improve flushing and to enhance water quality within the Lagoon remain a valid focus at this time.

An Integrated Monitoring Programme for Muri Lagoon is required, building on the MMR "Water Quality Manual" produced in 2011. This needs to involve an integrated approach, in tandem with other key stakeholders, to agree on the strategy for monitoring (key parameters needed to help deliver the indicators set within the NSDP 2016-2020). Updates to monitoring protocols, including emergency monitoring and reporting (to assist the "State of the Coast" reporting approach, is recommended (currently drafted in Appendix F).

Regarding updates to existing databases and Information Management System, there is a need to review and replace the current RFID system to help this to be more user friendly for MMR. The introduction of a specific geodatabase is also required adopting the current ARC GIS platform though adding specific software "platforms" such as ARC Enterprise and ARC Collector etc.)

PART C: IMPROVING OUTREACH AND COMMUNICATION

A new Health Card structure and format is adopted, that embraces (in addition to scoring water quality) biodiversity and also public health. It is also recommended that the current 6 graded scoring system is reduced to 5 to better reflect international statistical best practice and Health Card score systems adopted in similar environments. A supporting, easy to use spreadsheet has been created

to assist MMR in presenting time series data for specific locations which can be used in future "State of the Coast" reporting templates. A final Warrant of Fitness score card can only be completed upon receipt of updated environmental monitoring results to be attained from the MTVKTV project in mid-2018.

Regarding improvements to public education, a series of posters, new Fact Sheets, social media posts and "State of the Coast" templates have been produced. Additional recommendations have been put forward to encourage wider awareness programmes to be put forward to help with outreach to schools (gamification ideas), tourists ("lagoon-snap" social media image capture) and the general Cook Islands public (re-launch of "Lagoon Day" etc. Updates to the current Draft MMR Communication Strategy has also been provided placing special emphasis on the need to improve coordination between agencies and ministries, and to be more proactive on the delivery of timely and accurate information on the health status of Muri Lagoon to the public.

Finally, AECOM propose that an update to the MMR Business Plan is undertaken to embrace the key activities that require attention into 2018. A preliminary estimate of budget requirements to achieve the whole range of tasks outlined in the report is calculated as being circa EUR 360,000 excluding Draft Infrastructural Intervention Measures (which require the completion of MTVKTV to determine precise requirements).

1. INTRODUCTION AND BACKGROUND

1.1. Project Overview

The Cook Islands comprise of 15 islands with a total residential population of almost 15,000. About 10,000 people live on the main island of Rarotonga (Census 2012). Nearly all infrastructural development is located on the coast where coral sands overlay a shallow groundwater table that drains rainwaters (via catchments) into an encircling coral lagoon. Muri Lagoon, which represents the widest part of Rarotongas' circling lagoon is the focus of this report and study. It is situated on the eastern shores of Rarotonga, in the Southern Cooks Islands (Figure 1.1).

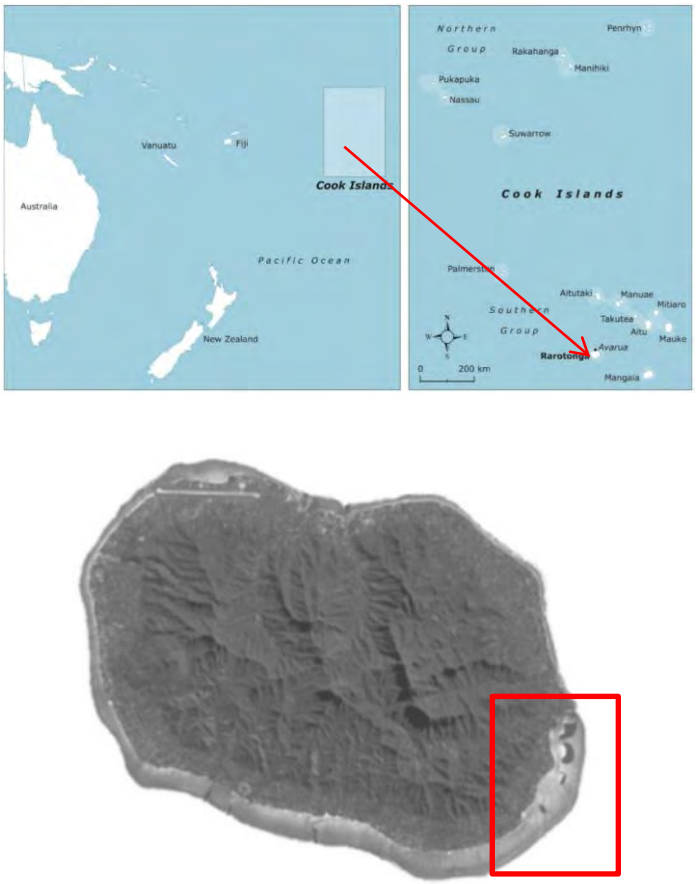


Figure 1.1: Study Area (Muri Lagoon, Rarotonga) identified by red box

Muri Lagoon represents the focal point for tourism in Rarotonga, however, for the last twenty years there has been concern over the health of Muri Lagoon, in particular its apparent deterioration from the effects of anthropogenic activities including sewage disposal and seaweed growth. Maintaining its natural health and visual quality is critical as the Cook Islands Sustainable Tourism Development Policy Framework (2016) cites tourism as the key driver for economic development in the Cook Islands, contributing over 60% of its GDP. The

Cook Islands Tourism Corporation in fact has estimated that Muri accounts for approximately 25% of bed usage on the island. Significant commercial development has occurred adjacent to Muri Lagoon to provide tourism services including resort accommodation and recreational activities. Details of the specific problems being experienced at Muri is presented in Appendix A.

1.2. Project Purpose and Objectives

1.2.1. Purpose

The global objective of this consultancy assignment (commissioned to AECOM) is to undertake a multidisciplinary review of key parameters impacting on the health and quality of the marine ecosystems at Muri Lagoon. The geographic limits of the study area span a 2.4km stretch of foreshore from Parengaru stream to Avana Harbour (see Figure 1.2). It also has a key purpose to provide professional judgement on the cause of the prolific algae growth recently witnessed in Muri Lagoon (resulting from adverse impacts from land based activities) and from this, to provide recommendations for a future integrated monitoring programme for the Ministry of Marine Resources (MMR), designed in such a way as to provide the required information to help introduce steps, policies and approaches towards helping to rejuvenate the lagoon ecosystem for safe public use. The projects conclusions shall be deemed (as far as possible) applicable to elsewhere in the Cook Islands so that recommendations presented may be applied to similar situations being faced on other parts of Rarotonga, islands in the Southern Group and Northern Group.

Importantly, the framework of this consultancy is to ensure that all findings deduced are closely intertwined with the goals of the Cook Islands government National Sustainable Development Plan (NSDP) "Te Kaveinga Nui'' 2016-2010 and the indicators for the marine and health sector as follows:

- 4.2 improve management of sanitation.
- 11.1 Protect wetlands,
- 11.3 Protect biodiversity and
- 12.1 Support healthy coral reefs,
- 12.4 Improve water quality

These indicators are addressed in more detail within Part B Section 8 of this report.

1.2.2. Objectives

Specific objectives to be undertaken within this consultancy (as defined in the ToR) include the following:

- Undertake a comprehensive review (with correlations) of all relevant water quality data collected and other key parameters that contribute to the negative impacts in Muri with relevant comparisons to other locations in the Cook Islands. From this, determine key parameters for an improved monitoring program. ***(see Part A – Section 2).***
- Review the coral and fish surveys of the Muri Lagoon and develop biodiversity indices for comparison and future monitoring. Compile a comprehensive habitat map with biodiversity indices of the Muri Lagoon showing benthic habitats, biodiversity hotspots and other notable features that are important ecological and eco-tourism features of the area ***(see Part A – Section 3).***
- Carry out a coastal hydrology study of the area to determine budget inputs into the lagoon. The coastal hydrology study should determine nutrient loads from the groundwater, streams and surface runoff; influence of intrusions, surface current flows, tidal flushing on residence times and seasonal changes; sedimentation and coastal erosion and other issues should be dissipated and a relevant coastal model of the locality should encompass both land and lagoon parameters (***see Part A – Section 4)***.
- Review public health safety concerns surrounding ciguatera, bacteria loads and other noxious agents and the current techniques for monitoring these such as enterococci and the development relevant public health standards ***(see Part A – Section 5).***
- Develop a resource monitoring programme to assess the health of the marine ecosystem and developing it into an indicator for marine ecosystem health. This monitoring program is essential as it will complement ongoing sanitation upgrades and provide a basis to assist decision makers to decide whether to (1) continue with the current sanitation on-site treatment or (2) commission the construction of a reticulated system ***(see Part A – Section 6).***
- Investigate sites for establishing coral gardens within Muri Lagoon that may be used to supplement tourism snorkelling and other marine tourism related activities ***(see Part B – Section 7).***
- Investigate options for the removal of the re-occurrence of benthic algae outbreaks ***(see Part B – Section 7).***
- Develop statistical sampling methodology and biometric standards for routine and intensive monitoring programs to ensure accurate and precise reporting relevant to ranges for survival of marine species **(see Part B – Section 8).**
- Review and update (as required) a consolidated database that can be shared among agencies and templates for public information ***(see Part B – Section 9)***.
- Design communication and information materials related to the protection of the Muri Lagoon ***(see Part C – Sections 10 and 11).***
- Design a communication plan for public awareness and informing regulating agencies ***(see Part C – Section 12).***
- Provide work plans that meet specific objectives with timelines and cost breakdowns ***(see Part D – Section 13).***

1.3. Report Structure

The detailed requirements for this Final Report are clearly set out as per the Terms of Reference (ToR) and reflect the objectives set out in Section 1.2 above. A slight revision to the order of the sections of the Final Report is carried out to avoid repetition and the better streamline the report without omitting any expected sub-section. This Final Report is therefore structured into 4 key "Parts" (A to D) to help convey the work undertaken. The specific sections (within each Part) are set out below:

PART A: TECHNICAL FINDINGS

- Section 2: Water Quality Data Assessment;
- Section 3: Marine Biodiversity Assessment;
- Section 4: Coastal Hydrology Assessment;
- Section 5: Public Heath Safety Assessment;
- Section 6: Field Monitoring and Laboratory Procedures;

PART B: PROPOSED RECOMMENDATIONS

- Section 7: Proposed Intervention Measures to Rehabilitate Muri Lagoon;
- Section 8: Proposed Monitoring and Reporting Programme;
- Section 9: Proposed Database and Information Management System;

PART C: IMPROVING OUTREACH AND COMMUNICATION

- Section 10: Reporting Templates (Public Sector Requirements);
- Section 11: Public Education Information Materials;
- Section 12: Communication Plan.

PART D: IMPLEMENTATION WORK PLAN AND BUDGET

- Section 13: Proposed Work Plan

NB: This Final Report (AECOM Dec 2017) builds on the work presented within a detailed Draft Report that was submitted and accepted by MMR in September 2017. It closely embraces the outputs and field work produced as part of the parallel project"Mei Te Vai Ki Te Vai (MTVKTV): Restoring the Health of our

Lagoons" undertaken by GHD for Ministry of Finance and Economic Development. (MTVKTV) (See Project website www.vaikitevai.com). (See Appendix B).

At the time of writing (December 2017), apart from routine monitoring of water quality undertaken by MMR/NES which was made available up to November 2017, no additional environmental monitoring fieldwork (groundwater surveys – see table below etc.), marine ecological mapping or coastal hydrodynamic modelling data or results have been completed for Muri Lagoon since June 2017. As a consequence of this, no new analytical results could be undertaken by AECOM in the Technical Findings (Part A) and subsequent findings reflected in the Proposed Recommendations (Part B) of this report. Additional updates to the findings put forward by AECOM will be required by MMR, during 2018, after completion of this consultancy.

At the time of writing, the GHD current groundwater environmental field work and monitoring programme schedule is as follows:

Action	Proposed Dates for completion
Drilling works and permanent groundwater monitoring sites (Limited monitoring/trouble shooting if required)	November 2017 to approx. 20 December 2017.
Detailed monitoring programme	28 February– end of April 2018.
EIA completion (stream delta)	Awaiting confirmation from NES regarding the EIA ToR. Subject to acceptance, EIA due for completion by early January 2018 and proposed works scheduled for February 2018.
Coastal Hydrodynamic Model	MFEM accepted (University of New South Wales) as preferred supplier. Indicative start date = January 2018 for circa 6 months.

PART A: TECHNICAL FINDINGS

2. WATER QUALITY DATA ASSESSMENT

This Section addresses the following project objectives (already defined in Part A Section 1.2)
Undertake a comprehensive review (with correlations) of all relevant water quality data collected and other key parameters that contribute to the negative impacts in Muri with relevant comparisons to other locations in the Cook Islands. From this, determine key parameters for an improved monitoring program.

2.1. Stream Water Quality

The three ephemeral streams (i.e.: that only exists for a short period following precipitation) are identified within the Muri Catchment: The Aroko, Aremango and Parengaru Streams. Run-off during rainfall events (and via groundwater) reports to the streams and swamp areas, and flow is generally channelled parallel to the beach before discharge to the lagoon. The exception to this general pattern of flow is Parengaru Stream, which has a stream channel that provides flow more directly to the beach (see Figure 2.1).

Enterococci spp is used as a parameter in the monitoring work as it is commonly found in the faeces of humans and other warm-blooded animals. The presence of Enterococci in water is an indication of faecal pollution and the possible presence of enteric pathogens. The findings of laboratory analyses are presented in Part A Section 5 (Public Health).

Figure 2.1: Stream Locations Draining into Muri Lagoon (taken from MMR 2011)

2.1.1. Ground Water Quality

Two recent phases of investigation have provided more detailed investigations of geology, hydro-geology (groundwater) and water quality. These include the range of investigations undertaken by Southern Cross University between 2011 and 2014 and work by Tonkin and Taylor (2014). Assessment undertaken by Southern Cross University has been relatively independent of Govt of Cook Islands (CIG) oversight, although they have also contributed to the assessment of a low cost on site wastewater treatment system (eco-trench).

The work undertaken by Tonkin and Taylor (2014) was undertaken in response to the initial recommendations by NIWA (2010) to expand the existing shallow groundwater monitoring well network. Figure 2.4 outlines the location of inland wells where ground water monitoring stations are positioned (from Tait *et al* 2014). Figure 2.5 shows the recorded presence of ammonium related nutrients (NH4) being source via the Parengaru Stream. Figure 2.6 shows a conceptual diagram of groundwater nutrient source pathways in Muri Lagoon.

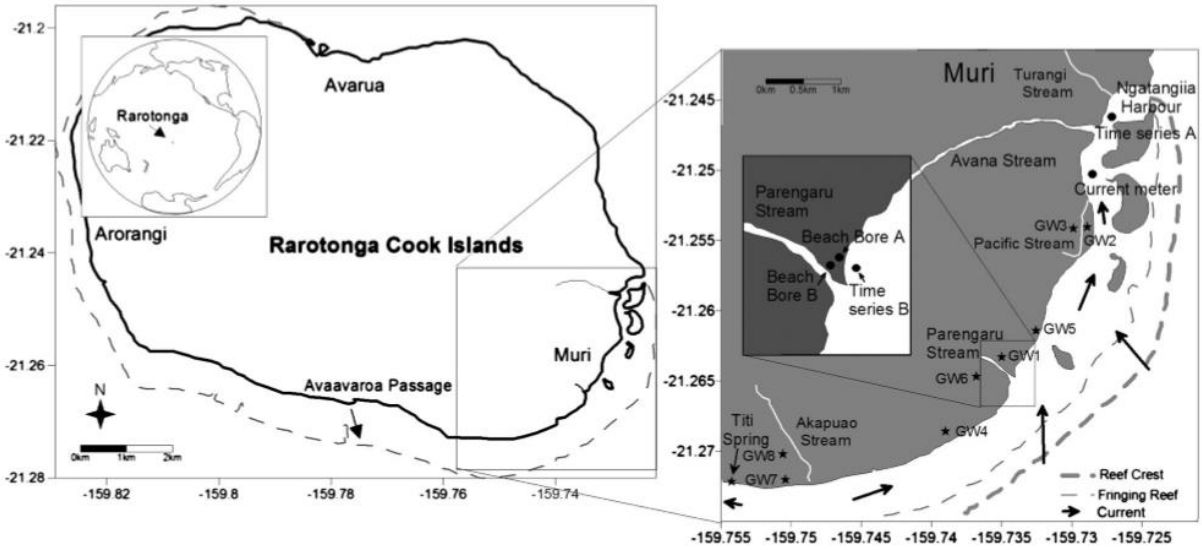


Figure 2.4: Map of Muri Lagoon and inland wells sampled are indicated with a "⋆" (taken from Tait *et al* 2014).

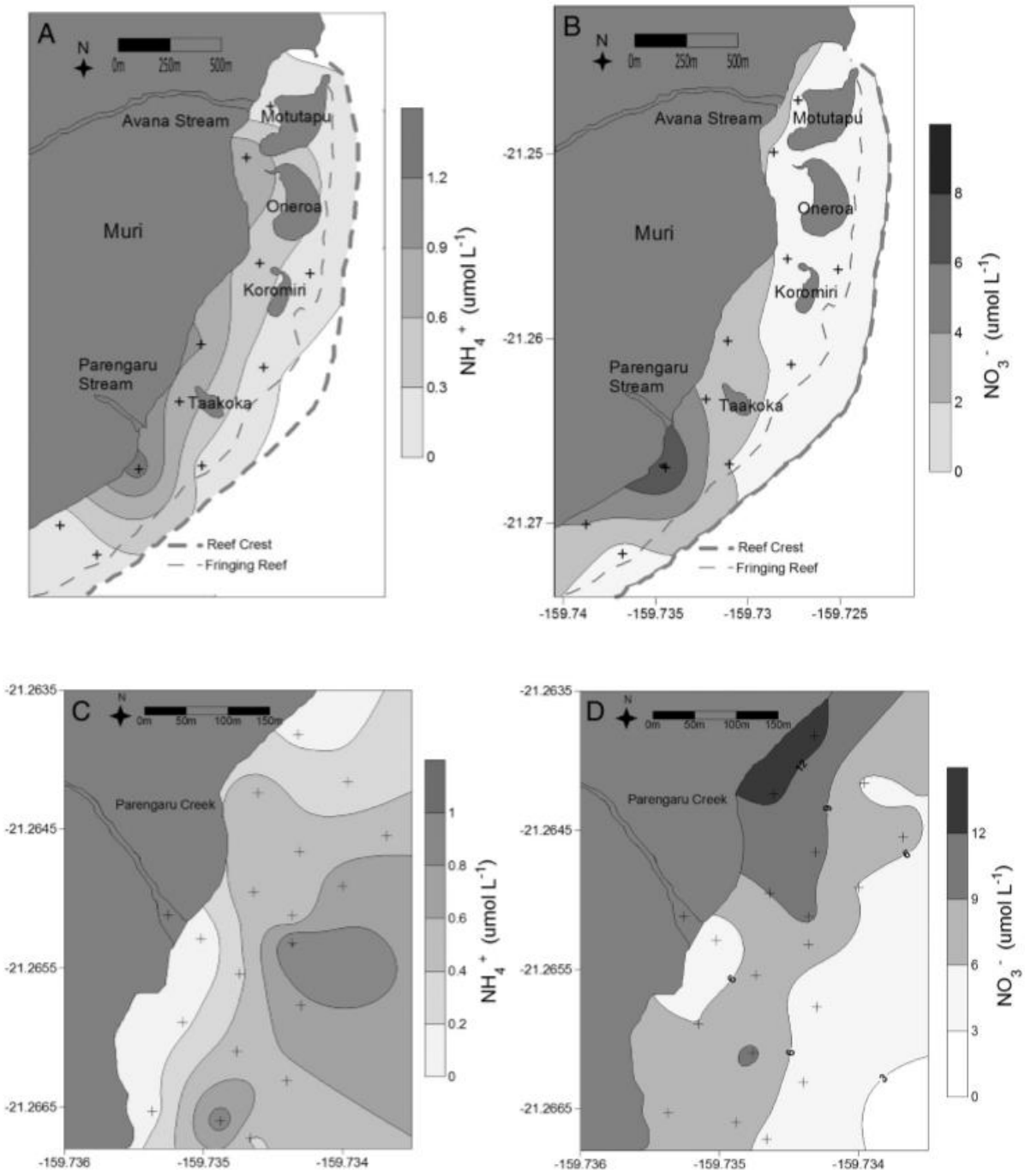


Fig. 2.5 Nutrient concentrations at large (A and B) and small (C and D) scales in the Muri Lagoon, Cook Islands. The "+" symbol indicates sampling sites (from Tait *et al* 2014).

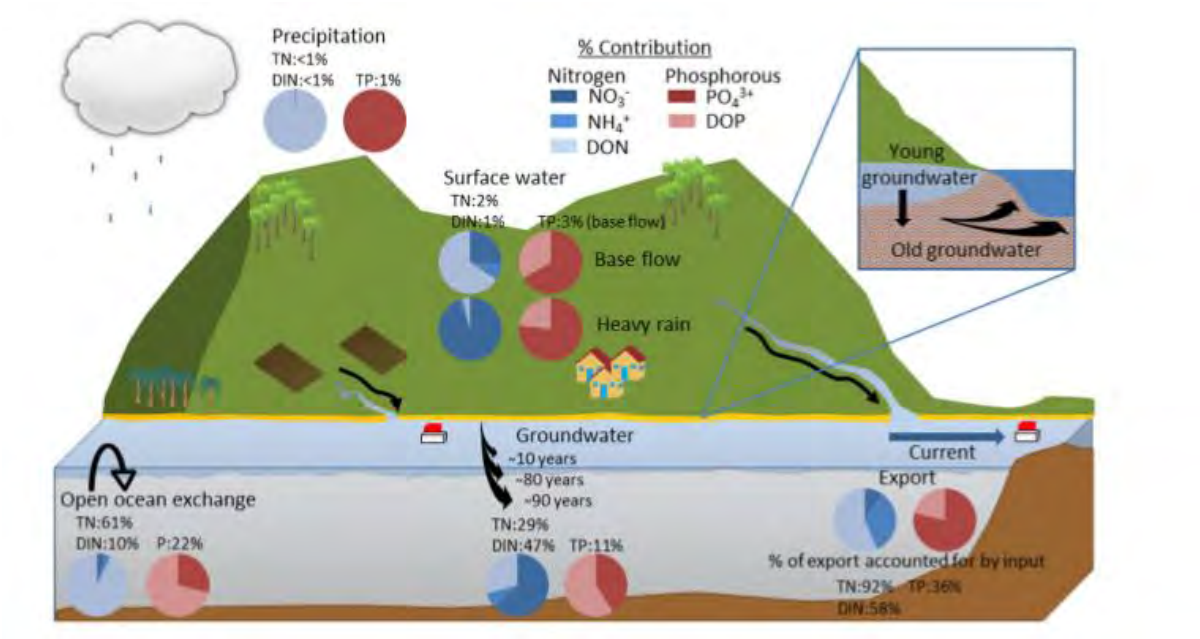


Figure 2.6 Conceptual diagram of the contribution of nutrient sources to the Muri Lagoon. Source percentages are expressed as the percent of DIN, TN and TP of export accounted for by the individual sources. The pie charts indicate the contribution of N and P forms to each input and output (from Tait *et al* 2014)

In summary, and as recently presented by GHD (2017) the identified groundwater flow paths which may contribute nutrients to the lagoon include the following:

- Groundwater discharging to the Lagoon will typically flow through the Lagoon floor sediments. The composition of the sediments (thickness, mineralogy and organic carbon content) will influence the nutrient transformations that occur and ultimately the nutrient discharge to the Lagoon from groundwater.

- Shallow groundwater at beachfront areas is thought to discharge within the intertidal zone and near shore. Nutrient attenuation within the coral sands occurs, reducing the nutrient concentrations within groundwater

- Groundwater within coral limestone is thought to discharge as submarine groundwater discharge through the lagoon floor and may discharge preferentially in current and historical reef zones, or areas less impeded by sediments, and

- Shallow phonolite rock may provide a preferential pathway for groundwater flow to the southern areas of the lagoon, where it is outcrops adjacent to the lagoon and as the motu Taakoka.

At the time of writing, GHD and the MTVKTV project team have embarked on initiating new drilling boreholes around the Muri Lagoon area. The installation of temporary and permanent monitoring wells has taken place

with relevant landowners as part of their environmental monitoring programme. Results of this exercise are likely to be made available to MMR during the Q1 of 2018.

2.2. Water Quality and Laboratory Standards

2.2.1. Water Quality Standards

MMR are currently using the standard water quality scaling system as set out below (Table 4.1):

Table 2.2: Water Quality Scaling System adopted by MMR for Muri Lagoon.

			Limits						
Subject	**Parameter**	**Units**	**A**	**B**	**C**	**D**	**E**	**F**	**Reference**
Nutrients	DIN (Dissolved Inorganic Nitrogen) . Sum of Nitrogen in Nitrate (NO3) and Ammonia (NH4)	ug/L	<2	>= ; <7	>=7; <14	>=14; <28	>=28; >56	>=56	Bel 1992 <14ug/L
Nutrients	DRP (Dissolved Reactive Phosphorous)	ug/L	<1	>=1; <1.8	>=18; <2.6	>=2.6; <5.2	>=5.2; <10.4	>=10.4	Bel 1992 <2ug/L
Water Clarity	TSS (Total Suspended Solids)	mg/L	<1.25	>=1.25; <2.5	>=2.5; <5	>=5; <10	>=10;<20	>=20	Bel 1992 <5 mg/L
Water Clarity	Chlorophyll	ug/L	<0.1	>=0.1; <0.25	>=0.25; <0.5	>=0.5; <1	>=1; <2	>=2	Bel 1992 <0.5 ug/L
Bacteria	Enterococci Bacteria	Bacteria per 100ML	<40	>=40;= <100	>=101; =<200	>=201;=<350	>=351; =<500	>=501	WHO Guidelines (2007-2015)
Bacteria	Enterolett Bacteria	Bacteria per 100ML	<41	>=40;= <101	>=101; =<201	>=201;=<351	>=351; =<501	>=502	WHO /EPA Guidelines (Adopted in 2015)

Dissolved Inorganic Nitrogen (DIN), dissolved reactive phosphorus (DRP), total suspended solids (TSS) and chlorophyll are all set via a benchmark establish by Bell (1992). A new benchmark for phosphorus assessment specifically for Rarotonga is currently being assessed (MMR 2011 – Table 2.3). This guideline is apparently not used for freshwater samples (to evaluate the bacterial water quality of the streams) as they flow directly into the lagoon and are likely to impact the bacterial water quality of the lagoon.

Table 2.3: Bathing water standards set by WHO (2001)

Category	Indicator Counts	Microbiological Assessment
A.	≤ 40 *Enterococci*/100ml	Suitable for swimming
B.	≥ 41 to ≤ 200 *Enterococci*/100 ml	Suitable for swimming but requires surveillance
C.	≥ 201 to ≤ 500 *Enterococci*/100 ml	Not suitable for swimming, requires assessment
D.	≥ 500 *Enterococci*/100 ml	Not suitable for swimming, public warnings

Overall, according to MMR reports, level of nutrients have been above standards for almost all test sites since 2007 up to July 2014. However, existing level of bacteria have been good since that date as well. Overall, water clarity seems acceptable most of the time. Figure 2.7 presents the Nutrient levels between 2010 and 2016 *(NB: this is not using MMR related data which only extends to July 2014)*. Nutrient levels are at an alarming level especially at two sites namely the Public Works site and at Arorangi School in addition to the Muri-Lagoon area. Overall, this is a Rarotonga wide problem.

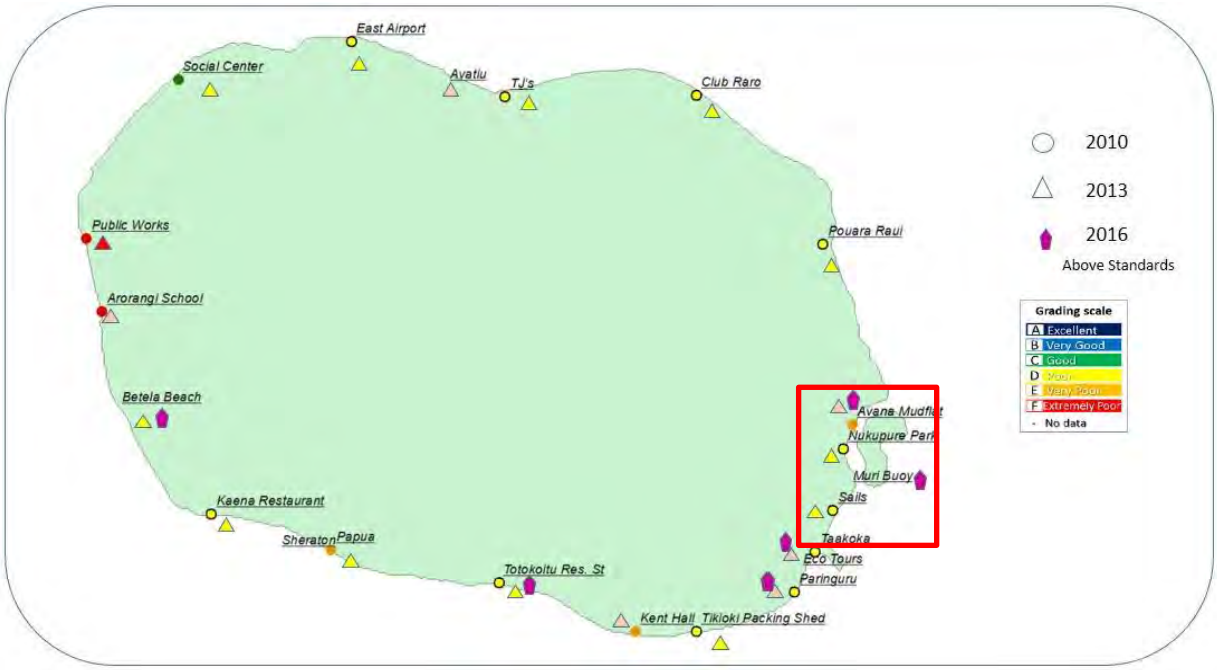


Figure 2.7: Recorded nutrient levels around Rarotonga 2010-2016 (Muri Lagoon within boxed area).

Although the level of nutrients are above the set health standards, bacteria levels are deemed at acceptable levels for all test sites in 2013. Figure 2.8 shows the results of bacteria tests for all sites specifically in 2013.

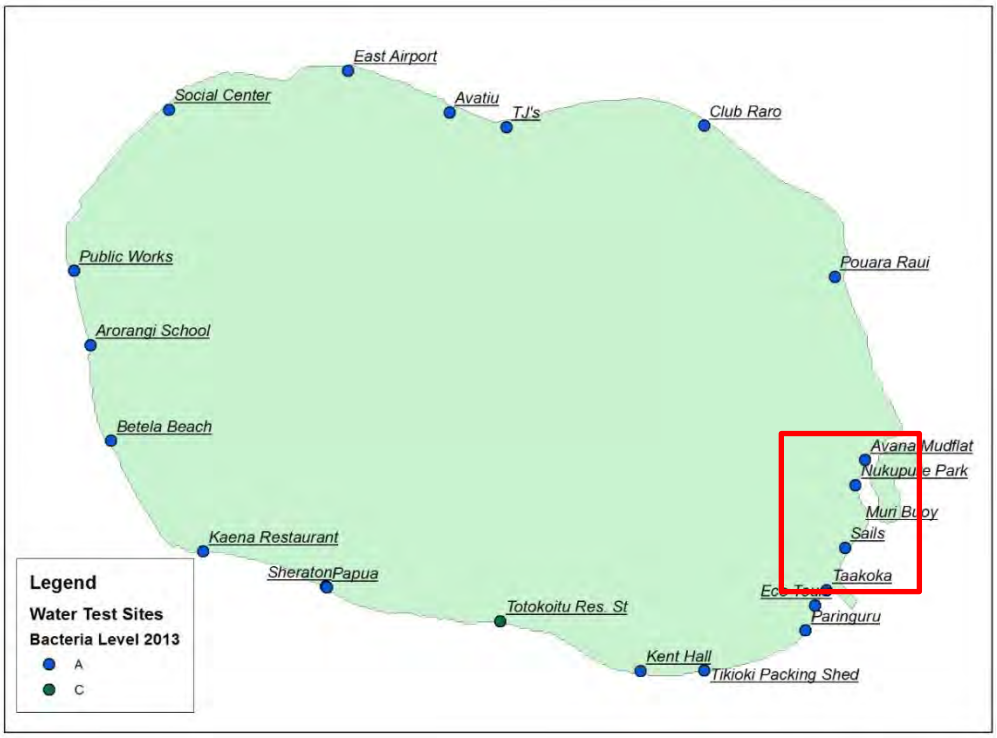


Figure 2.8: Recorded bacteria levels around Rarotonga in 2013 (Muri Lagoon within boxed area)

Sewage Standards

Current sanitation standards are set by the Public Health section of the Ministry of Health (MoH) who issue a set of guidelines for "on-site" sanitation as part of the development approval process. Two other government agencies may be involved in the permitting process; the NES may require an Assessment of Environmental Effect (AEE) and Infrastructure Cook Islands (ICI) who require a building permit. The Public Health guidelines are a three page document that sets out the requirements for a three chamber septic tank and soak hole/absorption trench. This same document specifies setback distances, from boundaries, public roads, buildings and water courses (Draker and Evans (2009)). These guidelines are now considered insufficient for the larger development projects and the environmental conditions typically found in the Cook Islands.

Infrastructure Cook Islands' Water, Waste and Sanitation Unit (WATSAN) has implemented a National Sanitation policy, as part of the Waste Management and Sanitation Improvement (WMI) Programme, that provides a high-level framework and set of guiding principles for the sanitation sector in the Cook Islands. This Policy has been integrated within the National Water policy in the interests of clarity and simplicity. Under the WMI Programme, WATSAN also developed a strategy for upgrading sanitation infrastructure by undertaking an assessment of potential options for the upgrade of sanitation systems on Rarotonga (and Aitutaki). The outcome of the assessment on both islands is that a combination of onsite treatment systems and public reticulated systems is recommended to achieve sustainable public health and environmental outcomes whilst recognising local constraints.

The Public Health (Sewage) Regulations 2007, drafted by the MoH, and more recent National Sanitation Policy (2012 & 2016) have been endorsed by Cabinet as has the current Cook Islands Water Policy (2016). This latter policy document integrates aspects of the sanitation and Integrated Water Resources Management policies, bringing together government policies for water resources management, infrastructure, water supply, drinking-water safety planning and sanitation. The statements and principles contained within the Sanitation Policy (2015) are consistent with the aims of the National Water Policy (2016) and a number of the planned activities cross water resources management and water supply. The new Water Policy (2016) and supporting legislation demands a considerably higher standard of sanitation practice than in the past, including increased capacity to deliver new standards within government agencies to support industry and engineering design requirements. For example the Regulations draw on many of the standards set in AS/NZS1547:2000 for on-site systems. The Regulations (see Appendix E) require the registration of Sanitary Professionals and Technicians. The registration of septic tanks and more advanced treatment units is required under Section 8&9 of the Regulations.

Laboratory Standards

Van Loon (2016) developed further the work of Leonardo (2006) to propose an integrated environmental and food analyses Centralised National Laboratory (CNL) within the Cook Islands. This is intended to broaden and

improve testing capabilities on island, provide considerable cost savings through efficiencies and eliminate duplication between separate laboratories that may exist in the country. This CNL is considered a priority to avoid delays in providing data so that informed decisions can be made to progress water and sanitation concerns as well as meet other testing requirements within the Cook Islands.

The Report identified the need for a CNL that is capable of producing high quality analytical data to overcome problems such as duplication of effort by different Ministries, getting analyses done within the required time frame and improving data quality. There is also an urgent need for increasing analytical capacity in order to implement sewage regulations, improve monitoring of drinking water as well as providing support to the relevant Ministries. The Report also identified that there was an urgent need to provide better and more consistent environmental analytical information and advice to support informed decision making to prevent or address environmental degradation and associated risks to the economy and human health.

Supporting the Leonardo Report, more recently, the Cawthron (2014) report stipulates that there is a strong need for a centralised laboratory on Rarotonga. By combining the laboratories there would be significant savings through economies of scale cost savings, procurement, quality systems management and staffing. A larger laboratory would also generate a larger pool of capabilities, resources and potentially laboratory space, which could be used as a platform for future developments and/or collaborations with overseas (research) partners. For example, a central laboratory could provide the space and other resources to host an experienced phytoplankton expert to support investigations of the algal blooms in the lagoons, and also address the ongoing issues with lagoon health and drinking water quality monitoring.

Specific details on the laboratory standards being adopted are presented within the Feasibility Report (2017). This report seeks to determine the requirement standards (approaches and protocols for environmental (including water & sanitation), food, plant and animal analyses for MOH, MMR, ICI, National Environment Service (NES) and Ministry of Agriculture (MOA).

2.3. Water Quality Monitoring Observations

2.3.1. Lagoon Water Quality Analysis

Table 2.4 provides the average water quality statistics that have been recorded by MMR between 2007 and July 2014 *(NB: this represents the most recent date for MMR laboratory testing on nutrients and phosphates. It must also be noted that MMR have not been analysing DRP (Dissolved Reactive Phosphorous) and DIN (Dissolved Inorganic Nitrogen = NH4+NO3) values since July 2014, although other parameters (except for chlorophyll) have been analysed as per Table 2.4).*

Table 2.4. Annual Average Statistics for Lagoon Sample Sites in Muri

Years	DRP (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	DIN (µg/L)	Chl a (µg/L)	TSS (mg/L)	Entrococci (cells/100mL)	Temperature (ºC)	Salinity (‰)	pH	Rain (mm)
2007	7.2	12.0	15.3	27.3	0.4	5.5	89.2	25.4	34.4	8.1	5.2
2008	6.3	11.7	15.6	27.3	1.0	3.9	393.6	25.5	33.8	8.0	5.4
2009	6.5	9.4	32.8	42.1	0.6	4.8	34.0	24.6	33.1	8.3	4.5
2010	5.9	10.9	11.1	22.0	0.7	2.6	180.0	25.6	34.2	8.1	4.3
2011	2.8	15.8	8.9	24.6	0.6	4.2	62.7	26.7	35.0	8.1	46.8
2012	6.6	16.4	9.4	25.8	0.4	7.0	65.2	25.7	34.3	8.2	19.5
2013	4.1	11.7	9.7	21.4	0.8	17.3	8.5	26.2	34.2	8.1	4.9
2014	8.6	14.8	8.5	23.3	0.5	4.3	67.1	24.8	34.4	8.1	5.2
Average	**6.0**	**12.8**	**13.9**	**26.7**	**0.6**	**6.2**	**112.5**	**25.6**	**34.2**	**8.1**	**12.0**

A key observation is that the level of DRP and DIN is reported as being higher than the defined water quality standards[1] which are adhered to by MMR (see Part A Section 2.2). With regards to water clarity, both TSS (total suspended solids) and CH-a (*NB: chlorophyll levels were tested in a laboratory in New Zealand but not at MMR's laboratory. Results all reported as being slightly above the standard values. Levels of bacteria are reported as being below the accepted standards (i.e.: below 200 bacteria per 100 MI)*.

Table 2.5 shows that the level of DRP and DIN recorded within the lagoon is well above what had been deemed acceptable when setting the standard. The applied standard of 2.6 for DRP and 14 ug/L for DIN was set by MMR between 2007 and 2014 however, it is clear that water quality results have recorded the existence of high levels of DRP and DIN within the lagoon since 2007 *(up to the last recorded MMR laboratory test results that were made available in July 2014)*.

Figures 2.9 and 2.10 provide monthly average DRP and DIN values for Lagoon sites between January 2007 and July 2014 (last recorded information for nutrients and phosphates). During this period, both DRP and DIN values were often higher than standards. Furthermore, it can be seen that the vast majority of the DRP and DIN values were mainly above the standard values after August 2011.

[1] DIN maximum acceptable level is below 14 ug/L . DRP maximum acceptable level is 2.6

Figure 2.9. Average Monthly DRP values for Lagoon Sites between Jan 2007 and July 2014 (arrow denotes period of growth)

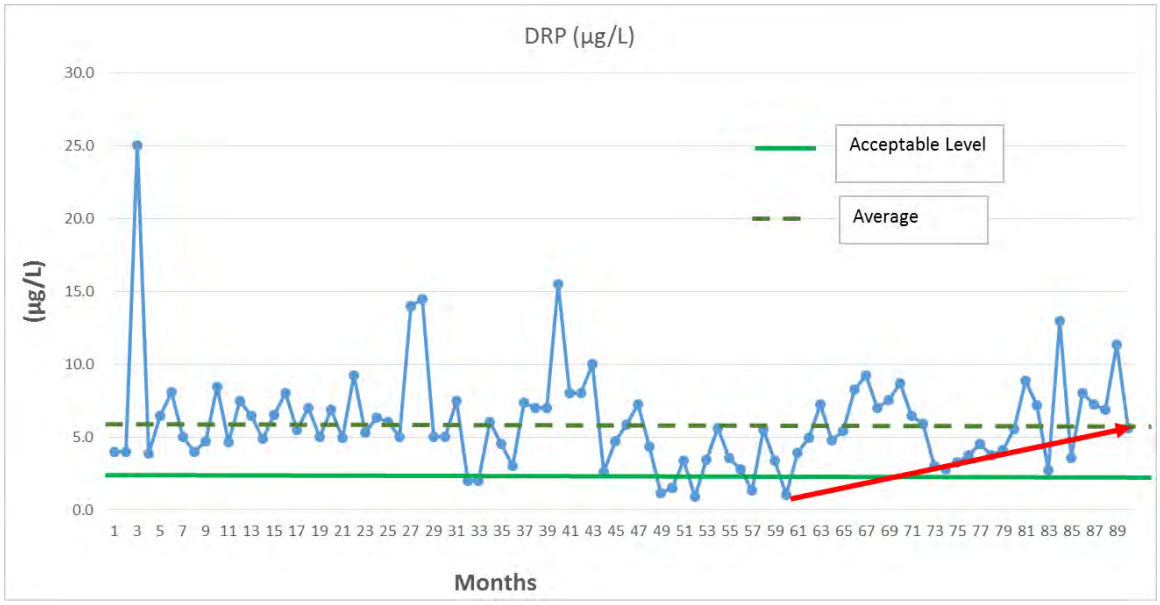


Figure 2.10. Average Monthly DIN values for Lagoon Sites between Jan 2007 and July 2014 (arrow denotes period of growth)

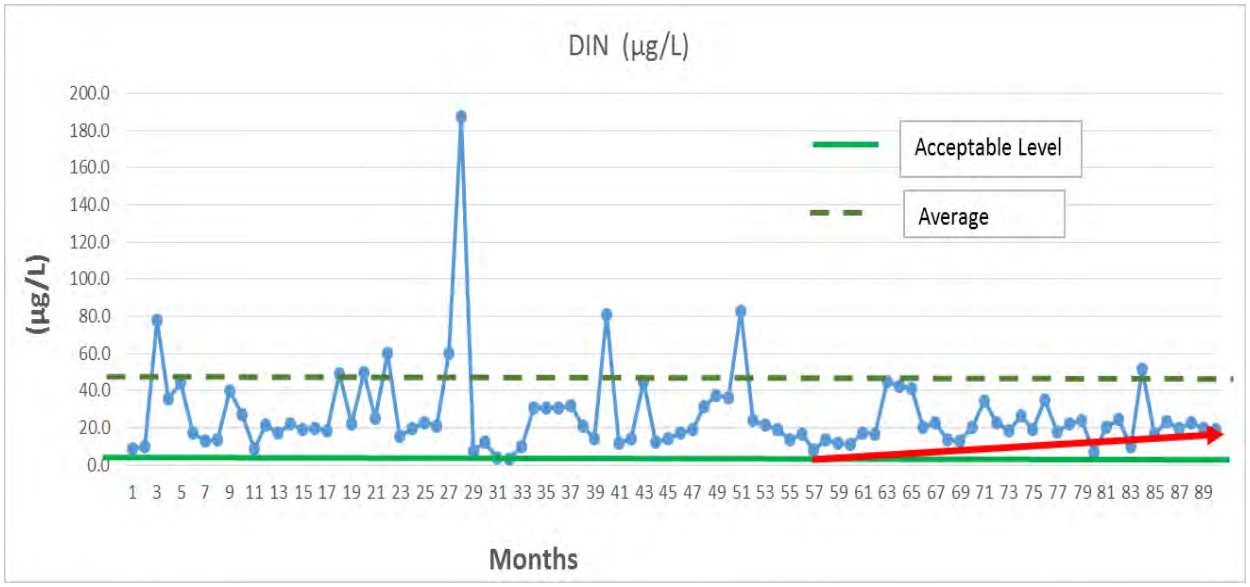


Table 2.5provides the monthly averaged water quality statistics for the collected Lagoon sites in Muri.

Table 2.5. Average monthly Water Quality Statistics for Lagoon Sites all around Rarotonga between Jan 2007 and July 2014

Months	DRP (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	DIN (µg/L)	Chl a (µg/L)	TSS (mg/L)	Entrococci (cells/100mL)	Temperature (ºC)	Salinity (‰)	pH	Rain (mm)
January	5.9	19.6	10.5	30.1	0.8	10.1	98.9	27.0	33.5	8.4	16.0
February	3.7	13.6	8.7	22.2	1.6	5.2	63.0	26.9	34.3	8.3	17.3
March	7.8	25.3	19.2	44.5	1.4	6.6	290.0	27.2	33.7	8.0	8.7
April	6.3	16.2	30.9	47.1	1.0	8.3	122.4	26.4	34.0	8.1	11.9
May	5.7	18.7	7.3	26.1	0.4	6.9	79.3	25.6	34.6	8.1	10.1
June	8.8	10.1	11.0	21.0	0.5	4.7	76.0	24.2	34.3	7.6	4.2
July	6.0	9.2	9.1	18.3	0.6	5.6	55.2	23.8	34.1	8.2	4.2
August	4.1	7.8	8.4	16.2	0.3	3.2	58.1	23.5	34.4	8.1	4.6
September	4.9	9.4	7.2	16.6	0.4	5.5	298.2	25.0	34.8	8.1	3.1
October	7.2	11.7	11.3	23.0	0.5	7.2	23.5	25.1	31.3	8.1	3.6
November	6.3	9.5	14.5	24.0	0.6	3.1	27.2	25.5	34.0	8.1	10.5
December	4.5	12.6	10.7	23.3	1.1	6.0	51.2	27.6	32.4	8.2	15.4

This data indicates that DRP values appear usually high in the months of March, June and October. Furthermore salinity levels also are recorded as being low in these same months. Available data from MMR suggests that statistically, there is a negative correlation between DRP and salinity. That means that as the levels of salinity reduce, DRP values increase. Table 2.6 (as a matrix) provides the correlation values between the water quality parameters for the Lagoon.

Table 2.6. Correlation Matrix between the Water Quality Parameters recorded by MMR

	DRP (µg/L)	*NH4-N (µg/L)*	*NO3-N (µg/L)*	*DIN (µg/L)*	*Chl a (µg/L)*	*TSS (mg/L)*	*Entrococci (cells/100 mL)*	*Sea Temp. (ºC)*	*Salinity (‰)*	*pH*	*Rain*
DRP (µg/L)	1.00										
NH4-N (µg/L)	0.03	1.00									
NO3-N (µg/L)	0.58	0.06	1.00								
DIN (µg/L)	0.53	0.45	0.92	1.00							
Chl a (µg/L)	0.02	0.01	0.10	0.09	1.00						
TSS (mg/L)	-0.02	-0.05	0.02	0.00	0.02	1.00					
Entrococci (cells/100mL)	0.18	0.01	0.11	0.10	0.01	-0.03	1.00				
Sea Temp. (ºC)	-0.11	0.28	0.10	0.19	0.14	-0.08	-0.05	1.00			
Salinity (‰)	-0.52	-0.04	-0.37	-0.36	-0.11	0.10	-0.08	-0.02	1.00		
pH	0.01	0.02	0.12	0.12	-0.09	-0.09	0.04	0.11	0.02	1.00	
Rain	-0.30	0.14	-0.07	-0.01	0.10	-0.09	-0.04	0.46	0.16	-0.02	1.00

Table 2.6 shows that between 2007 and 2014, DIN values appear highest during the months of March and April. In addition to this, there is negative correlation between salinity and DIN, which appears especially the case for the parameter nitrate. Hence, as stated above, as salinity reduces, both DRP and DIN levels appear to increase.

2.3.2. Sea Temperature, Salinity and Rainfall

With regards to average monthly sea temperate, these have been consistently recorded as being between 23.8 and 27.6 degrees Celsius. The lowest sea temperatures appear to be recorded between the winter months of June, July and August. Rainfall amounts appear to have a high positive correlation with sea temperature. It is apparent, from the analysis that as precipitation amounts increase, there appears to be an increase in sea

temperature which may be linked to regional climatic (El Nino/La Nina) oceanographic observations. Of interest, salinity appears to have a negative correlation with sea temperature, suggesting that as sea temperatures increase, salinity levels reduce.

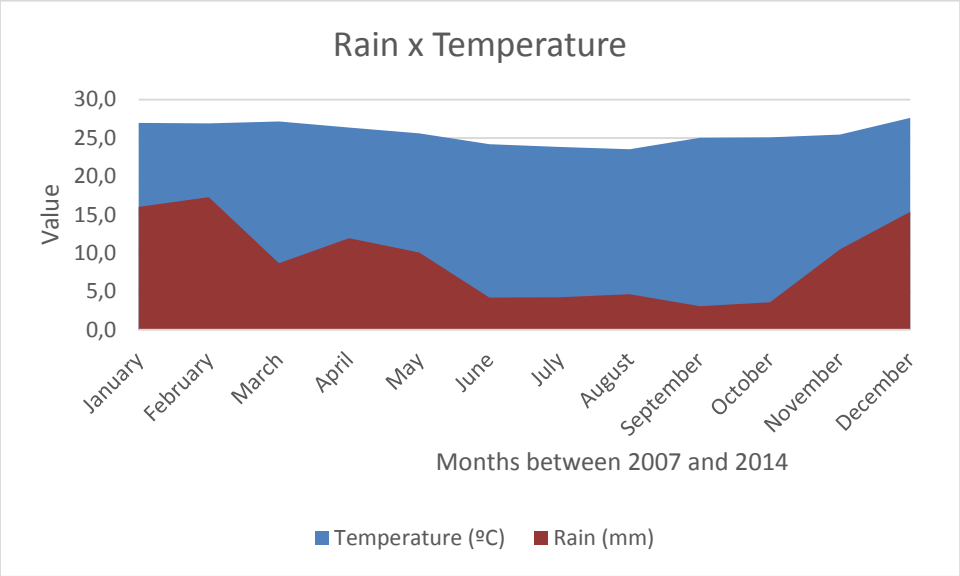


Figure 2.11: Monthly rainfall measurements mapped against monthly sea surface temperatures

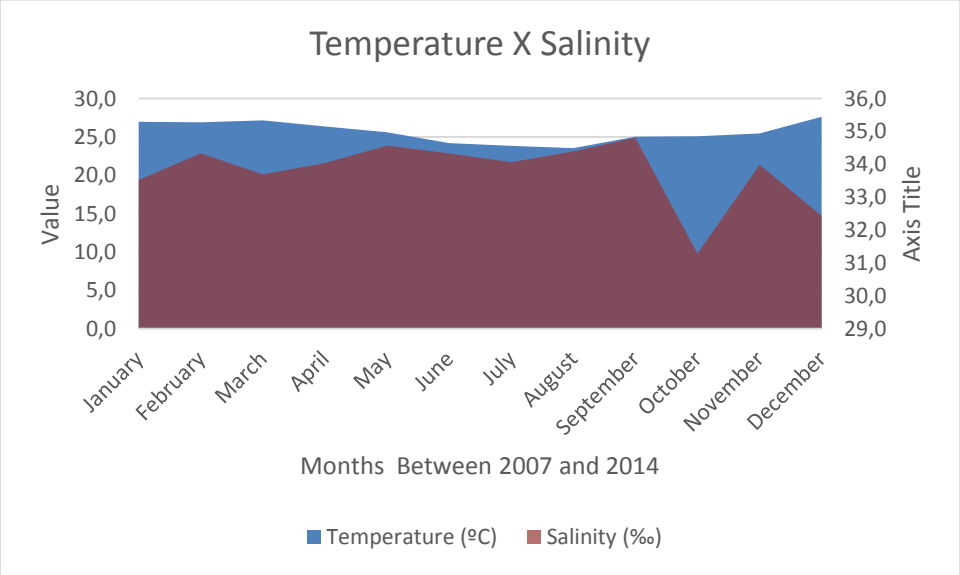


Figure 2.12: Monthly salinity measurements mapped against monthly sea surface temperatures

Regarding water clarity, CH-a value appear to be above the standard values set by MMR between the months of December and April (closely supporting the above observation regarding increased rainfall during the summer months). Total suspended solid (TSS) levels appear slightly above the MMR set standards though levels of bacteria consistently remain below the standard set (see Part A Section 5).

AECOM have used the available information (water quality and meteorological datasets) to assess seasonality change or implications over any calendar year. Table 2.7 presents the average values for water quality related statistics in 4 different annual quarters.

Table 2.7: Average Recorded values for water quality, oceanographic and climatic parameters

Months	DRP (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	DIN (µg/L)	Chl a (µg/L)	TSS (mg/L)	Entrococci (cells/100mL)	Temperature (ºC)	Salinity (‰)	pH	Rain (mm)
Quarter 1	4.7	15.3	9.9	25.2	1.2	7.1	71.0	27.2	33.4	8.3	16.2
Quarter 2	6.6	20.1	19.1	39.2	0.9	7.3	163.9	26.4	34.1	8.1	10.2
Quarter 3	6.3	9.0	9.5	18.5	0.5	4.5	63.1	23.9	34.3	8.0	4.4
Quarter 4	6.1	10.2	11.0	21.2	0.5	5.3	116.3	25.2	33.4	8.1	5.7
Overal all Avergare	**5.9**	**13.6**	**12.4**	**26.0**	**0.8**	**6.0**	**103.6**	**25.6**	**33.8**	**8.1**	**9.1**

NB: Period Definitions; Quarter 1: December – February; Quarter 2: March – May; Quarter 3: June – August; Quarter 4: September – November

Table 2.7 indicates that the Phosphates (DRP), Nitrates (DIN) and TSS levels are highest in Quarters 1 and 2 which corresponds with quarters when sea temperature and rainfall values are at their highest. Salinity levels are recorded as being lowest during Quarters 1 and 4. Rainfall values show the highest values recorded in Quarters 1 and 2. This new information suggests that the most suitable environmental conditions for seaweed development are within Quarters 1 and 2. Consequently, during the rainy summer season in the Cook Islands (December to February), sea temperature increases whilst salinity levels reduce. It is therefore suggested that the most likely period for seaweed development in Muri Lagoon is likely to be between December to February.

2.3.3. Stream Data Analysis

Descriptive statistics of stream water quality parameters (in the Muri area) are presented in Table.2.8 (2007 to 2015 only).

Table 2.8 Descriptive Statistics for Samples at Streams in Muri Lagoon (2007 and 2015)

Temperature (ºC)	24.3	**DRP (µg/L)**	29.1	**Entrococci (cells/100mL)**	2700.4
Salinity (‰)	2.7	**NH4-N (µg/L)**	41.5		
DO Saturation (%)	81.7	**NO3-N (µg/L)**	138.3		
DO (mg/L)	8.4	**DIN (µg/L)**	176.7		
pH	7.5	**TSS (mg/L)**	4.2		

Average DRP values can be seen as being almost 11 times higher than the MMR set standard levels (2.6 ug/L). In addition to this, average DIN was recorded as being almost 12 times above the standards (14 ug/L). As for the water clarity, although the level of TSS were below the standard limit (5mg/L) and the amount of bacteria levels recorded are almost 10 times above the quality threshold level (200 bacteria per 100 ML).

These results clearly indicate that the streams reaching Muri Lagoon have a strong contribution to nutrient levels entering the lagoon and hence a major contributor towards creating the correct chemical environment for the proliferation of algal growth (sea weeds). The reason for why high levels of DRP and DIN is being recorded in the streams may relate directly to current and past agricultural practices (including livestock practices) in addition to soil chemistry found in Rarotonga.

As illustrated in Figure 2.13 and 2.14, monthly average DRP and DIN values in the streams are reported as being much higher than the standard values set for these parameters nationally.

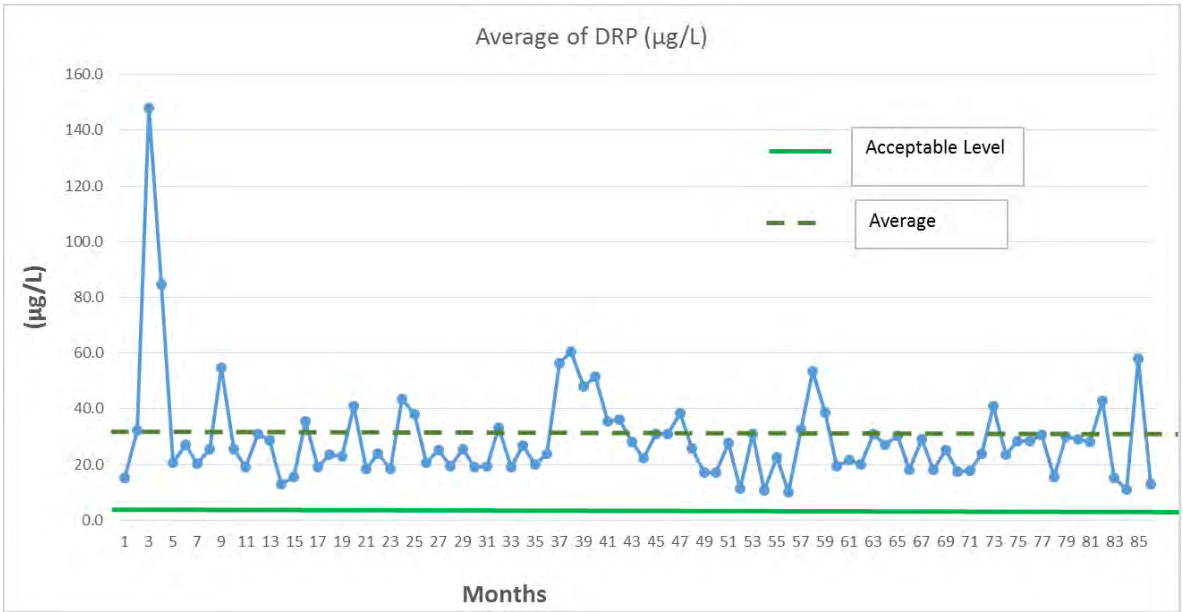


Figure 2.13. Average Monthly DRP values for Stream Sites between Jan 2007 and July 2014 in Muri

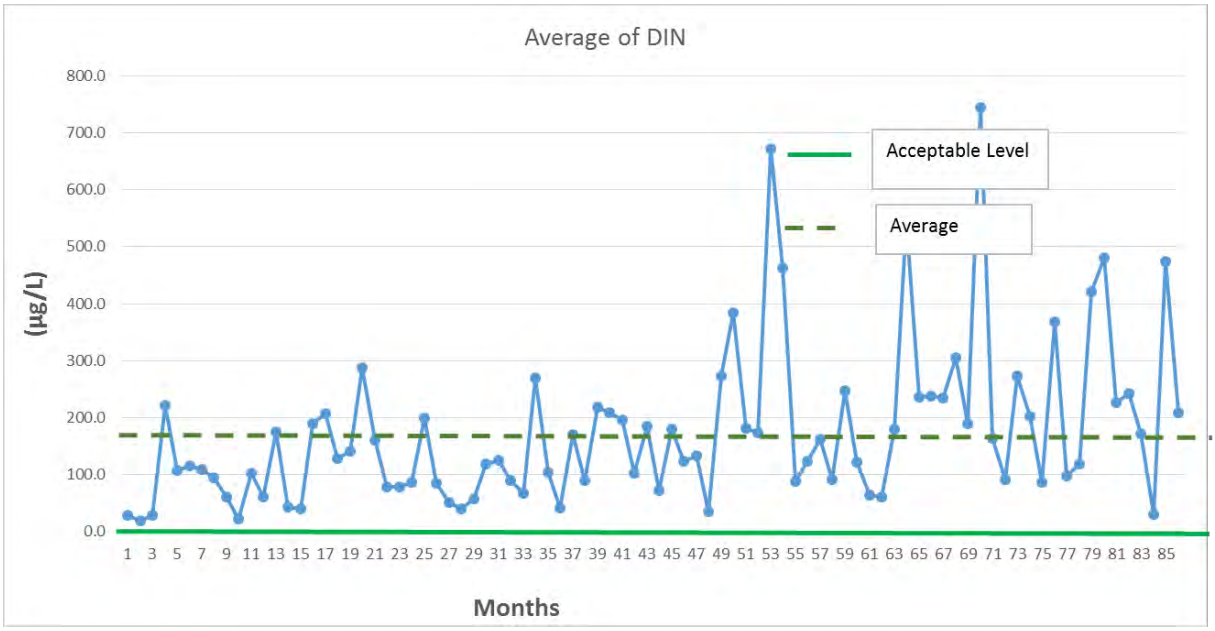


Figure 2.14. Average Monthly DIN values for Stream Sites between Jan 2007 and July 2014 in Muri

Table 2.8 provides the average annual and monthly water quality statistics for the streams entering Muri Lagoon.

Table 2.8. Annual Average Water Quality Statistics for Stream Sites (2007- 2014) in Muri

Years	DRP (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	DIN	TSS (mg/L)	Entrococci (cells/100mL)	pH	DO Satura	Temperature (ºC)	Salinity (‰)
2007	41.9	18.8	118.5	85.3	8.7	7660	7.3	81.2	23.7	1.1
2008	25.9	26.4	73.4	137.3	2.2	3477	7.0	95.5	24.9	2.9
2009	24.3	26.8	136.3	109.4	2.2	1452	7.7	94.7	24.5	2.5
2010	36.0	18.3	183.4	134.3	2.0	2717	7.6	83.7	24.4	3.1
2011	22.9	60.4	99.3	259.8	6.5	1893	7.9	79.7	25.6	6.4
2012	23.2	98.7	206.1	259.2	3.4	1517	7.6	81.1	24.9	2.8
2013	28.4	16.8	124.8	238.6	3.6	1972	7.3	74.5	24.3	4.4
2014	30.2	96.0	128.8	197.7	9.5	3677	7.3	48.3	23.3	0.4

Within Table 2.8 although DIN values show a mix trend, DRP levels loosely show levels have been increasing constantly since 2011 despite only 4 values being recorded. Water clarity values show this to be very poor in 2012 and 2014, the latter of which shows an alarming situation for the water quality of the streams reaching Muri Lagoon (see highlighted circle). Table 2.9 provides the monthly average water quality and clarity statistics for streams.

Table 2.9 Average monthly Water Clarity Statistics for Stream Sites between Jan 2007 and July 2014

Months	DRP (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	DIN	TSS (mg/L)	Entrococci (cells/100mL)	pH	DO Satura	Temperature (ºC)	Salinity (‰)
January	28.2	39.8	133.0	162.2	2.1	3944	7.7	79.2	25.5	0.6
February	25.1	28.8	79.2	145.0	2.9	1187	7.3	77.4	25.4	2.4
March	44.1	47.0	146.2	132.4	10.3	5843	7.5	77.7	25.1	1.3
April	37.6	60.1	126.8	254.1	5.4	4534	7.6	74.0	25.4	2.2
May	25.9	86.7	112.8	240.4	2.6	1992	7.8	73.1	24.2	2.2
June	24.9	38.6	129.8	240.6	4.9	1691	7.7	71.3	23.7	1.5
July	24.4	36.3	202.6	185.6	3.2	2597	7.5	84.5	22.9	3.0
August	26.3	31.2	125.0	171.9	5.1	2856	7.5	72.9	22.6	3.1
September	30.2	53.1	153.4	163.2	5.7	2907	7.5	88.0	23.1	2.9
October	30.4	33.8	138.1	214.2	2.7	1865	7.5	90.9	24.3	2.3
November	26.0	26.8	199.3	148.1	2.7	1945	7.3	86.9	24.9	4.6
December	28.1	16.7	110.0	69.9	3.4	1196	7.7	98.0	25.7	5.4

Overall, DRP values are reduced in March and April, also that DIN values increase in winter between April and June compared to the rest of the year. One of the possible reason for this may be higher levels of agricultural activities (herbicide/fertilizer application) coupled with more precipitation events between the months November and May (see Figure 2.11 and 2.12).

2.3.4. Comparing Outer and Inner Lagoon Data

AECOM have divided up Muri Lagoon into "management zones" to help better understand specific issues to help determine appropriate intervention options for the short term. The following information is purposely undertaken to attempt to appreciate whether flushing and salinity issues are statistically relevant to consider. These zones are re-presented below for clarity purposes (Figure 2.15).

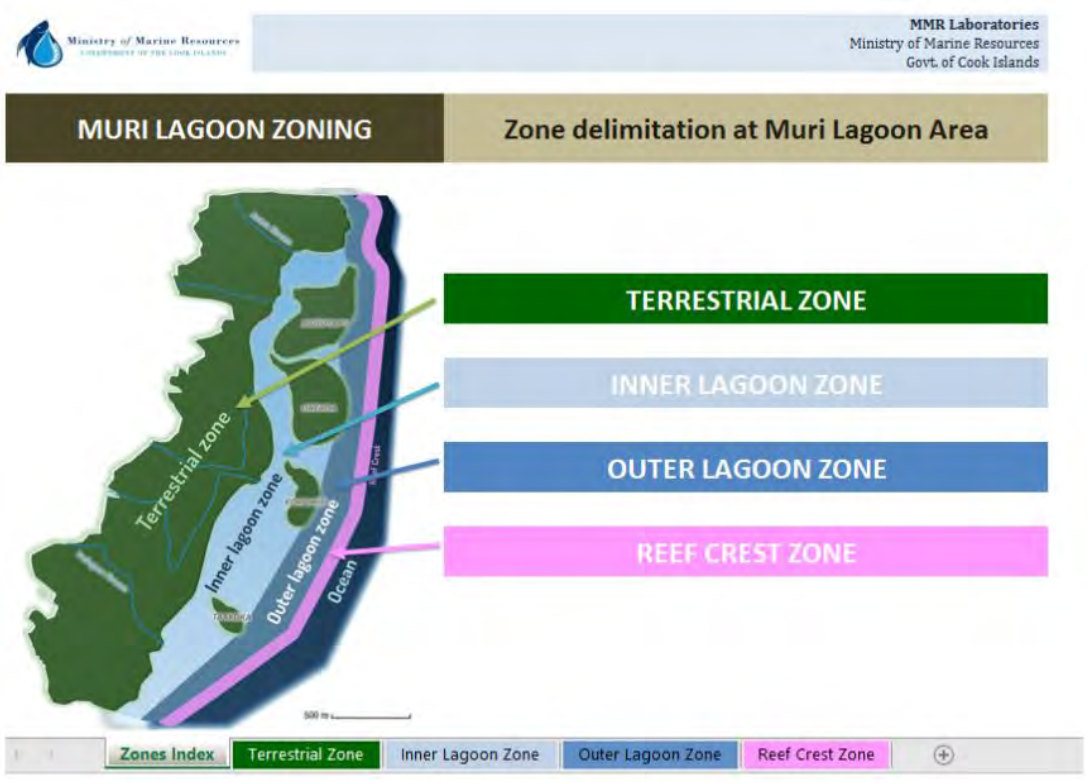


Figure 2.15: Proposed Muri Lagoon Management Zones.

MMR collected samples within the outer lagoon between 2014 and 2016 (NB: no reef crest zone data is available for any year). Although the amount of the data available is very limited, it still useful to compare the salinity levels between the inner and outer lagoon zones as shown in Figure 2.16.

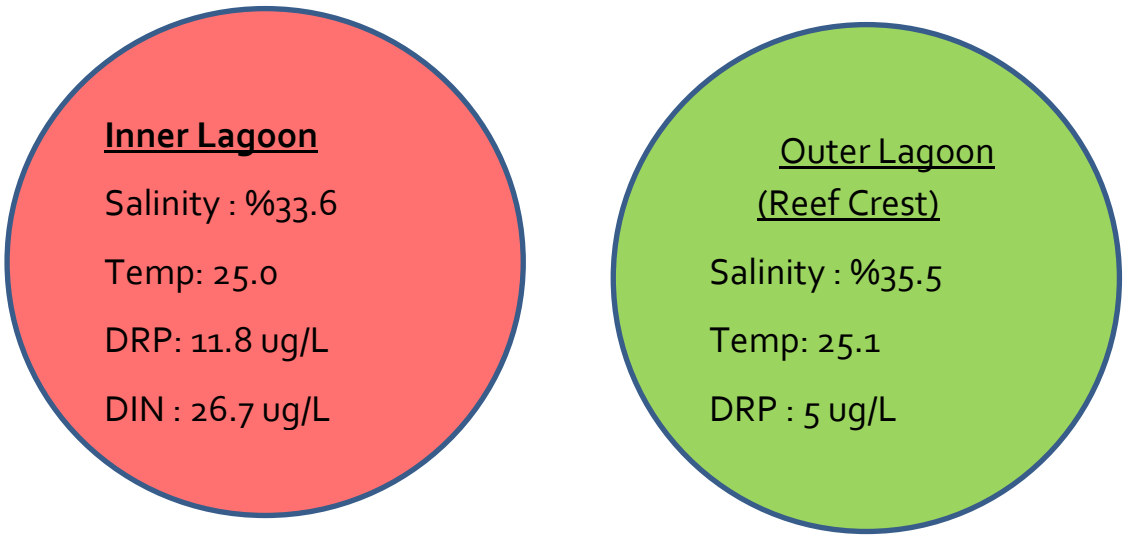


Figure 2.16. Comparison water quality statistics between the outer and inner lagoon "zones" in 2014

It is important to mention that although the DRP value in the Reef Crest (outer lagoon) zone is above the set standard (2.6ug/L), it was recorded as being well below the value for inner lagoon in 2014. The same finding applies for the DIN value. Figure 2.16 shows also that average temperature for both outer and inner lagoon zones are similar, however, the key difference between the two zones appears to be linked to average salinity levels for the Reef Crest (outer lagoon) which appears to be 2 percent higher (%) than that recorded within the inner lagoon. The timing of recordings has not been assessed in the above analysis, and this may prove influential with regards to storm related wave overtopping or monitoring during quiescent (minimal overtopping) conditions, likewise the depth of the sample taken is unknown. It may also reflect increased fresh water levels (from increased precipitation) within the inner lagoon.

AECOM suggest that based on analysis of available MMR data that as salinity levels reduce, water quality and clarity invariably improves (see Figure 2.17). Statistically, this is relevant as it is possible to develop a regression analysis between salinity and DRP. This provides the following information;

DRP= 47,335 - (1,214*Salinity), R_square= 0,274

These statistics, though weak in terms of a correlation, basically suggest that for every 1 percent (%) decrease in salinity levels, DRP will increase by 1.2ug/L.

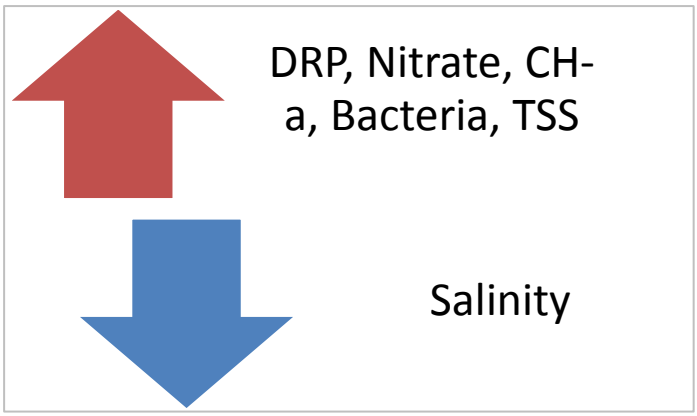


Figure 2.17. AECOM observation graphic based on MMR monitoring results of DRP/Nitrate and Salinity

As stated in Appendix A, there was a serious algae outbreak in February 2017. The magnitude of the event was quite significant from a tourist perspective as the amount of seaweed resulted in it being difficult to swim and walk between Muri Beach Club and Sails Restaurant. As shown in Figure 2.11 and 2.12, MMR laboratory data indicates that salinity levels at Muri Lagoon are recorded as low between December 2016 and February 2016. It was in fact noticeably low in December 2016 (23ppt). Assuming high rainfall (stream flow) is contained within the lagoon (see Appendix C – coastal conceptual model for Muri), and assuming "pre-storm" reef geomorphological conditions (i.e.: minimal reef crest damage), then it can be implied that salinity levels may be diluted during such conditions. When weather patterns change, resulting in increased storm wave conditions, it could be assumed that salinity levels could be quickly altered. Measurement of salinity show this to be the case whereby salinity increased significantly to 33ppt at the end of February into early March 2017 which coincided with a period of high cyclonic activity. During this time, the frequency of storm waves overtopping the reef crest would have been high resulting in salinity levels increasing to 35.3‰ in March 2017. At this time, seaweed volumes (anecdotally) reduced dramatically. From this analysis, Figure 2.18 presents a chronology of events that took place with recorded factual parameters to present a theory of seaweed ambient conditions for growth and subsequent die-off.

Figure 2.18: Concept Diagram to demonstrate the link between rainfall, seawater temperature and salinity

2.3.5. Comparing Muri and Non-Muri Lagoon Sites

Figure 2.19 provides the average water quality statistics for all Marine (lagoon) related sample sites both within Muri and outside of Muri (separate locations).

	Muri Marine (Lagoon)				Non-Muri Marine			
Months	**DRP (µg/L)**	**DIN**	**Salinity (‰)**	**Sea Water Temp (ºC)**	**DRP (µg/L)**	**DIN**	**Salinity (‰)**	**Sea Water Temp (ºC)**
January	5.9	30.1	33.5	27.0	6.2	17.5	35.0	27.2
February	3.7	22.2	34.3	26.9	5.6	19.4	35.1	27.7
March	7.8	44.5	33.7	27.2	7.7	24.4	34.3	27.8
April	6.3	47.1	34.0	26.4	8.4	26.2	34.3	26.6
May	5.7	26.1	34.6	25.6	5.6	17.6	35.1	25.8
June	8.8	21.0	34.3	24.2	6.1	20.0	34.4	25.0
July	6.0	18.3	34.1	23.8	6.6	15.6	34.5	24.0
August	4.1	16.2	34.4	23.5	5.0	15.4	34.7	24.1
September	4.9	16.6	34.8	25.0	5.8	16.7	34.8	24.5
October	7.2	23.0	31.3	25.1	5.8	17.7	34.7	24.8
November	6.3	24.0	34.0	25.5	5.4	18.6	35.0	25.5
December	4.5	23.3	32.4	27.6	5.5	25.1	34.2	27.1
Average	**5.9**	**26.0**	**33.8**	**25.6**	**6.2**	**19.5**	**34.7**	**25.8**

Figure 2.19. Average Annual Water Quality Statistics for Muri and Non-Muri Marine Sample Sites (2007-2014)

Although it can be seen that the average DRP value is slightly lower for marine sites in Muri, DIN values are higher compare to non-Muri sample sites between 2007 and 2014. It may also be seen that average salinity is almost 1 percent (%) lower in Muri Lagoon compared to non-Muri sites. AECOM believe that whilst no clear conclusion can be reached from this observation, that flushing aspects and the presence of the island "motus" at Muri may influence current speeds (hydrodynamic), increasing the input of higher saline oceanic waters (see

Figure 2.18 above) and fine material sedimentation fluctuating water depths in Muri, that is not experienced in other more higher energy lagoonal environments. This issue is considered in more detail within Part A Section 4.

Overall, high levels of nutrients represents a real contemporary challenge not just for Muri Lagoon, but island wide based on results for all Rarotongan marine monitoring stations. Indeed, it is also fact that algae and seaweed existence is not limited only to Muri but also around the whole of Rarotonga at similar times when algal outbreaks are influencing Muri. At the time of writing (December 2017), no evidence of seaweed outbreak was apparent along most of the shores of Rarotonga (which coincides with the period prior to increasing sea temperatures which commonly occurs during the months of December/January.

Table 2.11 provides the water quality statistics for stream sample sites in and outside of Muri. Overall, there appears to be no significant difference in the results when Muri and non-Muri stream sites are monitored. This is itself is significant in that it indicates that stream nutrient levels are consistently poor all around Rarotonga. The determining factor for Muri appears to be the level and rate of sedimentation (and hence shallowing of Muri Lagoon) which is likely to be strongly influenced by flushing and current speeds within the lagoon (quieter current conditions encourage sediment deposition etc.). Rongo and Dyer (2014) suggested that the effect of stronger currents and increased frequency of storm surge in recent decades (during La Nina events) may be responsible for increased sediment transport within many lagoons throughout the Cook Islands (including Muri). Sedimentation that then occurs can be detrimental to coral growth and recruitment and to this end it is likely that sedimentation is contributing to the slow recovery of reefs within Muri Lagoon (see Part A Section 3.4.3).

	Muri Streams				Non-Muri Streams				
Months	**DRP (µg/L**	**NH4-N (µg/L)**	**NO3-N (µg/L)**	**DIN (µg/L)**	**DRP (µg/L**	**NH4-N (µg/L)**	**NO3-N (µg**	**DIN**	**Rain mm**
January	28.2	39.8	133.0	162.2	53.8	32.8	112.1	144.9	16.0
February	25.1	28.8	79.2	145.0	45.3	41.9	88.8	130.7	17.3
March	44.1	47.0	146.2	132.4	56.4	28.7	156.2	184.9	8.7
April	37.6	60.1	126.8	254.1	41.6	41.2	100.2	141.4	11.9
May	25.9	86.7	112.8	240.4	42.3	22.7	91.8	114.6	10.1
June	24.9	38.6	129.8	240.6	39.7	60.6	163.9	224.5	4.2
July	24.4	36.3	202.6	185.6	30.5	30.1	116.8	146.9	4.2
August	26.3	31.2	125.0	171.9	51.3	141.3	50.6	191.9	4.6
September	30.2	53.1	153.4	163.2	50.5	25.7	81.6	107.3	3.1
October	30.4	33.8	138.1	214.2	35.0	45.5	34.9	80.4	3.6
November	26.0	26.8	199.3	148.1	39.4	31.7	38.8	70.5	10.5
December	28.1	16.7	110.0	69.9	57.1	32.3	99.2	131.5	15.4
Average	**29.3**	**41.6**	**138.0**	**177.3**	**45.3**	**44.5**	**94.6**	**139.1**	**9.1**

Table 2.11. Average Annual Water Quality Statistics for Muri and Non-Muri Stream Sample Sites (2007-2014)

Table 2.12 shows the correlation values of the information within Table 2.11 which suggests that there is a direct correlation for both DRP and NH4-N values between inner/outer lagoon and streams in Muri. This means that as the DRP and NH4-N values increase within streams (derived from surface waters), the same

increase takes place in the inner lagoon (see Figure 2.16). There does not, however, seem to be such a correlation for NO3-N values. More analysis of groundwater water qualities will be needed once this information becomes available into 2018.

Table 2.12 Correlation of Water Quality Statistics for Marine and Streams in Lagoon

		MARINE SITES										
		DRP (µg/L)	*NH4-N (µg/L)*	*NO3-N (µg/L)*	*DIN (µg/L)*	*Chl a (µg/L)*	*TSS (mg/L)*	*Entrococci (cells/100mL)*	*Temperature (ºC)*	*Salinity (‰)*	*pH*	*Rain*
STREAM SITES	Average of DRP (µg/L)	0.55	-0.01	0.23	0.20	-0.17	-0.04	0.09	-0.01	-0.28	-0.10	-0.11
	Average of NH4-N (µg/L)	0.03	0.35	-0.06	0.08	-0.18	-0.07	0.15	0.09	-0.02	0.15	0.32
	Average of NO3-N (µg/L)	0.10	0.09	-0.01	0.03	-0.03	-0.08	-0.01	-0.10	-0.09	0.19	0.08
	Average of DIN	-0.05	0.17	-0.13	-0.05	-0.15	0.08	0.00	-0.12	0.10	0.05	0.20
	Average of TSS (mg/L)	0.42	-0.05	0.20	0.16	-0.07	-0.08	0.07	0.12	-0.09	0.16	0.08
	Average of Entrococci (cells/100mL)	0.50	0.01	0.27	0.24	-0.08	0.01	0.16	0.06	-0.22	-0.06	0.03
	Average of pH	-0.05	0.04	-0.01	0.01	-0.13	-0.27	0.10	0.02	-0.07	0.16	0.22
	Average of DO Saturation (%)	0.11	-0.08	0.12	0.07	0.12	-0.18	0.18	-0.13	-0.14	0.11	-0.11
	Average of Temperature (ºC)	-0.17	0.12	0.04	0.08	0.29	-0.09	-0.32	0.65	-0.02	-0.02	0.44
	Average of Salinity (‰)	-0.26	-0.13	-0.10	-0.14	0.12	-0.06	0.01	0.14	0.12	0.07	0.16

To summarise, Figure 2.20 displays the strategic "score card" assessments of lagoon health and stream health between 2007 and 2014. A key observation from Figure 2.20 is that it is unable to differentiate between the inner or outer lagoon areas (see Section 2.3.4), which (in the short term) is very important to help determine nutrient inputs from streams plus also flushing considerations within the inner lagoon area. Therefore, from a detailed assessment of MMR water quality data, it can be seen that heath conditions remained very poor between 2007 and 2014 however one is not able to accurately "score" each zone identified within the lagoon.

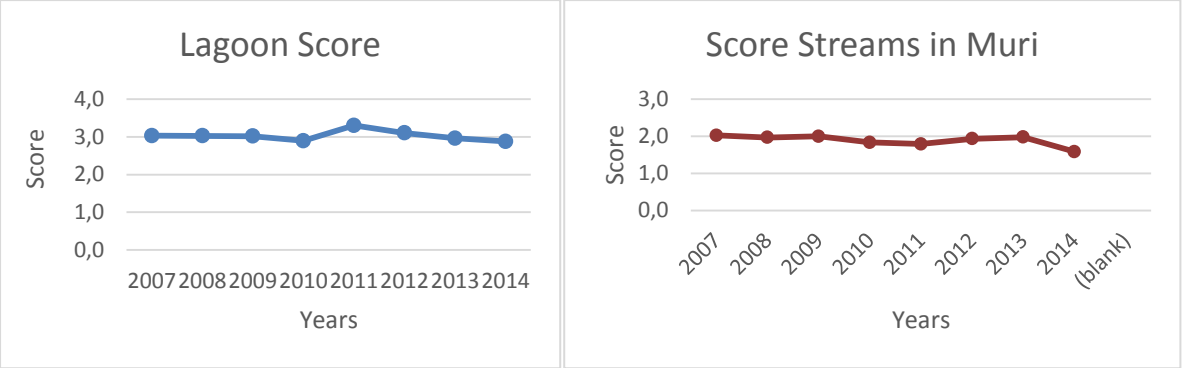


Figure 2.20 Annual Water Quality Scores for Streams and a Lagoon in Muri

2.4. Groundwater Observations

There is only limited MMR measured groundwater data in order to compare existing levels of nutrient input levels contributed from ground water. The only existing data held by MMR is for 2012. Table 2.13 suggests that nutrients levels within ground water are well below that recorded in the streams.

Table 2.13. Average Water Quality Statistics for Ground Water Sample Sites in Muri in 2012

Temperature (ºC)	24.9	**DRP (µg/L)**	15.2	**Entrococci (cells/100mL)**	751.3
Salinity (‰)	0.4	**NH4-N (µg/L)**	36.3		
DO Saturation (%)	66.8	**NO3-N (µg/L)**	21.5		
DO (mg/L)	5.5	**DIN (µg/L)**	57.8		
pH	7.6	**TSS (mg/L)**	2.7		

Any conclusion from this data cannot be made as statistically there is not enough data to analyse any correlation. Despite this, from field observations (Part A Section 4) and meetings with GHD (MTVKTV project) they do suggest a degree of confidence with the following:

- Groundwater recharge by rainfall or waterways is expected to be relatively slow in the weathered terrace soils, but rapid through the coastal sand or near-surface phonolite (volcanic) rock.
- In elevated areas, groundwater flow is expected to have a notable vertical component (downwards), only impeded by zones of lower permeability materials (clay layers), which promote horizontal flow.
- During periods of high rainfall, the streams, swamps and channels are expected to recharge groundwater. This condition is reversed during drier periods, when groundwater either discharges to waterways or waterways become dry. There is very high level of DRP, DIN, Bacteria and TSS levels in the streams flowing to Lagoon. Therefore, during the rainy season, it is very likely to expect decreasing water quality (surface run off).

To better understand and confirm/refute these theories, GHD shall be undertaking new environmental borehole investigations in order to better interpret groundwater contributions to lagoonal water quality and monitored information results are expected during February 2018. Despite this, some early new geophysical survey work has also been undertaken by GHD and preliminary result plots are being produced (see Figure 2.21) though, due to a lack of monitored data, no clear answers may be deduced from this as yet.

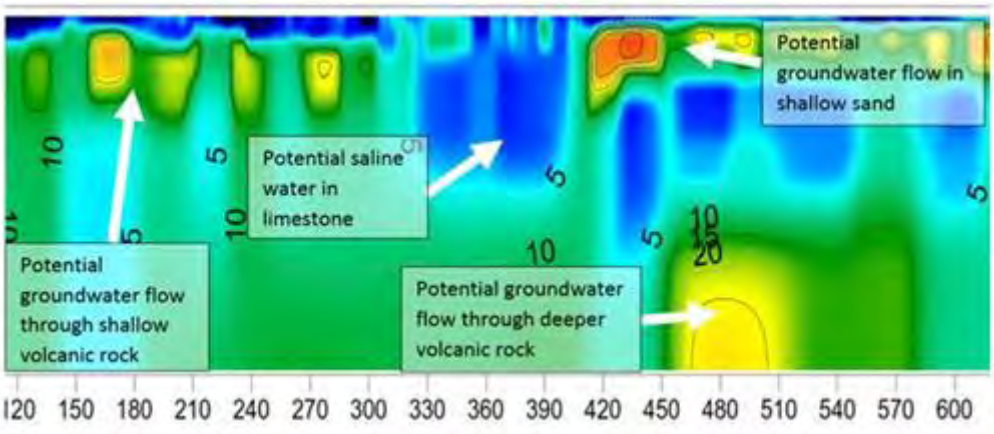


Figure 2.21 Geophysical Survey preliminary results (from GHD 2017)

2.5. Water Quality Conclusions and Findings

2.5.1. Water Quality Findings

It is clear that water column nutrients are most important as environmental indicators. There are two ways of improving the quality of polluted water in Muri Lagoon. The first option is to control the input of pollutants, particularly Nitrogen and Phosphorus (N and P), along with organic pollutants entering the water body. The other way is to remove these substances from the lagoon sediments and water itself. The preferred method is to control the inputs of pollutants entering into the Lagoon. After this is accomplished, measures can then be taken to restore the lagoon to an acceptable quality for local livelihoods and tourists alike. Part B provides some options for short term interventions prior to the larger infrastructure works being proposed under the MTVKTV project being undertaken for MFEM (GHD 2017).

Based on the data made available to AECOM, the following conclusions have been reached.

- Contaminated streams and groundwater both contribute to the nutrient levels recorded in the Lagoon. This is also believed to be one of the key causes of algae outbreaks within Muri Lagoon.

- Nutrients (DRP and DIN) are high for both the lagoon and streams for the entire Island and so water quality related problems in surrounding lagoon waters are NOT limited to Muri Lagoon exclusively. Ammonium and nitrate should be near levels of detection (< 5 micro molar).

- There is a suspected negative correlation between salinity and phosphates and between salinity and NO3. Therefore, as salinity levels reduce, dissolved phosphates and NO3 increases. Furthermore, as the salinity reduces the level of bacteria and total suspended sediments increases in Lagoon (possible associated with increased fluvial stream flow into the inner lagoon area). There is also correlation between existence of DRP in Lagoon and DRP in surface run off (streams) entering the inner lagoon area. The same applies for

Ammonia (NH4) levels. As the level of DRP/NH4 increases in streams, the level of DRP and NH4 likewise increases in the lagoon.

- There is a need to update the "standard" benchmark figure for DRP and DIN. This is proposed as a key action for MMR to address following an internal review is made of the new environmental monitoring observations that are currently being compiled by GHD and which should be made available from February 2018.

- The main difference between Muri and non-Muri Lagoon recorded water quality data appears to be the fact that lower recorded salinity levels occur in Muri than elsewhere around Rarotonga.

- During the summer season when precipitation levels are highest (December to February); sea temperature also appears to increase whilst salinity levels are recorded to reduce. It is therefore suggested that the most likely period for seaweed development in Muri Lagoon is between December – March (see Figure 2.22)

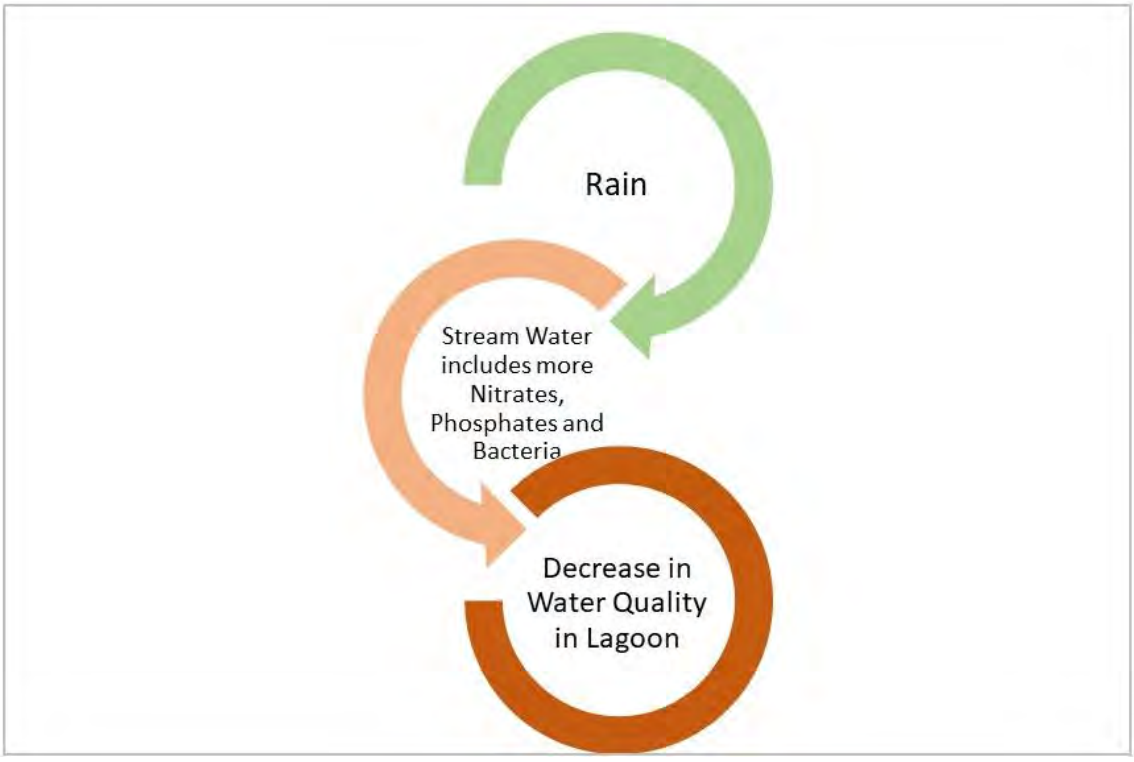


Figure 2.22: Conceptual Model of Seaweed Outbreaks in Muri Lagoon (and wider Rarotonga).

2.5.2. Recommendations

- The key water quality related parameters that are deemed critical for an improved monitoring program include nutrients (nitrogen, ammonia, phosphorus) in addition to oceanographic parameters (sea temperature and salinity) and meteorological parameters (rainfall and wind). It is advised that new data

collection techniques are adopted that ensure samples are collected from the terrestrial streams, inner lagoon and outer lagoon as a minimum.

- Protocols for extreme event situations should be prepared and formalised in collaboration with MoH (see Appendix F4 for a draft protocol). This is most important for bacterial water quality monitoring (see Part A Section 5). Monitoring should take place within 48 hours of a significant rainfall event (i.e.: any prolonged rainfall episode).

- MMR has not been able to analyse nutrients levels (Phosphates, Ammonia and Nitrates) since August 2014. Therefore, it is not possible to monitor the level of Nutrients which appear to be the main cause of seaweed development in the Lagoon since this time. Therefore, it is very urgent to ensure this capability is developed to help establish the necessary training on laboratory analysis of this parameter as soon possible. MMR have also been unable to conduct chlorophyll testing due to the technical and budgetary problems (though samples have been collected for future laboratory analysis.

- Water quality in Muri Lagoon can be improved (the response) by providing treatments for streams reaching the Lagoon and at the same time, increasing the natural flushing capacity and potential within the Lagoon. This approach (as defined in Figures 2.23) could minimise seaweed development during the "risk period which is identified during December to March in each year. To support this, it may be appropriate to consider, in addition to the proposed sanitation reticulation system for Muri, that a supporting storm water drainage reticulation system is proposed to capture pollutants draining off roads during peak rainfall events. It is recommended that efforts are made (in partnership with ICI) to consider establishing protocols, standards or "collecting systems" for road drainage. This issue is addressed in more detail within Part B Section 7.

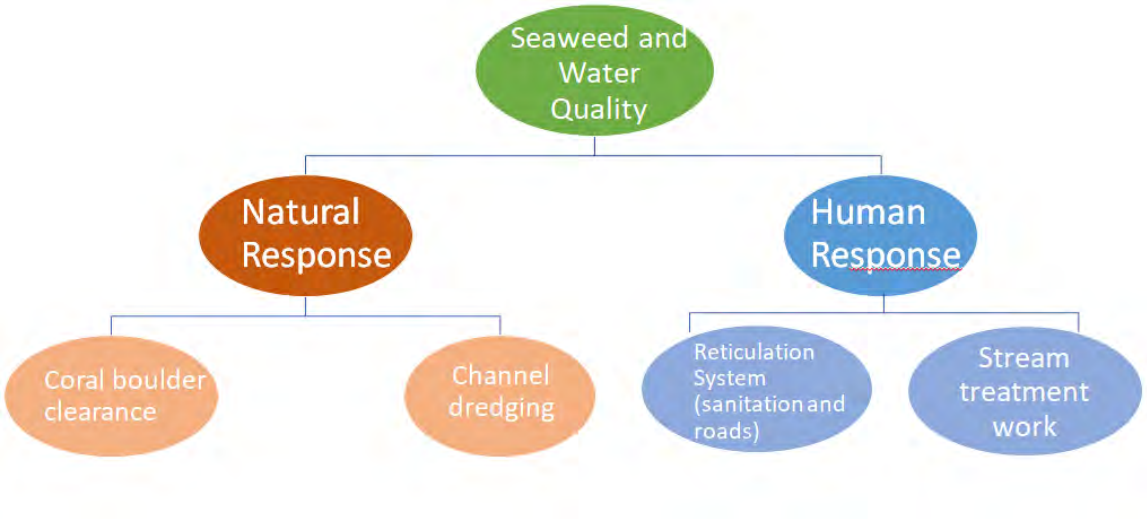


Figure 2.2.3: Strategic (natural and human) response to address causes of seaweed outbreak

3. MARINE BIODIVERSITY ASSESSMENT

3.1. Overview

A literature review has been undertaken by AECOM that encompasses readily available scientific literature and technical reports regarding marine habitats, ecology and biodiversity with Muri Lagoon. Where identified, other literature regarding the broader Rarotonga, Cook Islands or similar environmental settings have also been reviewed to provide insight into marine environmental processes.

It should be noted that MMR shall be carrying out a marine ecological mapping exercise of Muri Lagoon in January /February 2018 funded under externally funded projects (e.g.: R2R project). As a consequence, no new available habitat mapping data exists for Muri and so the preparation of a "map" has not been possible within this contract. The new schedule for the R2R RAPCA Field Work is to commence into 2018, the outcome of which should be embraced by MMR in terms of updating the proposed ecological indicators for future monitoring). It is also assumed that a new "map" showing marine habitat extent will be prepared at that time.

This Section addresses the following project objectives (already defined in Part A Section 1.2)
Review the coral and fish surveys of the Muri Lagoon and develop biodiversity indices for comparison and future monitoring. Compile a comprehensive habitat map with biodiversity indices of the Muri Lagoon showing benthic habitats, biodiversity hotspots and other notable features that are important ecological and eco-tourism features of the area *(not achieved – see point raised above).*

3.2. The Biological Environment

3.2.1. Coastal Habitat Types

3.2.1.1. Historic Habitat Maps of Muri Lagoon

There are a number of coarse grade habitat maps that have been produced in addition to specific ecological surveys that have been undertaken over the past decade. MMR (1997) undertook a broad scale ecological survey to help establish a Raui at Aroko. The work presented a preliminary analysis of scientific data collected at the proposed Raui. The work included the geographical mapping of the Aroko area with proposed reserve boundaries indicated, coupled with an assessment of bathymetry within the lagoon strata and some benthic mapping of substrate type in the foreshore and lagoon strata. Key observations from that work suggested by MMR (1997) stated that Muri Lagoon is characteristic of a shallow tropical lagoon ecosystem, comprising predominantly of benthic sands with intermittent coral “bommies”. The fringing reef defines the lagoon, which is broad and sandy to the south and narrow and rocky to the north and east...

The benthic cover of the lagoon is dominated by sand or sandbanks (54%), sand/rubble (24%), green (unidentified) filamentous algae(14%), black (*Luguburgia* sp) algal (12%), various algal/sand (3%) and mussel (*Lithophaga teres*) beds (1%). This is demonstrated in a diagram displayed in Figure 3.1. The biogeography of Muri Lagoon is strongly influenced by tidal currents, which are predominantly unidirectional in Muri Lagoon, and are concentrated by the reef islands into channels through which sand is regularly transported.

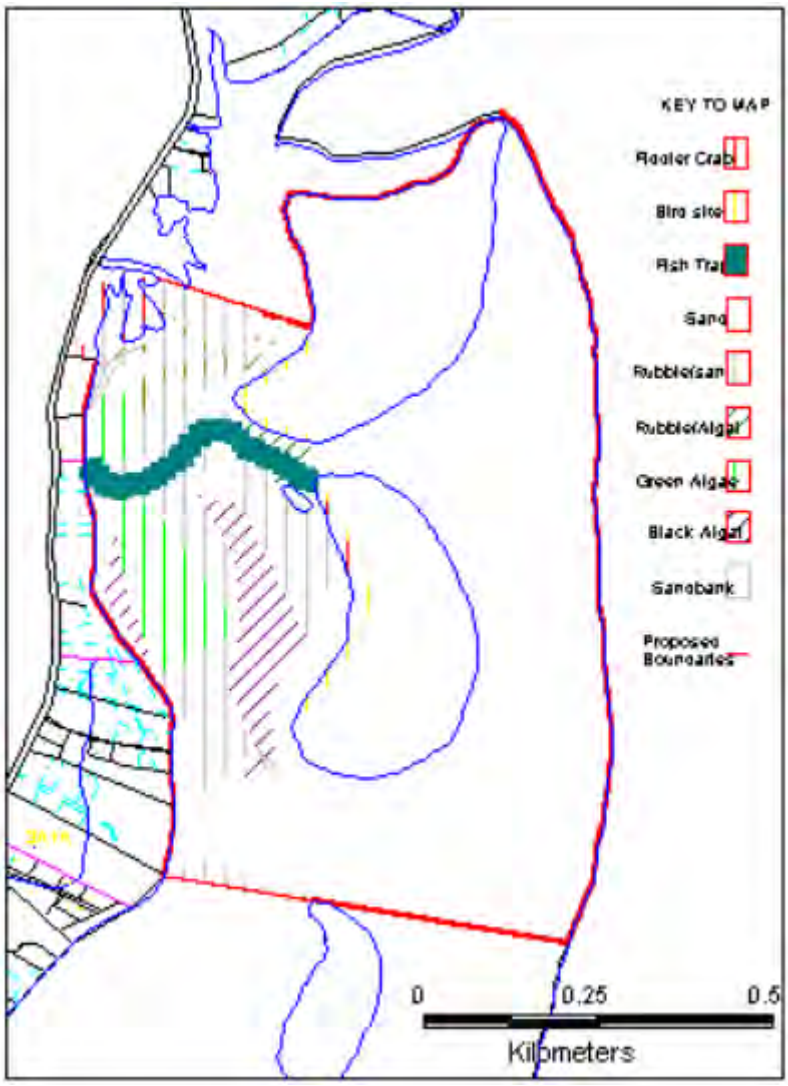


Figure 3.1: MMR 1997 habitat survey of Muri Lagoon

An interesting observation, not just for Muri but for Rarotonga as a whole is that there is no recognised mangrove habitat present. The work by MMR (1997) identified marshland close to Muri where *servassium* grass and red fiddler crabs were recorded at the time (one of the only areas on Rarotonga where it is found). *NB: AECOM learned that a current study is underway by the National Environment Service (NES) to monitor and map wetland areas (past and present) around Rarotonga. This work is not available for review at the tie of writing).*

More recent work coastal habitat mapping work was undertaken by Džeroskia and Drumm (2003) who described an investigation into coastal habitat conditions. A very simple island wide map of Muri Lagoon was produced (see Figure 3.2). Apart from the differentiation of sand to reef slope, no detailed information was presented for Muri Lagoon (see inset area).

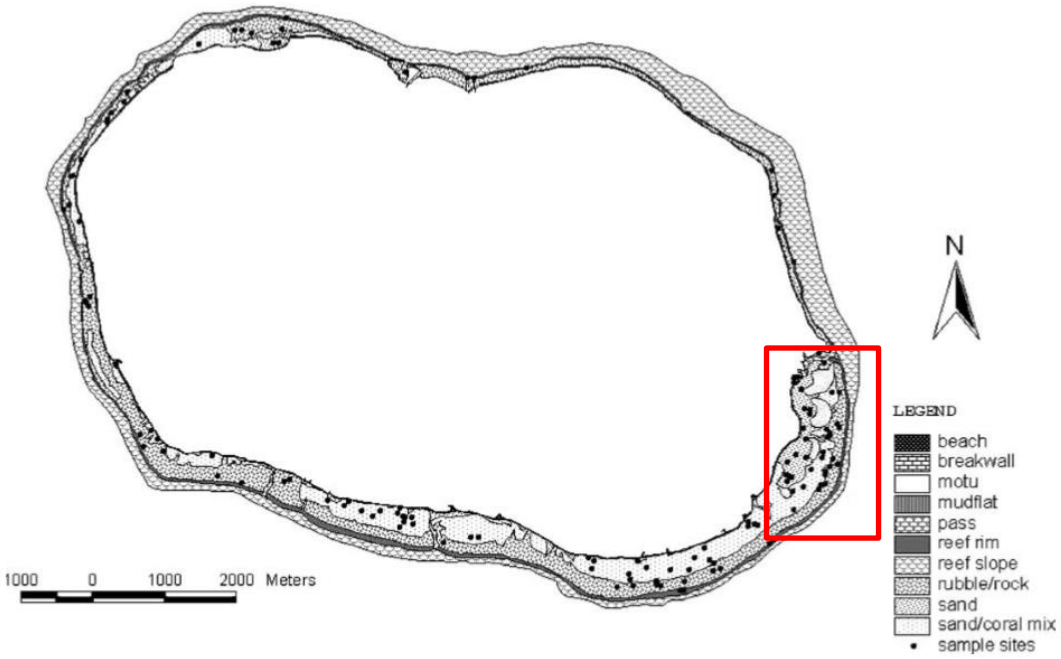


Figure 3.2: Coastal habitat extent (taken from Džeroskia and Drumm (2003)

The above map was updated with new research undertaken by Drumm *et al* (2011) as displayed in Figure 3.3 below. Drumm used aerial images drom 1998 to update work undertaken in 2003, hence this information was outdated due to a lack of data availability. The Muri area (denoted by the red rectangle) simply declares the lagoon habitat type as being composed of sand inland of the motu (islands).

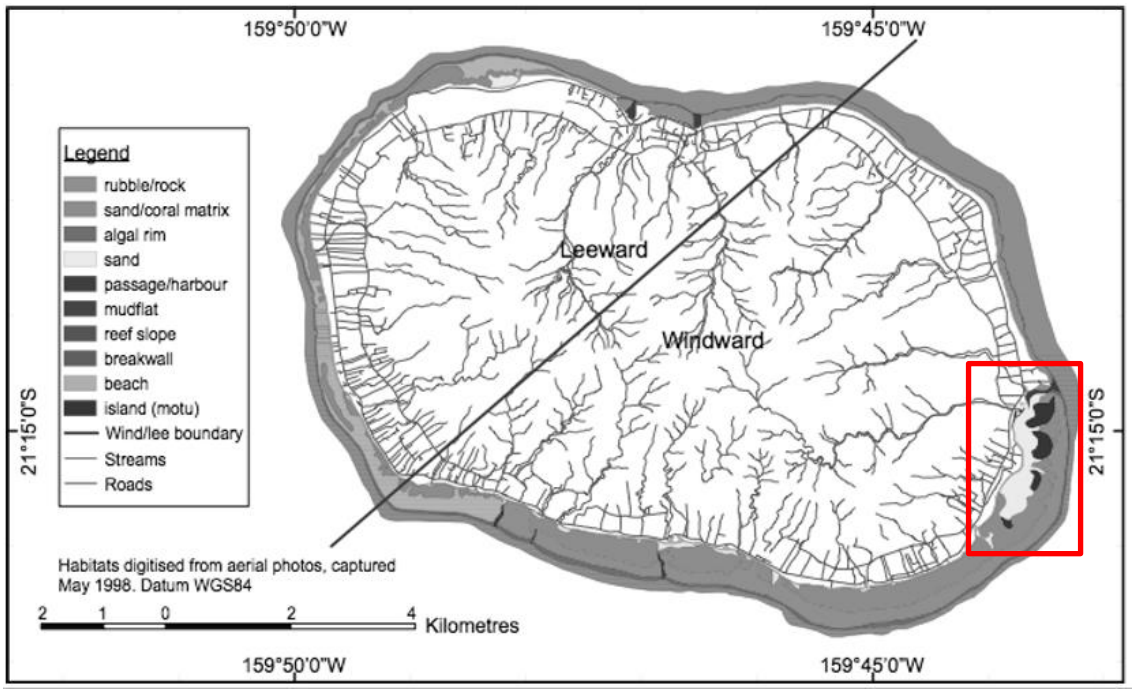


Figure 3.3: Categorical habitat map of the reef top habitats for the windward and leeward sides of Rarotonga, Cook Islands. The coarse geomorphological habitat biotopes were digitized from the textural properties of the rectified aerial photographs (from Drumm *et al* 2011)

In general, the dominant coastal habitats (as defined by Drumm *et al* 2011) were similar in composition for both the windward and leeward sides of Rarotonga, except the rubble/rock habitat where there was a greater proportion of the reef rock/ pavement microhabitat on the leeward (Table 2) than on the windward side (see Figure 3.4 – from Drumm *et al* 2011).

Table 2. Mean percent cover (±1SE) of each of the microhabitat types for the coarse habitat categories over the entire island. No mudflat habitat was found on the leeward side of Rarotonga and the passage/harbour habitat on the windward side was not sampled due to adverse and dangerous current and tidal conditions. — = not sampled.

Microhabitat and exposure	Habitat rubble/rock	sand/coral matrix	algal rim	sand	passage/harbour	mudflat
(a) Windward (N=96)	(32)	(42)	(6)	(13)	(0)	(3)
rubble	57.0 ± 6.3	9.3 ± 3.3	0	2.5 ± 1.2	–	0
consolidated rubble	14.2 ± 4.1	1.4 ± 0.9	0	0	–	0
boulder	3.7 ± 1.4	0	0	0	–	0
sand	2.1 ± 1.6	49.1 ± 4.3	0	92.8 ± 2.0	–	13.3 ± 8.8
live coral	2.4 ± 0.7	11.9 ± 1.8	9.7 ± 3.8	0.8 ± 0.4	–	0
dead coral	1.1 ± 0.7	27.2 ± 2.9	0	3.1 ± 1.0	–	0
reef rock/pavement	19.5 ± 5.1	1.1 ± 0.5	90.3 ± 3.8	0.8 ± 0.8	–	0
mud/silt	0	0	0	0	–	73.4 ± 17.6
gravel	0	0	0	0	–	13.3 ± 8.8
Area (ha)	314.1	299.8	82.4	70.9	10.7	
(b) Leeward (N=32)	(14)	(10)	(2)	(3)	(3)	(0)
rubble	43.9 ± 10.0	19.2 ± 5.7	0	6.7 ± 4.4	8.0 ± 6.1	–
consolidated rubble	7.5 ± 2.9	1.0 ± 1.0	0	0	0	–
boulder	5.9 ± 2.1	3.1 ± 1.3	0	0	23.7 ± 18.4	–
sand	3.5 ± 1.6	23.7 ± 8.7	0	91.7 ± 4.4	6.7 ± 6.7	–
live coral	2.6 ± 1.5	4.3 ± 1.8	0	0	1.7 ± 1.7	–
dead coral	0.3 ± 0.3	28.8 ± 3.8	0	1.3 ± 1.3	28.3 ± 28.3	–
reef rock/pavement	36.3 ± 8.1	17.9 ± 7.5	100.0 ± 0.0	0.3 ± 0.3	0	–
mud/silt	0	2.0 ± 2.0	0	0	31.6 ± 31.6	–
Area (ha)	170.1	85.2	37.0	7.4	5.8	0

Figure 3.4: Macro habitat types over Rarotonga (Drumm *et al* 2011)

Most recently, the Ocean and Islands Programme (OIP) of SOPAC has delivered a number of assessments to the Cook Islands in the reporting period including several tasks funded in-kind by the Cook Islands Government. These include work undertaken by MMR (2011) including a desktop review of existing data and information related to the Muri Lagoon; and the collection of oceanographic data and the development of a benthic habitat map of Muri Lagoon (see Figure 3.5).

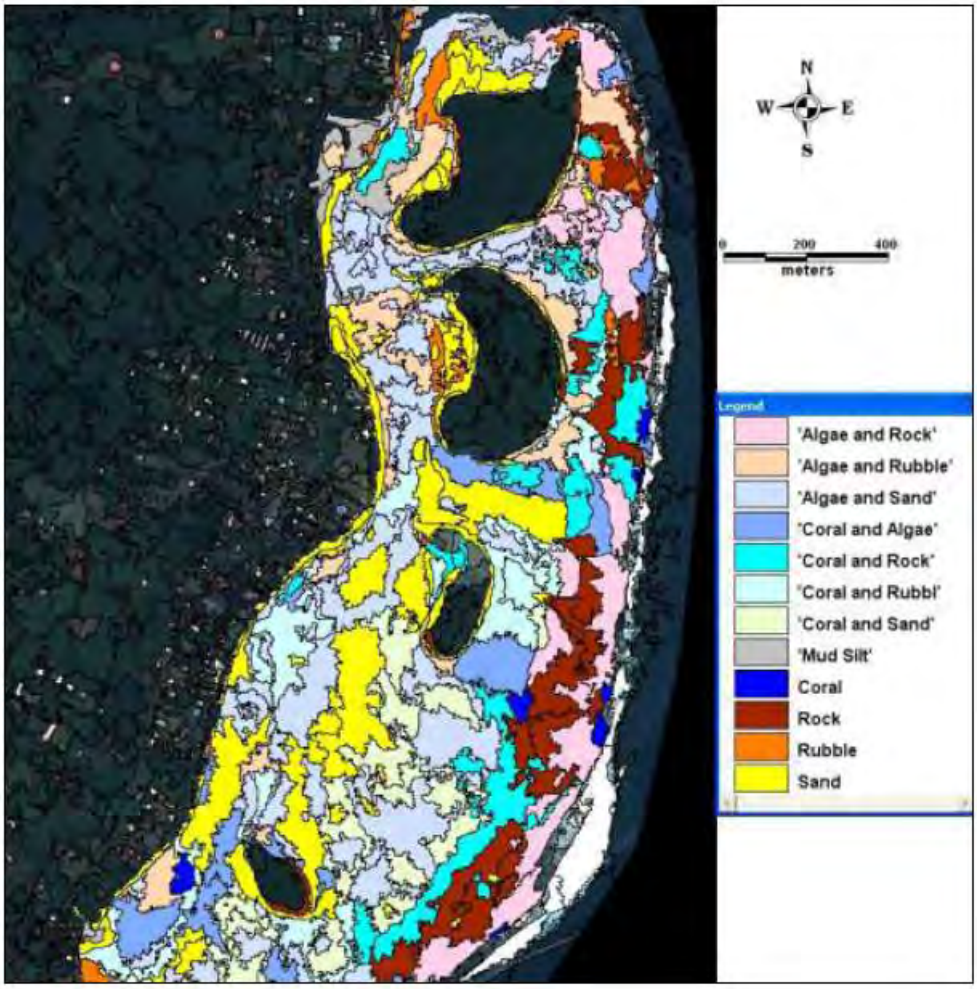


Figure 3.5: Latest available Coastal Habitat map (produced by SPC in partnership with MMR).

3.2.2. Coral Reefs

The total length of the barrier reef system around Rarotonga is some 34 km and the total surface area of the lagoon is 3 km2 (MMR 2011). On Rarotonga, reefs have experienced several natural disturbances over the last few decades (see Rongo and van Woesik, 2013). In the 1970s, Devaney & Randall (1973) documented the first reported crown-of-thorns starfish (COTS) outbreak on Rarotonga during a Pacific-wide outbreak (Sapp, 1999). According to their report, most of the damage occurred between Ngatangiia/Matavera (north-eastern side) counter-clockwise to Arorangi (western side). A second COTS outbreak in the mid-1990s to around 2001 that was limited to fore reef communities also reduced coral cover from more than 30% to less than 5% in 2006 (Rongo *et al*., 2006), but recovery seemed to be well on the way in subsequent years. For example in 2011, coral cover ranged from 10 – 15%. While reef recovery to pre-COTS conditions after the 1970s outbreak occurred over a period of less than 10 years, recovery from the 1990s outbreak has been slow even over a decade later. However, a notable increase in larger coral colony sizes of *Acropora* spp. indicate that a shift towards pre-COTS conditions of the 1990s has occurred on the fore reef thus indicating a degree of recovery..

Coral bleaching has also impacted Rarotongan reefs particularly in 1991 and 1994 during a regional warming event, causing high coral mortality within the lagoon and to a lesser extent the fore reef slopes (Goreau & Hayes, 1995). Bleaching events associated with extreme low tides were observed in subsequent years (e.g., 1998, 2006, 2009, 2014, and 2017) where corals on the reef flats experienced aerial exposure for several hours (see Rongo & van Woesik, 2013). The 2015/2016 very strong El Nino event did not bring any major disturbance to Rarotonga compared with the extensive bleaching event that devastated all reefs in the northern islands (Rongo, 2016). The impact on hard coral populations following the passing of five cyclones in the region between 2003 and 2005, was difficult to determine as reefs were still recovering from the recent major COTS outbreak. Rarotonga did not experience any cyclones for 11 years (2005 – 2016), and this was a critical period allowing reefs to recover.

Although coral reef monitoring on Rarotonga has been inconsistent in terms of methodology, intervals, and also the Government ministry involved, reef monitoring has been ongoing for more than 20 years. The first monitoring effort was carried out in 1994 (Miller *et al*., 1994), and subsequent monitoring was conducted in 1999 (Ponia *et al*., 1999), 2000 (Lyon, 2000), 2003 (Lyon 2003), 2006 (Rongo *et al*., 2006), 2009 (Rongo *et al*., 2009), 2011 (Rongo and van Woesik, 2013), and 2014 (Rongo *et al*., 2015). The present survey in 2016 is a continuation of this coral reef monitoring, which was a collaborative effort between Climate Change Cook Islands and Te Ipukarea Society.

3.2.2.1. Muri Specific Surveys

One original key source of coral related information is the work published by Scoffin (1985). This work concluded that Muri Lagoon is the only area on Rarotonga's reef flat that is sheltered by reef islands from ocean waves. Scoffin stated that free-living massive and branching spheroidal growths (about 5 cm diameter) of calcareous red algae (rhodoliths) and corals (coralliths) occur in abundance on the sea bed of shallow Muri Lagoon on Rarotonga's reef flat (inside of “motus”). These rhodoliths are composed of one or more species of *Neogoniolithon, Lithophyllum, Tenarea*, and *Porolithon*; the coralliths are *Pavona varians* and *Porites lutea*.

Following the last crown-of-thorn starfish (COTS) outbreak around Rarotonga from 1995 – 2001, reefs for the last 16 years have been steadily recovering despite the various disturbance regimes during this period. With specific reference to Muri Lagoon, live coral and algae assessments were carried out by MMR (2011) at three sites in Muri (Aroko, Nukupure and Eco Tours) and at the control site at Kent Hall, Titikaveka. At each site three 50m transects were laid, at random, perpendicular to the shore, with one in each lagoon zone (inshore, mid lagoon and reef – see Figure 3.6). Each of the live coral, algae or non-living form of benthos recorded was put into the following categories:

- Non-Living Calcified Structures: Sand, Rubble, Boulders, Dead Coral and Rock;
- Algae species: Macro Algae, Turf Algae, Micro Algae and *Halimeda;*

- Coral Form,

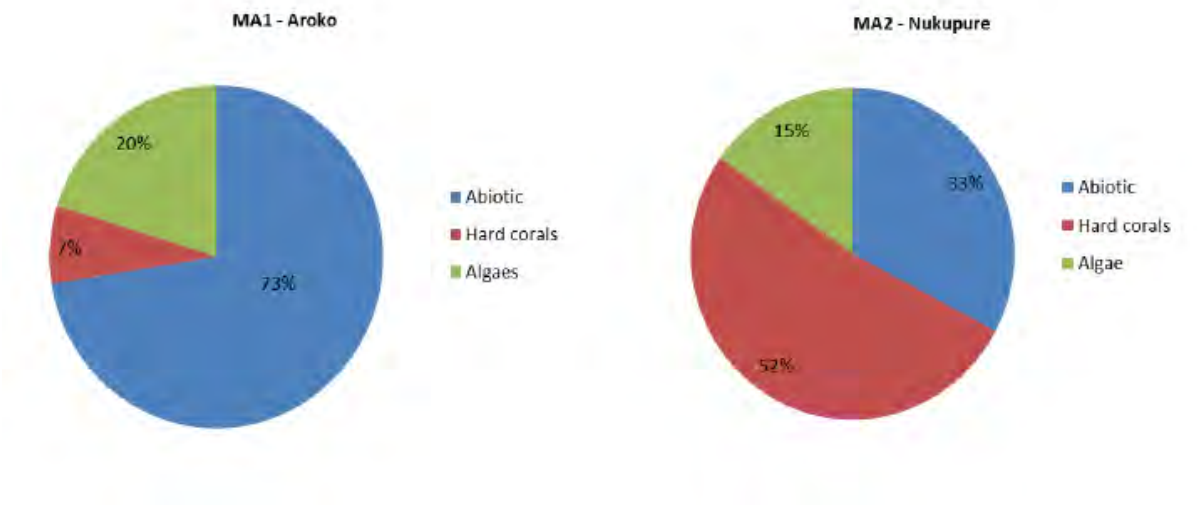


Figure 3.6: Coral Survey results for locations within Muri Lagoon (MMR 2011)

Aroko site is mainly made up of abiotic coverage i.e. sand, rubble, and rocks (field observation). This site had the largest abiotic percentage coverage (73%) and algae percentage coverage (20%) out of all four sites (Figure 3.16). Algae coverage was made up of *Dictyota spp, Turbinaria spp, Halimeda spp, and Boodlea spp* (field observations). Aroko also had the lowest percentage (7%) coverage of hard corals (Figure 3.16). Based on the percentage coverage of all three categories, this site was the most different compared to the other sites.

Sites at Nukupure and EcoTours were the most similar when compared, with these sites being made up of mainly hard coral coverage (52% and 67% respectively) i.e. dead corals covered with algae and encrusting Leptoria spp (field observations). Both of these sites also had similar abiotic coverage of around 30% (Figure 3.7).

The control site at Kent hall was also mainly made up of abiotic coverage (50%) (Figure 3.17; sand, rubble, and rocks (field observation). However, compared to the other sites, this sites hard coral coverage (43%) was made up of mostly living corals i.e. Massive non-Acropora *(Leptoria spp*), purple encrusting coral, Acropora (Bottlebrush) and Millepora (fire coral), as well as some dead corals (field observations). Algae coverage at Kent hall was only 7% and made up of mainly turf algae (field observations).

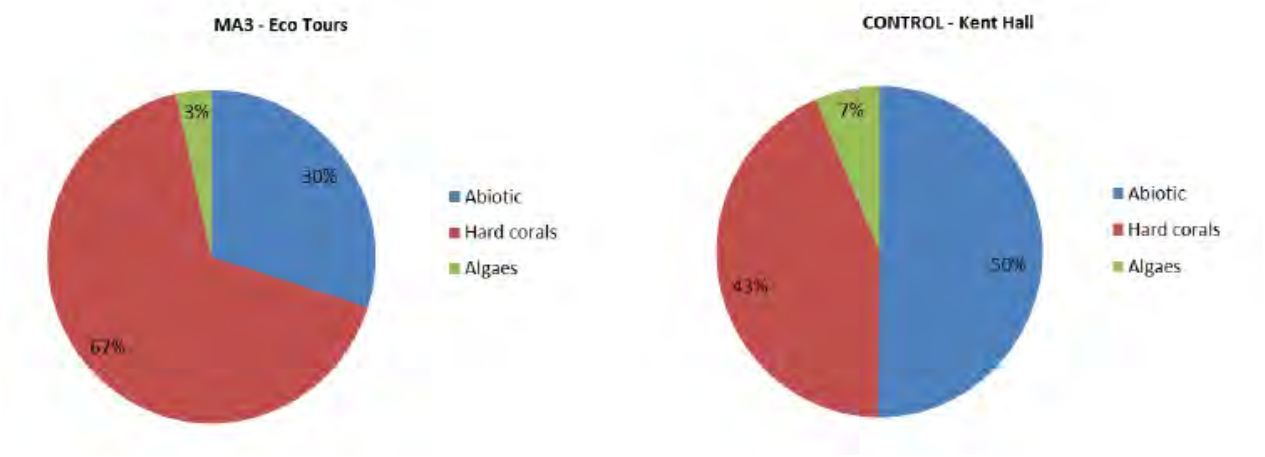


Figure 3.7: Coral Survey results for locations within Muri Lagoon (MMR 2011)

More resuts from Bricker (2014) showed that several species of coral are recorded at Muri Lagoon, including *Porities sp, Galaxia sp. and Montipora sp*. Most corals (in shallow water) were from 5-15 cm diameter and live cover was 2-10%. In deeper waters (outside lagoon zone of Muri Lagoon), the community is dominated by *Porites* but these have extensive patches of old mortality; colonies consist predominantly of medium to large sized remnants that have grown up 8-15 cm. A high diversity of massive, plating and branching corals also occurs on the tops and sides of dead parts of the *Porites* colonies. The majority of all corals are 5-20 cm in diameter with only a few larger *Porites. eydouxi* colonies.

Bricker (2014) confirmed the work of Hoffman (2002) by stating that the reefs around Rarotonga (including Muri Lagoon) have a history of disturbance including: 1) a severe COTS outbreak in the mid-1970s and a second outbreak from 1995-2001; 2) several major cyclones in the early 2000s; and 3) minor bleaching during recent El Niño years. Of importance, and with reference to coral habitat directly within Muri Lagoon, the coral species present all demonstrate low biodiversity levels of coral cover and significantly, that most coral stands within the lagoon appear mosly dead (Lyon 2016).

The most recent reef surey was undertaken as a joint effort between Climate Change Cook Islands of the Office of the Prime Minister and Te Ipukarea Society (Rongo *et al* (2016)). The objective of this work was to resurvey sites established around Rarotonga as part of a long-term monitoring program designed to understand temporal changes of communities on the fore reefs. The survey revisited sites at Motutapu and Taakoka which are of most relevance to Muri Lagoon (the former being at the entrance to Avana Harbour). The monitoring focused on collecting information on benthic communities (i.e., fish, corals, algae, and other macro-invertebrates). The recorded coral species at these two locations are presented in Table 3.1.

Table 3.1: Checklist of coral species recorded at Moutapu and Taakoka (closest recordings to Mui Lagoon). Taken from Rongo *et al* (2016).

FORE REEF SPECIES	Motutapu	Taakoka
ACROPORIDAE		
Acropora danai		x
Acropora digitifera	x	x
Acropora humilis		x
Acropora hyacinthus	x	x
Acropora lutkeni		x
Acropora monticulosa	x	
Acropora samoensis	x	x
Montipora (brown)	x	x
Montipora (purple)		x
AGARICIIDAE		
Pavona clavus		x
FAVIIDAE		
Cyphastrea serailia	x	x
Favia rotumana	x	x
Favia stelligera	x	x
Favites flexuosa		x
Leptastrea purpurea	x	x
Leptastrea transversa	x	
Leptoria phrygia	x	x
Montastrea curta	x	x
MERULINIDAE		
Hydnophora microconos	x	x
MUSSIDAE		
Acanthastrea echinata	x	x
PECTINIIDAE		
Echinophyllia spp		x
POCILLOPORIDAE		
Pocillopora damicornis	x	x
Pocillopora eydouxi		x
Pocillopora meandrina	x	
Pocillopora verrucosa	x	x
PORITIDAE		
Porites lobata		x
Porites lutea	x	x
SIDERASTREIDAE		
Psammocora obstusangula	x	x
ALCYONIDS (soft corals)		
Cladiella sp		x
Sinularia spp		x
TOTAL SPECIES	**19**	**27**
TOTAL FAMILIES	**7**	**10**

Of interest with regards to reef condition and health relates to the prevalence of sea urchins, in particular , Echinothrix diadema. SPC (2009) recorded that *Echinothrix diadema*) were common and recorded in all reef-front searches and 62% of RBt stations) and could be found at an average station density reaching 3167 /ha on the outer-reef slope as well as on shallow inner reefs. More recently, research by Rongo *et al* (2016) declares a *"mass die-off of vana (Echinothrix diadema) on Rarotonga — where a 99% loss was noted compared with data collected in 2014"*. Rongo et al (2016) state that densities of *E. diadema* decreased significantly from around 40 ind./100m^2 in 2014 to less than 1 ind./100m^2 in 2016.

This is ecologically significant as *Echinothrix diadema* is an important grazer and its loss would likely increase algal cover in coral habitats where this species originally had occurred (i.e., fore-reef slopes and reef crest habitats).

3.2.3. Marine Invertebrates

3.2.3.1. Holothurians and Echinoderms

MMR (1997) surveyed benthic invertebrates within Muri Lagoon. The most common species recorded were rori (Holothurians) (particularly rori pua, matu rori and rori toto which number in the tens of thousands). The number of paua was quoted as being "remarkably high given the general scarcity of this animal on Rarotonga". However, it should be noted that of the 169 paua counted, only 3 paua were > 8 cm shell length and 11 paua between 4 - 8 cm length. The remainder of paua (92%) being smaller then 4 cm. This highly skewed, small sized population structure suggests a high mortality rate amongst the older, larger sized animals, perhaps due to fishing pressure. Similarly, amongst the 7 ariri counted only 1 animal exceeded 8 cm basal width, which also suggest a low number of larger, older sized population. Certain species (excluding sea cucumbers) of mollusca and other shellfish recorded by MMR (1997) are listed below:

Mollusca:
Trochus niloticus - small size common, adult size observed
Trochu maculatus - small size
Astraea rhodostoma - Karikao
Turbo argyrostomus Spiny-shelled turban - Ariri
Turbo setosus Rough Turban - Ariri
Turbinaria origalatus
Patella flexuosa Star-shaped limpet - Mapi'i
Mangeongeo
Cymatium muricinum
Isognomon *perna*
Nerita plicata
Nerita polita
Nerita albicilla
Cowrie moneta
Tridacna maxima
Asaphis violascens Ka'i
Cypraea obvelata
Cypraea tigris
Cerithium nodulosum To'eroa
Tonna perdix Pacific Partridge Tun
Stylocheilus longicauda Patito - seasonal
Lithophaga teres Date mussel
Pinna muricatum Prickly Pen-shell Kotata
Urca crassipes Scarlet Broad-front Fiddler crab (yellow pincer) Raukoiti - common
Urca tetragonon Pink Narrow-front Fiddler crab (pink pincer) -common
Ocypode laevis Common Ghost crab Koiti
Cardisoma carnifex Tupa
Clypeomorus brevis
Coenobita perlatus Red Land-hermit crab
Coenobita crassipes Chocolate-brown Land-Hermit

A more recent detailed assessment of invertebrate species was carried out by MMR (2011) at three sites in Muri (Aroko, Nukupure and Eco Tours) and at the control site at Kent Hall, Titikaveka. At each site 18, 50m transects were laid, at random, perpendicular to the shore, with six transects in each lagoon zone (inshore,

mid lagoon and reef). The "strip transect method" was used to determine the density of a selection of lagoon invertebrates (see Appendix F). Invertebrates were observed two metres on either side of the transect line and recorded to species level. Detailed results of the MMR (2011) are not replicated here at this time though are clearly reported (pp52-59) in that report for the Muri Lagoon area. The results suggest that the lagoon seafloor has high concentrations of marine species which are detritus feeders such as sea cucumber and sea urchins (Figure 3.9a and b).

Holothurians:
Holothuria hilla Kanaenae
Holothuria atra Rori toto
Stichopus chloronotus Rori matie
Actinopyga mauritiana Rori puakatoro
Holothuria cinerascens Rori pua
Holothuria leucospilota Rori kaa (maturori)

Figure 3.9a: Holuthurians recorded at Muri Lagoon by MMR (1997)

LOCAL NAME	COMMON NAME	SCIENTIFIC NAME
Avake	Short spine sea urchin	*Tripnestus gratilla*
Kina	Pink sea urchin	*Echinometra mathaei*
Vana	Long spine sea urchin	*Echinothrix dialema*
Matu Rori	Soft black sea cucumber	*Holothuria leucospilota*
Rori Matie	Green sea cucumber	*Stichopus chloronatus*
Rori Toto	Sandy sea cucumber	*Holothuria atra*
Trochus	Trochus	*Trochus niloticus*
Paua	Rugose giant clam	*Tridacna maxima*

Figure 3.9b: Invertebrate species collected at Muri Lagoon (MMR 2011)

Holothuria leucospilota is the most heavily targeted species of the traditional sea cucumber fishery, yet little is known of this species' present spatial distribution and abundance around the island. This was studied in depth by Džeroskia and Drumm (2003) who describe an investigation into the coastal habitat conditions preferred by *Holothuria leucospilota* on Rarotonga, Cook Islands. Their work focused on the fact that If favourable habitat conditions could be effectively identified, steps can be taken to preserve these areas and help the population to thrive. Their findings noted that *H. leucospilota* occupies a distinct ecological niche. It prefers areas with a larger grained physical structure, such as areas of rubble, consolidated rubble and boulder, rather than a fine grained structure like sand. These preferred substrate types offer the necessary interstitial spaces and cover required for protection.

Survey work was also undertaken by Drumm *et al* (2011) who surveyed, over 46 000 invertebrate animals within Muri Lagoon, representing 30 species, that were counted from the six coarse habitat types (Tables 3.3 and 3.4). The holothuroids (68%) and echinoids (30%) comprised 98% of the total epibenthic invertebrate assemblage; the remaining 2% were gastropods, bivalves and asteroids. Although only three species of gastropod were recorded, the topshell *Trochus niloticus* was the only species to exceed 100 individuals, and accounted for 86% of the entire gastropod assemblage. The giant clam *Tridacna maxima* was the only bivalve

found and occurred in all habitat types, except the mudflat. It was more abundant in the rubble/rock and sand/ coral matrix habitats.

Table 3.3: Summary of the number of each species of holothurian in each of the main habitat types for the entire shallowwater environment of Rarotonga (taken from Drumm *et al* 2011)

	Habitat						
Class / *Genus* / *species*	rubble/rock	sand/coral	algal rim	sand	passage/ harbour	mudflat	Total
Holothuroidea							
Holothuria atra	3 730	6 333	119	3 966	1	7	14 156
Holothuria leucospilota	7 573	1 584	56	192	2	0	9 407
Holothuria hilla	115	411	0	7	0	0	533
Holothuria cinerascens	205	1	3 114	0	27	0	3 347
Holothuria difficilis	3 107	1	2	0	0	0	3 110
Holothuria pervicax	249	17	0	0	0	0	266
Holothuria impatiens	55	5	0	0	0	0	60
Holothuria arenicola	7	0	0	0	0	0	7
Holothuria nobilis	0	1	0	0	0	0	1
Holothuria pardalis	6	14	0	0	0	0	20
Holothuria rigida	2	0	0	0	0	0	2
Stichopus chloronotus	338	76	2	4	1	0	421
Stichopus horrens	138	9	0	0	0	0	147
Actinopyga mauritiana	8	0	96	0	1	0	105
Actinopyga palauensis	1	0	0	0	0	0	1
Bohadschia marmorata	0	1	0	0	0	0	1
Chirodota rotifera	0	1	0	0	0	0	1
Euapta godeffroyi	10	1	0	0	0	0	11
Stichopus spp.	0	1	0	0	0	0	1
Total holothurians	15 544	8 456	3 389	4 169	32	7	31 597
Total holothurian species	15	15	6	4	5	1	19

Table 3.4. Summary of the number of echinoids, gastropods, asteroids and bivalves in each of the main habitat types for the entire shallow-water environment of Rarotonga (taken from Drumm *et al* 2011).

Class and species	Habitat						
	rubble/ rock	sand/ coral matrix	algal rim	sand	passage/ harbour	mudflat	Total
Echinoidea							
Echinometra mathaei	7 855	5 159	80	32	447	0	13 573
Echinometra oblonga	21	3	39	0	2	0	65
Tripneustes gratilla	91	19	0	0	0	0	110
Heterocentrotus mammilatus	1	0	1	0	0	0	2
Diadema savignyi	86	17	0	0	18	0	121
Echinothrix diadema	21	4	137	0	39	0	201
Total echinoids	8 075	5 202	257	32	506	0	14 072
Total echinoid species	6	5	4	1	4	0	6
Gastropoda							
Trochus niloticus	160	6	83	0	0	0	249
Aplysia dactylomela	31	4	0	0	0	0	35
Dolabella auricularia	3	1	0	0	0	0	4
Total gastropods	194	11	83	0	0	0	288
Total gastropod species	3	3	1	0	0	0	3
Asteroidea				0			
Linckia laevigata	45	74	0	0	0	0	119
Bivalvia							
Tridacna maxima	174	156	5	3	4	0	342
Total individuals	24 032	13 899	3 734	4 204	542	7	46 421
Total species	26	25	12	6	10	1	30
Total transects	46	52	8	16	3	3	128

The broad-scale pattern of distribution and abundance for the most abundant invertebrate species of Rarotonga (including Muri Lagoon) showed a general pattern of greater abundance in the windward lagoon on

the southeast side of the island (Fig. 3.10). The greater densities of the main species of black sea cucumber (e.g.*: Holothuria leucospilota)* are recorded along the windward, southeast and southern parts of the lagoon reflect the greater heterogeneity and extent of habitats in this region than on the leeward, northern coast, where the reef-flat is very narrow (Fig. 3.11). The southeast region on Rarotonga also has the widest reef-flat (up to 1 km wide) which may also contribute to the greater abundance and diversity of macrofauna (e.g. burrowing urchin) are found there.

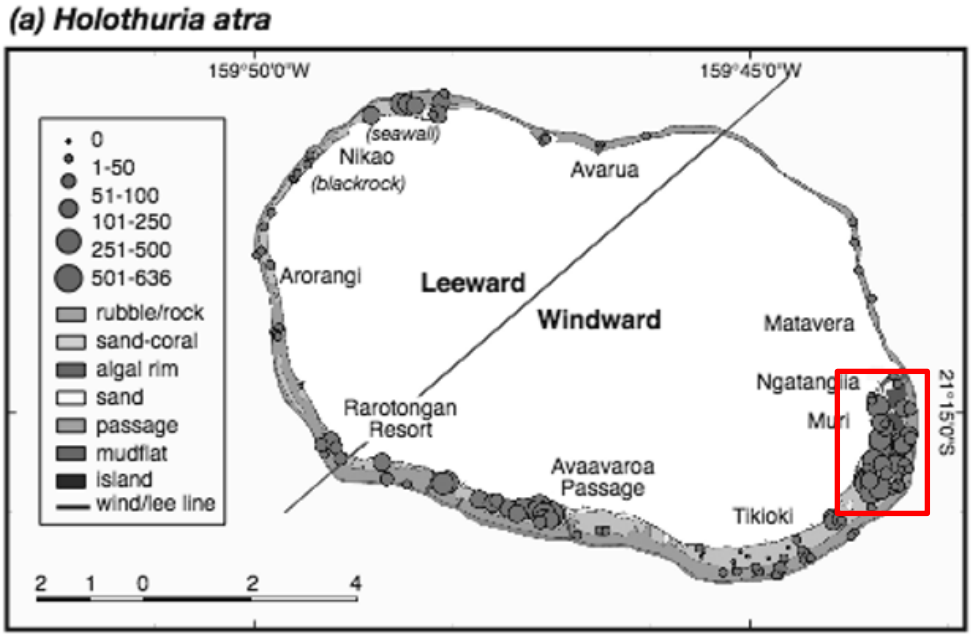


Figure 3.10:Distribution of *Holuthuria atra* (black sea cucumber) on the windward and leeward sides of Rarotonga (Muri Lagoon is boxed). Taken from Drumm *et al* (2011)

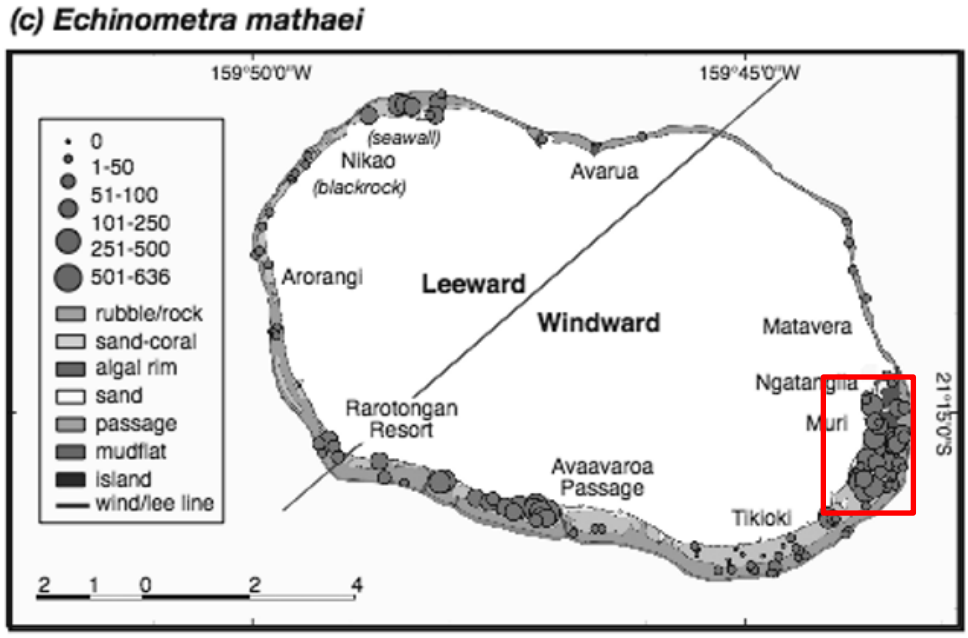


Figure 3.11: Distribution of Echinometra mathaei (burrowing urchin) on the windward and leeward sides of Rarotonga (Muri Lagoon is boxed). Taken from Drumm *et al* (2011)

The latest research was carried out by MMR (2017) who surveyed marine invertebrates within Muri Lagoon (July 2017). Figure 3.12 shows the abundance and frequency assessment of marine invertebrates recorded within Muri Lagoon by MMR between 1997 and 2017 (20 year span). Of interest, it can be seen that there is a decline in species abundance within the Lagoon with the lowest figures most recently recorded in July 2017(at the time, algal coverage within the lagoon was very low and this was a survey carried out in the winter period (lower sea temperatures). The bottom diagram shows the site variation within Muri Lagoon (Aroko is within the Ra'ui).

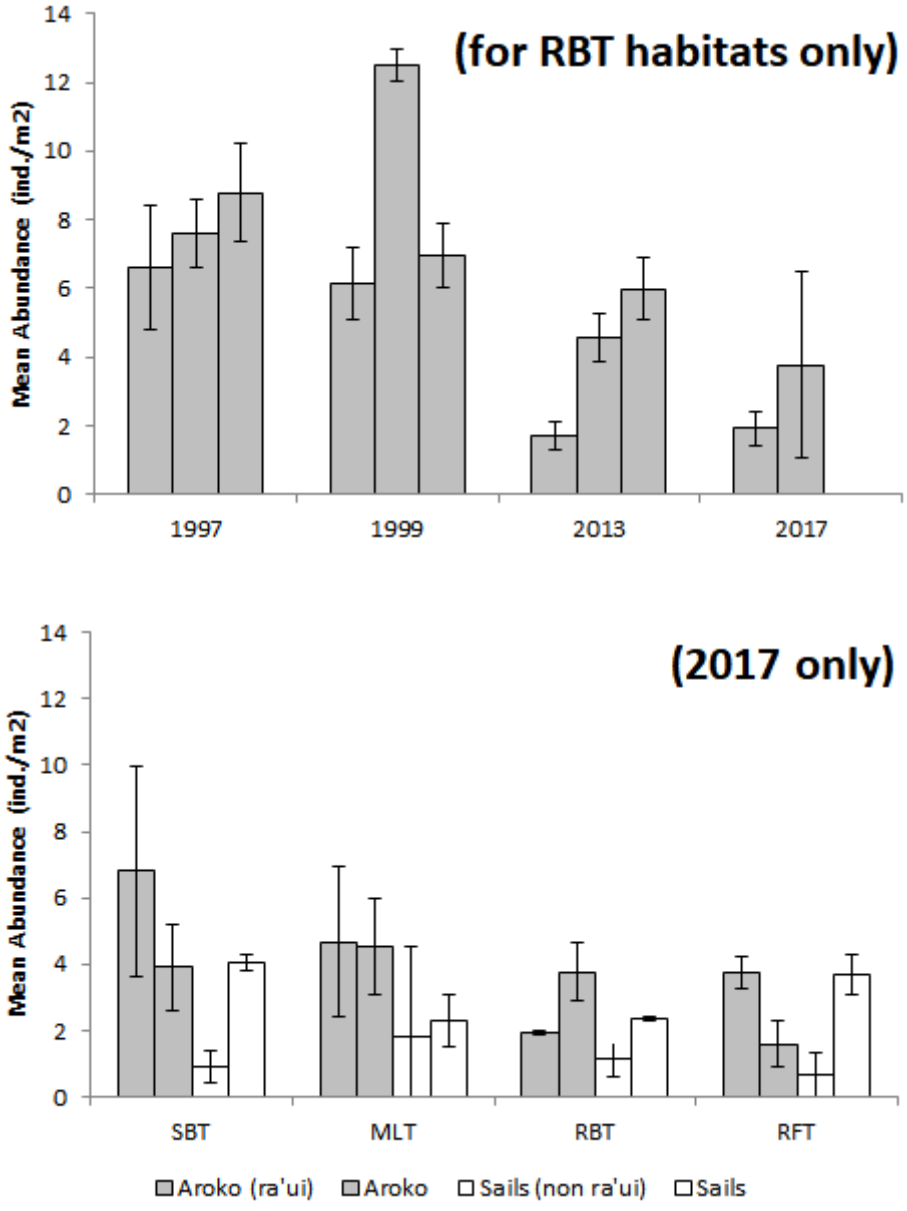


Figure 3.12: Species abundance (invertebrates) change between 1997 and 2017 (upper diagram) and variation at 4 recording stations (north to south) within Muri Lagoon).

These observations are strategically significant (as a bio-indicator) as when species numbers reduce (either by over fishing or other means), there is the potential for detritus to build up, creating conditions that can promote the development of non-palatable algal mats (blue–green algae) or anoxic conditions to develop. This point is elaborated in Part C Section 10 “indicators”).

3.2.4. Fisheries

3.2.4.1. Rarotonga

A number of publications exist that make reference to the status of reef and pelagic fish stocks around the Cook Islands (e.g.: FFS 1993). The lagoon around Rarotonga supports an extensive subsistence fishery that targets many invertebrate species, including sea cucumbers, sea urchins, giant clams and trochus. This traditional fishery provides a substantial component of the protein requirements for the Rarotongan people.

Work by SPC (2009) under the PROCFISH project collated information the Cook Islands as athe Pacific Regional Oceanic and Coastal Fsheries development Programme (survey undertaken in Feb 2007). It declares that marine resources have been heavily impacted in the past both through fishing activity and other human activities including pollution, soil erosion and agriculture runoff (from farming and animals). Many reef fish species are now considered ciguatoxic, which has caused a change in subsistence activities (see Part A Section 5).

Finfish resources and associated habitats were assessed in Rarotonga by SPC (2009) between 16 and 20 October 2007, from a total of 17 transects (8 back- and 9 outer-reef transects, see Figure 3.8 for transect locations and coordinates respectively. The results showed the following findings.

The back-reef environment of Rarotonga *(defined by AECOM as a combination of the inner and outer lagoon areas – see Figure 2.13)* was dominated by Acanthuridae and Mullidae and, to a much lesser extent, Lethrinidae. Goatfish were more important than surgeonfish in terms of biomass). These three families were represented by 15 species; particularly high biomass and abundance were recorded for *Mulloidichthys flavolineatus, M. vanicolensis, Acanthurus triostegus, Ctenochaetus striatu*s and *Gnathodentex aureolineatus* (Table 3.1). This reef environment presented a fairly diverse habitat with very high cover of hard bottom (44%), average cover of live coral (22%) and good cover of soft bottom (27%, Table3.2).

Table 3.1: Finfish species contributing most to main families in terms of densities and biomass in the back-reef environment of Rarotonga (taken from SPC 2009)

Family	Species	Common name	Density (fish/m^2)	Biomass (g/m^2)
Acanthuridae	*Acanthurus triostegus*	Convict tang	0.29 ±0.20	30.5 ±22.6
	Ctenochaetus striatus	Striated surgeonfish	0.20 ±0.07	22.4 ±9.9
Mullidae	*Mulloidichthys flavolineatus*	Yellowstripe goatfish	0.15 ±0.14	71.0 ±70.3
	Mulloidichthys vanicolensis	Yellowfin goatfish	0.05 ±0.04	40.6 ±40.5
Lethrinidae	*Gnathodentex aureolineatus*	Goldlined seabream	0.10 ±0.10	16.1 ±15.9

Table 3.2: Primary finfish habitat and resource parameters in Rarootonga (not Muri specific) Taken from SPC (2009).

Parameters	Habitat		
	Back-reef [1]	Outer reef [1]	All reefs [2]
Number of transects	8	9	17
Total habitat area (km^2)	6.6	9.9	16.5
Depth (m)	1 (1-2) [3]	9 (7-11) [3]	6 (1-11) [3]
Soft bottom (% cover)	27 ±5	1 ±0	9
Rubble & boulders (% cover)	6 ±1	2 ±0	3
Hard bottom (% cover)	44 ±6	79 ±3	67
Live coral (% cover)	20 ±4	7 ±2	13
Soft coral (% cover)	1 ±0	11 ±3	7
Biodiversity (species/transect)	23 ±4	31 ±2	27±2
Density (fish/m^2)	0.9 ±0.4	0.9 ±0.3	0.9
Size (cm FL) [4]	20 ±1	17 ±1	16
Size ratio (%)	64 ±3	58 ±3	59
Biomass (g/m^2)	210.2 ±137.0	120.6 ±35.8	113.7

The density of finfish recorded arund Rarotonga was equal to the density recorded in outer reefs. Biomass, size and size ratio were, however, higher than at outer reefs, while biodiversity was lower (SPC 2009). In terms of habitat variance, the the back-reefs displayed a quite diverse composition of substrate, mostly hard bottom (44%) but also adequate mobile bottom (27%), offering suitable habitat for carnivores (Lethrinidae but especially Mullidae) as well as herbivore fish species.Despite this, the statistical variability presented in Table 3.2 suggests the recorded differences are not significant in term sof making any judgements on habitat parameters.

Within the outer reef of Rarotonga (defined by AECOM simply as “ocean” for simplistic terms with regards to the current contract requirements), the deeper waters are largely dominated by herbivorous Acanthuridae, with very few other fish. This family was represented by 14 species; particularly high biomass and abundance were recorded for *Ctenochaetus striatus, Naso lituratus, Acanthurus triostegus, A. leucopareius and A. olivaceus* (Table 5.7). Most of the substrate was hard bottom (79%) and only very little live coral was present (7%). Soft-coral cover was more important (11%). In fact, recent research by Rongo *et al* (2016) states that coral recovery on Rarotonga appears to be consistently correlated to the increase of coral-associated fish species since 2006. In particular, pomacentrids (i.e., *Chromis vanderbilti and Pomachromis fuscidorsalis*) and chaetodontids (*Chaetodon* spp.) showed an increase from 2006 to 2016. Acanthurids, on the other hand, showed a decline since 2006 (SPC 2009).

3.2.4.2. Muri Lagoon

A more recent finfish assessment was carried out at three sites in Muri Lagoon (Aroko, Nukupure and Eco Tours and at the control site at Kent Hall, Titikaveka. Surveys were carried out on the 31st of August and 1st September 2011 by MMR (2011). At each site, three 50m transects were laid, at random, adjacent to the

shore, with one in each lagoon zone (inshore, mid lagoon and reef). A list of some fish families recorded during the survey is provided in Figure 3.13.

FAMILY	COMMON	LOCAL
Acanthuridae	Surgeon fishes	Maito/Manini/Api/
Balistidae	Trigger fishes	Kokiri
Chaetodontidae	Butterfly fishes	Taputapu
Fistulariidae	Pipe fishes	Papa
Holocentridae	Squirrelfishes	Ku/Ku ta
Kyposidae	Drummer fishes	Pipi
Labridae	Wrasses	Karore
Lethrinidae	Sea breams, Emperors	Iroa
Lutjanidae	Snappers	Tangau
Mullidae	Goatfishes	Koma/Vete/Takua
Pomacanthidae	Angelfishes	Taputapu
Scaridae	Parrotfishes	Pakati/Uu/
Serranidae	Rock cods, groupers	Patuki/Tarava
Siganidae	Rabbit fishes	Morava/Maemae
Zanclidae	Moorish idols	Tiitii

Figure 3.13: Taken from MMR (2011)

The MMR (2011) work compliments that of SPC (2009) whereby catches from the sheltered coastal reef are determined by very few target species. Among these are *Mulloidichthys flavolineatus, Selar crumenopthalmus* and kokokino and tumaro(which have not been scientifically identified). Lagoon catches are reported to be more varied, mainly determined by *Siganus argenteus* (34%), *Kyphosus cinerascens* (26%), *Myripristis sp*. and Kyphosus bigibbus (each 18–19%). Again, the few species reported are explained by the known high ciguatera risk and the belief of fishers that certain species are of low or no risk. Because fishers may target species at the outer reef that are less prone to ciguatera poisoning, reported catches may include more species as compared to the lagoon area. Catches are *determined by Chlorurus frontalis (26%), Siganus argenteus, Naso unicornis, Kyphosus cinerascens, Epinephelus hexagonatus* (each representing 12–13%), and nine other species that may represent 0.6–8.2% of the total reported catch.

3.3. Macro Algae (Seaweed)

3.3.1. Caulerpa

Caulerpa is a genus of seaweeds in the family *Caulerpaceae* (among the green algae). They are unusual because they consist of only one cell with many nuclei, making them among the biggest single cells in the world. It is thought that *Caulerpa* species have such invasive properties in these regions due to their capability to thrive in tropical waters, along with their freedom from natural predators.

This interesting species of *Caulerpa cupressoides* features long, stiff, uprights with finger-like clusters of notched blades. It is typically found growing in sea grass beds in shallow water habitats to about 10 ft. This alga prefers fine material substrates, but will attach to rocks and coral fragments. Interestingly, it is apparently

not palatable to fish and invertebrates. *Caulerpa*, however, readily regrows if buried or fragmented (Williams *et al* 2012).

The key species within Muri Lagoon appears to comprise of the species *Caulerpa cupressoides* (Figure 3.14) with some other species present. Since October 2015 the *C. cupressoide*s provides a stabilization of the lagoon floor, enhancing sedimentation and as a consequence, other algal species have been able to flourish, including *Halimeda sp*. which otherwise would only normally grow on rocky outcrops.

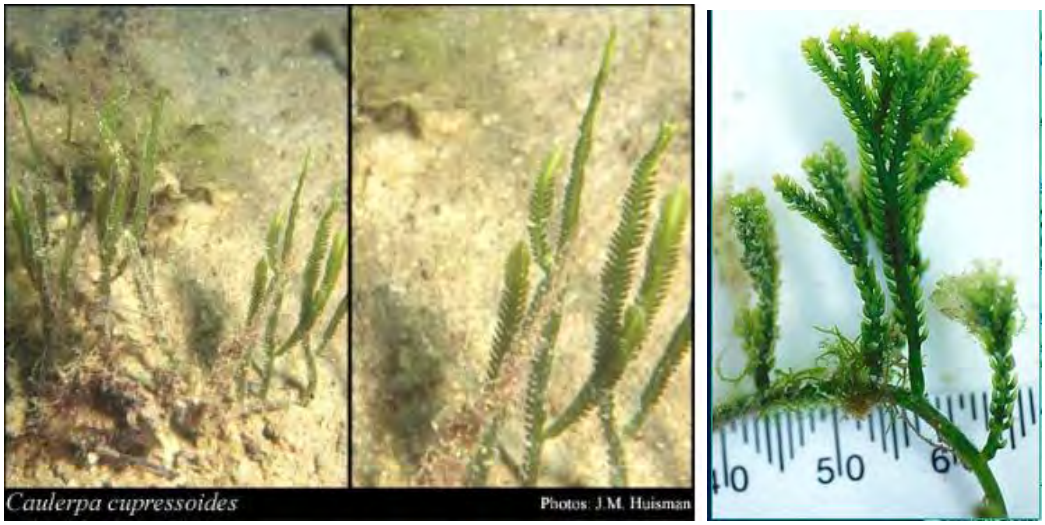


Figure 3.14: Caulerpa cupressoides images.

*C. cupressoide*s is found in the tropics in shallow lagoons and deeper coastal waters up to a depth of 45 m. Salinities below 10 ppt and above 38 ppt proves lethal to the plant which is significant in the scientific understanding of seaweed outbreaks (see Part A Section 2.3). The salinity range is broad enough to support the ability of this species to thrive and invade lagoon areas as climatic/oceanographic parameters change. Although unicellular, *Caulerpa* develops "pseudo-organs" similar to roots, shoots and leaves of more complex plants. The plant consists of a horizontal stem-like rhizome that produces a series of colourless root-like rhizoids downward, anchoring the plant to the sea floor and responsible for absorbing food, water and nutrients. Branch-like "assimilators" shoot upward from the root-like rhizome composing the recognizable featherlike fronds which are its photosynthetic component.

In native populations, reproduction is primarily sexual, although reproduction can also occur through asexual fragmentation when small sections of *Caulerpa* break off and float to a new location, where they develop into a viable clone of their parent plant. Their ability to reproduce asexually makes them key opportunistic invaders. It is also possible that its introduction was from boats contaminated from specific *Caleurpa* prone areas. *Caulerpa* often spreads when fragments of the plant break off due to currents, as well as boating, fishing, swimming, and other human activities.

Caulerpa sp. creates toxic products during metabolism, a unique defence strategy against herbivores (plant eaters) and epiphytes (plants that grow on top of other plants). This is perhaps why the level of fish

biodiversity is often low to very low in locations where *Caulerpa* patches occur. Possible future tests of the phenol content may prove of value. Toxins also are released into the water column, which can damage adjacent plant communities. This results in the displacement of native communities, and the creation of dense uniform mats that impact benthic communities and eliminate important fish habitat for spawning and feeding. Negative impacts on commercial and recreational fishing, as well as tourism and scuba diving also can therefore be substantial.

Of interest, these species found at Muri are believed to take up ammoniacal nitrogen (NH3N) from the rhizomes in the sediments and not exclusively from the water column as other algae often do. The ability of rhizoids to take up nutrients from sediment sources does not indicate whether the sediments are the primary source of nutrient supply (Williams 1984 - Uptake of sediment ammonium and translocation in a marine green macro-alga *Caulerpa cupressoides*)

http://onlinelibrary.wiley.com/doi/10.4319/lo.1984.29.2.0374/pdf

With reference to a similar species of *Caulerpa*, work in New South Wales suggests that during winter, the cover of *C. taxifolia* in NSW waterways generally decreases and the alga is typically much smaller, which is consistent with findings in other countries (Meinesz *et al*. 1995, Ceccherelli and Cinelli 1999a). Large-scale die-off occurs in shallow water (0.5–2 m) in most waterways during the cooler months and this has been particularly evident after heavy rainfalls. Thus, it is possible that die-back in Muri Lagoon may be a consequence of decreased temperature, decreased salinity, increased turbidity or some combination of these factors. Some of the water quality analysis work implies that there may be some link to these parameters.

Another key observations and literature finding is that *Caulerpa* only settles in fine sediment environments and as a result will trap sediment. It also tolerates anoxia. The *caulerpa* observations to date, within Muri Lagoon, show that it often exists as a fine algal mat with epiphytes growing over it. *Caulerpa* also provides a substratum for other algae species (see Boodlea below) to grow over a soft bottom. Consequently, by increasing flushing within the whole lagoon area, the settlement of fine material would be mitigated thus preventing the suitable environment for Caulerpa growth to form.

3.3.2. Key Green Algae Species

3.3.2.1. Enteromorpha spp.

Often known as turf green seaweed, *Enteromorpha* (bright green filamentous seaweed – see Figure 3.15) is commonly seen around Cook Islands shores. The seaweed often forms a bright green hair like, short-pile carpet over rocks and stones. Clumps are sometimes seen on sandy areas. Clumps of flexible, translucent tubes about 3-8cm to 10cm long, 0.2-0.5cm in diameter. The tubes only branch at the base and are usually bright green. This seaweed grows abundantly in nutrient-rich waters.

The seaweed is found in many places around the tropics and in all the oceans, estuaries and even some freshwater habitats. It is also among the organisms that commonly grow on ship bottoms, known as fouling organisms as they are considered a nuisance. Other members of the Family Ulvaceae can go through a stage in their life cycle where they resemble *Enteromorpha*.

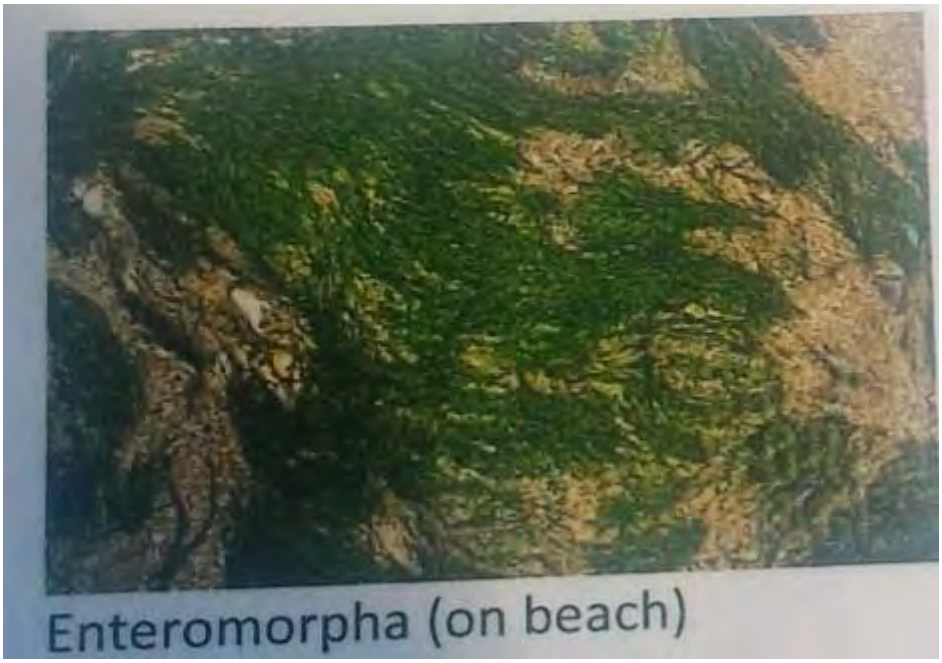


Figure 3.15: Enteromorpha image on the MMR reporting card

3.3.2.2. Boodlea kanaeana

Boodlea kanaeana is fast colonising species which appears to be one of the most prevalent species found during fast onset seaweed outbreaks in Muri Lagoon (see Appendix A). It is a final "hair like" species (see Figure 3.16) appears to be able to grow over *Caulerpa sp* which grows prolifically in Muri Lagoon. Of interest, in November 2017, clear evidence of Boodlea appears to be forming in other parts of Rarotonga and also on Aitutaki which appeared quite significant on a specific mission to Aitutaki on 3 December 2017 by Jonathan McCue).

Figure 3.16: Boodlea kanaeana image on the MMR reporting card

More ecological research is required to better determine the growth dynamics of Boodlea within Muri Lagoon and it is recommended that the invitation of an algal expert (Dr Williams) should assist in better understanding the environmental niche conditions for this species (her invitation is scheduled to Rarotonga for 2018 through the MTVKTV project).

3.3.2.3. Halimeda

Halimeda sp. only grows on rocky outcrops in normal situations. *Halimeda* is a calcareous alga that adds significant weight and density to the benthic algal mat, therefore enabling other algae that would normally not grow on the lagoon floor to establish and grow vertically though the water column, sometimes forming floating rafts on the surface. *Halimeda* sp. are slow growers due to the 'expense' of having calcified cell walls and they are normal in healthy lagoon (Figure 3.17). Their presence is of no concern to the health of the lagoon unless they are also getting covered with epiphyte which is linked back to eutrophication issues.

Figure 3.17: Halimeda spp image on the MMR reporting card (MMR 2011)

3.3.3. Red Algae

Recent surveys by Rongo *et al* (2016) concluded that patches of macro-algae (mainly a red alga named *Asparagopsis*) were present at sites along the eastern exposure and the western exposure of Rarotonga, with extensive areas in close proximity to the Avana passage (Motutapu site) which are dominated by *Asparagopsis*. This species remains the most common macro algae observed on the reef slopes, which was particularly high at shallower sites (4 – 8 m). .

Of interest, this species is not one registered within the MMR algal classification sheets (Appendix 49 of the MMR Water Quality Monitoring Network (Volume 5) Report (2011)). This is something that needs to be reviewed and assessed to determine whether MMR had (in the past) interpreted this species incorrectly, or whether this was mis-identified by Rongo *et al* (2016). The arrival of algal expert Dr Williams (invited to visit MMR in 2018) shall be valuable to clarify this anomaly.

3.3.4. Blue Green Algae Species

Blue green algal mats appear to be establishing in Muri Lagoon, these are often noxious and can can cause dermatitis in certain species. They are also more likely to survice in warmer waters (ie: during summer plus in dry period when lagoon water mixing is reduced). Of interest, these can also smother *Caulerpa,* which could have been responsible for its die-off. Blue green algae species are also highly odourous when compared to *Caulerpa* and other macro seaweeds. The types of species present are shown in Figure 3.18.

64.*Lithophyllum kotschyanum*

65.*Cyanobacteria* assemblage

66.Cyanobacteria forming silky pink tuft

Figure 3.18 (from MMR (2011) Water Quality Monitoring Network for Cook Islands Manual (Version 5)

3.4. Marine Biodiversity Conclusions and Findings

3.4.1. Coral Cover

With reference to coral surveys, the most recent (Rongo *et al* 2016) showed that the average coral cover around Rarotonga is now similar to cover noted in the 2000 survey (Lyons, 2000). For the last 13 years, following the COTS outbreak between 1995 and 2001 and the passing of six cyclones in 2004 and 2005, hard coral cover has seen an increase from 1% in 2006 to 5% in 2009, 8% in 2011, 16% in 2014, and 27% in 2016 (Figure 3.18). When compared with average coral cover of 22.1% estimated from 2,667 Indo-Pacific reefs in 2003 (Bruno & Selig, 2007), the average estimate for Rarotonga is clearly above this in 2016. The recovery period estimated from the 1970s COTS outbreak actually took less than 10 years. Factors such as increased cyclone frequency (de Scally, 2008), coral bleaching (Rongo and van Woesik, 2013), nutrient overloading (e.g., Anderson *et al*., 2004), and perhaps ocean acidification (e.g., Kleypas *et al*., 1999) may all play an important role (n the future) thus determining the future state of Rarotonga's reefs.

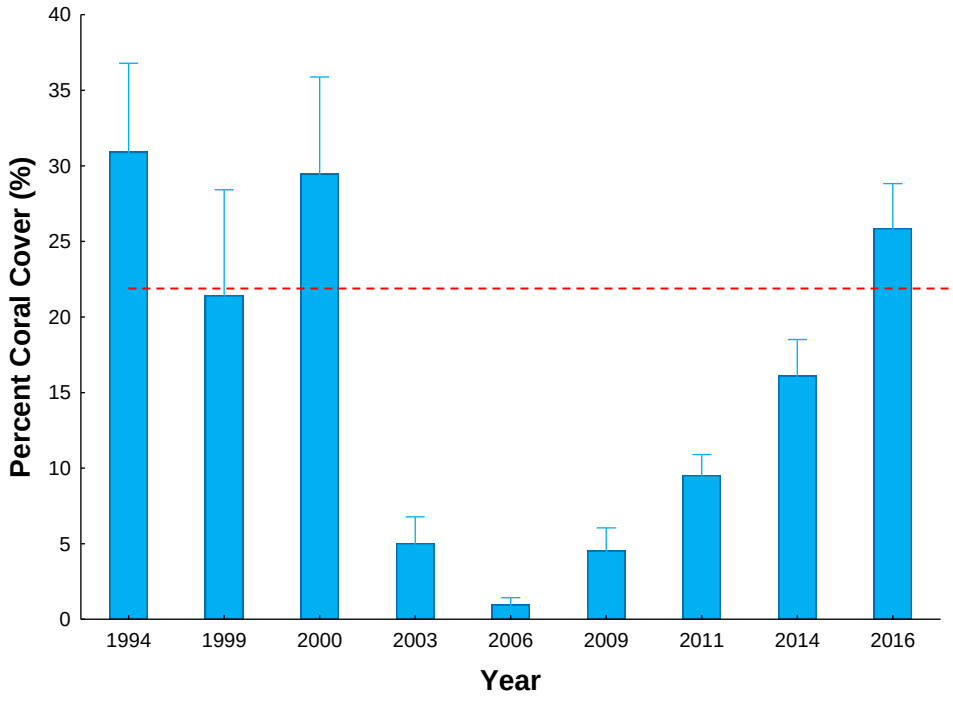


Figure 3.18. Taken from Rongo *et al* (2016) Mean percent coral cover for all sites lumped for each year. Data taken from 1994 (Miller, 1994), 1999 (Ponia *et al.*, 1999), 2000 (Lyon, 2000), 2003 (Lyon, 2003), 2006 (Rongo *et al.*, 2006), 2009 (Rongo *et al.*, 2009), 2011 (Rongo & van Woesik, 2013), 2014 (Rongo *et al.*, 2015) and 2016 from the present survey. Dotted red line represents the Indo-Pacific average of 22.1% estimated in 2003 (Bruno & Selig, 2007).

Considering that coral cover has increased over the years, it may be expected that coral bleaching may become more evident and assessments should be included in future MMR surveys (see Part B Section 8 and Part C Section 10). Although monitoring every two to three years has been carried out (by the Climate Change Department - CCD), intermittent disturbances such as coral bleaching and reef diseases that may occur, between survey intervals, may need to be examined through the proposed "emergency" or "extreme event" monitoring protocols (see Section 10).

Of note, according to Rongo *et al* (2016) between December 2016 and April 2017 around 80% of corals were observed to have been bleached, though some corals (especially partially bleached colonies) were observed to have fully recovered in June during the preparation of this report (T. Rongo, pers. comm).

3.4.2. Invertebrates and Macro- Algae

With regards to sea cucumber monitoring results collated to date (MMR or others since 1997), the general indication from presence and density data collected in survey shows that sea cucumbers are reducing in species and abundance, partly due to heavy fishing pressure with previous fishing possibly eliminated some species. Sea cucumbers play an important role in 'cleaning' hard (limestone) and processing soft (sand and mud) benthic substrates. When these species are overfished, there is the potential for detritus to build up,

creating conditions that can promote the development of non-palatable algal mats (blue–green algae) or anoxic conditions (oxygen-poor areas unsuitable for most life). Regular monitoring of sea cucumber populations is important and is recommended to be included as a key bio-indicator species for Muri Lagoon and other monitoring ecological surveys in the future (see Part B Section 8 and Part C Section 10). Their value within the Muri Lagoon ecosystem has been captured as part of the public (social media) communications strategy being adopted (see Figure 3.19 and Part C Section 11).

Figure 3.19: Public education sample to outline the importance of sea cucumbers to the Muri ecosystem.

3.4.3. Seaweed Coverage

The findings and data evaluation exercise by AECOM (see Part A Section 2.3) suggests that seaweed tend to thrive in the conditions experienced during La Nina (wetter and warmer conditions) with low salinity recordings. Caulerpa spp which is commonly found at Muri is sensitive to salinities below 10 ppt (brackish waters and not an issue at Muri Lagoon) or above 38 ppt. Both extremes prove lethal to the plant which is significant in the scientific understanding of seaweed outbreaks. Frequent rainfall events often associated with La Niña events are likely to dilute salinity within the lagoon due to increased overland flow through stream inputs from land.

ENSO is an inter-annual climate cycle that alternates between two phases (El Niño and La Niña) every two to seven years. Both phases are predictable and very important for understanding the state of Muri Lagoon, especially the link to the Southern Oscillation Index (SOI). El Niño events bring cool temperatures, drought conditions, extreme low tides, and very calm sea conditions to Rarotonga. Alternatively, La Niña events bring warm temperatures and more rainfall to Rarotonga. Rongo and Dyer (2014) suggested that the effect of stronger currents and increased frequency of storm surge in recent decades (during La Nina events) may be responsible for increased sediment transport within many lagoons throughout the Cook Islands (including Muri). Sedimentation that then occurs can be detrimental to coral growth and recruitment (plus being a

facilitator to seaweed growth) and to this end it is likely that sedimentation is contributing to the slow recovery of reefs within Muri Lagoon. Understanding recruitment patterns of reef fishes and the rates of marine sedimentation should be monitored in upcoming surveys to determine their contribution to the state and recovery of reefs on Rarotonga.

The cyclic nature of this climate regime including seasonal changes (e.g., wet and dry season) would suggest that algal blooms are a common occurrence in this area and will continue to occur and possibly become more prevalent in the future considering the nature of the Muri area (i.e., natural wetlands, embayment, and recently a highly developed area).

3.4.4. Next Steps

At the time of writing (December 2017), there is a real need to undertake an up to date marine habitat mapping exercise of Muri Lagoon to better determine the spatial extent, health and ecosystem service value that each habitat component contributes to the health of Muri Lagoon. MMR are scheduled to carry out a marine ecological survey and habitat mapping exercise into the first quarter of 2018. This work, using drone technology and ground trothing techniques, is important to assess biodiversity levels within the lagoon, and importantly to assess habitat health within the lagoon.

The absence of an integrated programme to use drone technology has made quantifiable analysis of algal outbreaks within the lagoon quite challenging to quantify. GHD are undertaking catchment assessments with the use of drone technology. Likewise, new studies for ICI (by Tonkin and Taylor 2017) are undertaking coastal assessments for the coastal area between the Rarotongan Hotel and the old Sheraton Hotel site at Titikaveka). If properly combined, a very sound database of coastal conditions for all areas around Rarotonga could be achieved, whilst also assisting MMR in coastal habitat mapping in recording the spatial extent of sand habitat as an “indicator” of seaweed coverage and extent (Figure 3.20).

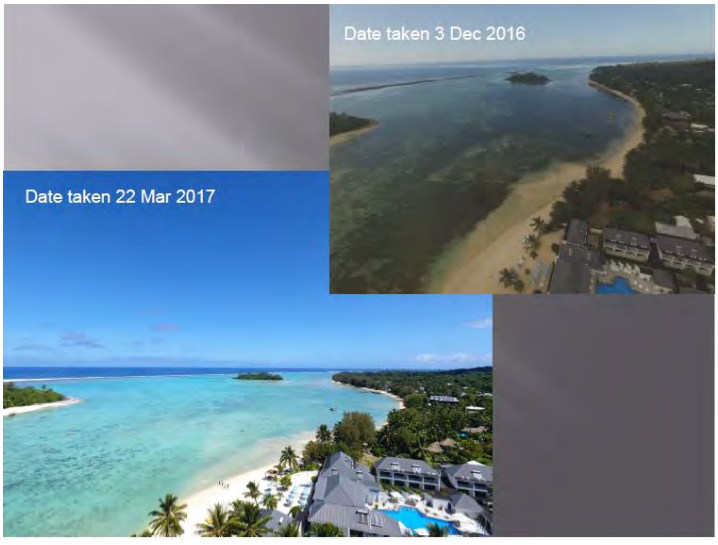


Figure 3.20: Drone footage of Muri in Dec 2016 and March 2017 (taken by P. Maoate)

MMR are intending to purchase a Drone under the MMR-MTVKTV Project (possibly a DJI Phantom 4 Pro model). It is critical that the drone purchased is able to assist towards monitoring the growth and distribution of algae on a monthly basis. To maximise MMR input, they should only be monitor seaweed extent though, where possible, the images should be used for benthic habitat mapping purposes as well with a “pilot” focus being on Muri Lagoon. Future collaboration from agencies can be initiated to up-scale this activity to cover all of Rarotonga, and onto Pa Enau. Specific software is also needed to ensure that ortho-mosaics can be prepared and also that important spatial analysis tasks can be undertaken (e.g.: Arc map, Image J software etc.).

4. Coastal Hydrodynamic Assessment

4.1. Overview

A following literature review has been undertaken to encompass readily available scientific literature and technical reports regarding the physical environmental and coastal dynamic related conditions of Muri Lagoon. Where identified, other literature regards the broader island of Rarotonga or Cook Islands are considered to provide insight into coastal dynamic (lagoonal) processes of relevance to Muri Lagoon.

NB: No additional field data collection (separate to that presented by AECOM in Appendix C) has taken place to embrace or use for analysis within this section. Recommendations for additional studies are therefore put forward at the end of this section.

This Section addresses the following project objectives (already defined in Part A Section 1.2)
Carry out a coastal hydrology study of the area to determine budget inputs into the lagoon. The coastal hydrology study should determine nutrient loads from the groundwater, streams and surface runoff; influence of intrusions, surface current flows, tidal flushing on residence times and seasonal changes; sedimentation and coastal erosion and other issues should be dissipated and a relevant coastal model of the locality should encompass both land and lagoon parameters.

4.2. Coastal Forcing Parameters

4.2.1. Meteorology

4.2.1.1. Wind Conditions

From year 2007 to 2016. For month Jan , Local Clock Time(s): all

Site Name: **Rarotonga Nikao (Airport)** Site Number: **J91843**
Latitude: **-21.1950** Longitude: **-159.8117** Elevation: **6.400m**
Commenced: **Jan 1929** Status:**Open**

Wind Direction	Wind Speed (Kts)												
	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	>50	Total %	Count
Calm												1	32
Vrb												0	0
NE	1	4	2	1	0	0						8	223
E	10	31	13	1							0	55	1,457
SE	5	6	3	0	0							14	371
S	4	1	0	0								5	130
SW	0	1	0									1	31
W	1	1	0	0								2	57
NW	1	1	1	1	0	0						4	97
N		3	2	2	1	0						7	196
N	2											2	56
Total %	25	47	21	5	1	0	0	0	0	0	0	100	
Count	653	1,250	551	123	32	8	0	0	0	0	1		2,650

Figure 4.1a: Wind direction and speed (knots) recorded for Nikao Airport, Rarotonga

Figure 4.1a uses information from Nikao (airport) which geographically is situated at the opposite side of the island to Muri Lagoon. This shows clearly that the predominant wind direction influencing the area is from an easterly direction (see wind rose in Figure 4.2). A more specific automated weather station (AWS) is located at Titikaveka (to the south of Muri Lagoon. The station is located on the Bluesky mast next to the Enua Manea Hall in Tikioki in the Raina burial ground (next to the fish sanctuary in Tikioki). Wind data closer to Muri Lagoon (for the period that data is available) can be accessed by the Met Services Department via the NIWA website (only accessible and downloadable via Met Services Division). AECOM analysis of the Muri specific wind for October and November 2017 suggests a very close (if not identical) correlation to the winds recorded at Nikao airport and so no further data interrogation was undertaken.

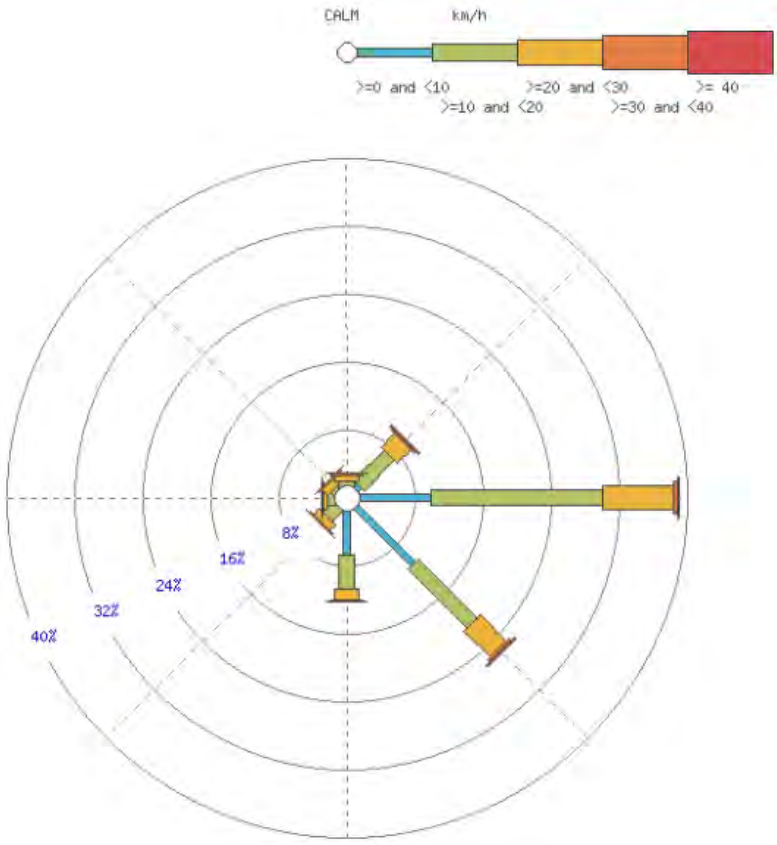
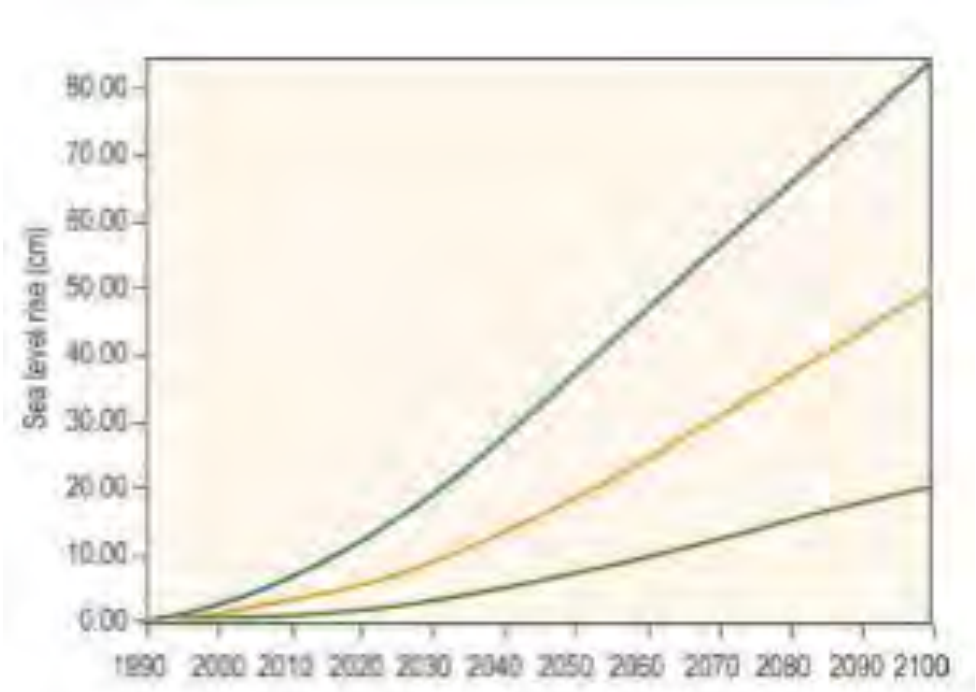


Figure 4.2: Wind rose for winds recorded for Nikao Airport, Rarotonga (2007-2017)

With regards to cyclone frequency in the Cook Islands, the average number of cyclones in Cook Islands is between 7-8 events per year. The cyclone season extends from November and May. Evidence suggests that a cyclone event occurs at least once in the month of February (NIWA 2016), although Rarotonga (at the time of writing) has not experienced an event for 11 years.

4.2.2. Sea Level Rise

The indicated increase in sea level over the next century in Rarotonga is driven by global and regional changes in mean sea level as a consequence of global warming. Figure 4.3 illustrates the magnitude of this contribution.



Notes: Uncertainties related to global climate model sensitivity are indicated by the blue, red and green lines, representing high, best estimate, and low sensitivities, respectively.

Source: CCAIRR findings.

Figure 4.3 Sea Level Rise predictions for Cook Islands (from PACCSAP 2012)

The sea level data recorded since installation is summarised in Figure 4.4 (AusAid 2010). The middle curve (green) represents the monthly mean sea level. The upper and lower curves show the highest and lowest values recorded each month. Unlike many of the SEAFRAME sites, sea level at Avatiu Harbour, Rarotonga did not experience a dramatic decrease in 1998 as a result of El Niño, although it did disrupt the normal seasonal cycle and produced a negative sea level anomaly of almost 20 cm between early 1997 and early 1998. Rarotonga is relatively far from the equator, which is where El Niño signals are most pronounced.

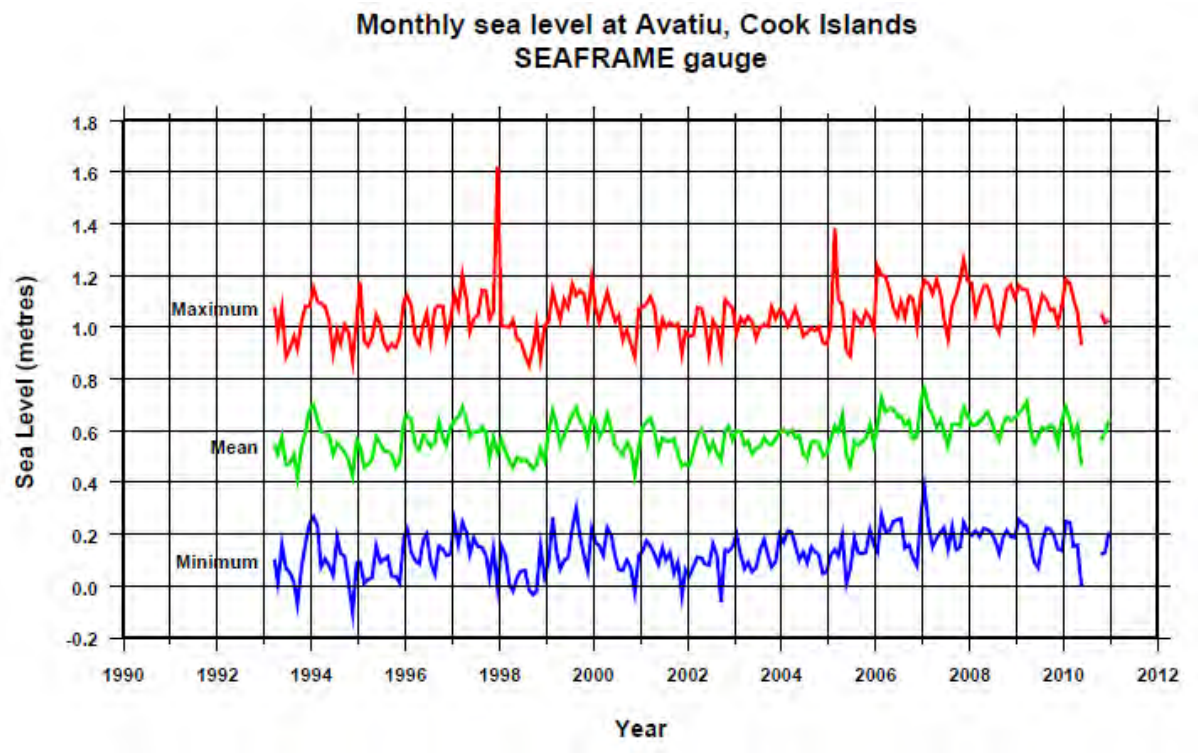


Figure 4.4: Monthly sea level at Avaiatu, Cook Islands (from AusAid 2010)

Figure 4.5 is prepared as a map of the Pacific region showing net relative sea level trends (in mm/year) after subtracting the effects of the vertical movement of the platform and the inverse barometric pressure effect, utilising all the data collected since the start of the project up to the end of December 2010. Cook Islands is displayed as a red circle showing a net increasing sea level rise trend of +4.3mm (based on 23 years of data spanning from 1977 to 1997).

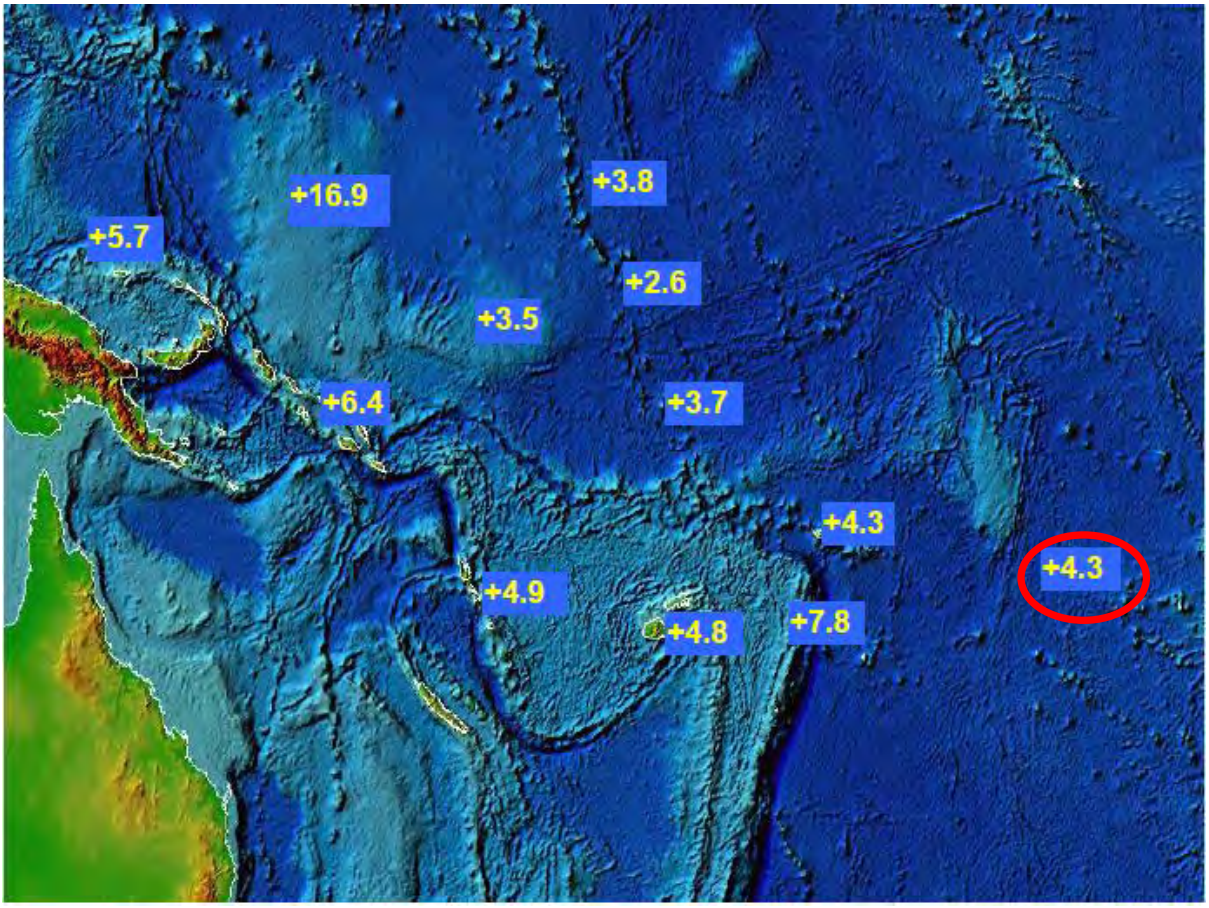


Figure 4.5: Map of region showing net relative sea level trends (in mm/year) after subtracting the effects of the vertical movement of the platform and the inverse barometric pressure effect, utilising all the data collected since the start of the project up to the end of December 2010 from AusAid 2010).

4.2.3. Oceanography

4.2.3.1. Waves

Rarotonga lies south of the South Subtropical Current, which creates a south west to westerly wave current flow towards Rarotonga (SOPAC, 1993). The predominant wave direction is from the east or south east, however, during the cyclone season, wave direction has been observed from the north or north east (Thompson, 1986). The dominance of the easterly winds off Rarotonga (Figure 4.6) generates easterly wind waves and swells over the ocean on the east and south east side of Rarotonga and wind chop on Muri Lagoon. Ninety percent (90%) of waves approaching Rarotonga are less than four (4) metres in height and are predominantly from the east and southeast. Waves over six metres are rare but tend to be most frequent in winter (April to September). During cyclone season, waves from the north and north east are observed but again these are very rare. Average wave heights increase slightly during the winter season (April – September) and decrease slightly during summer (October – March) (SOPAC, 1992).

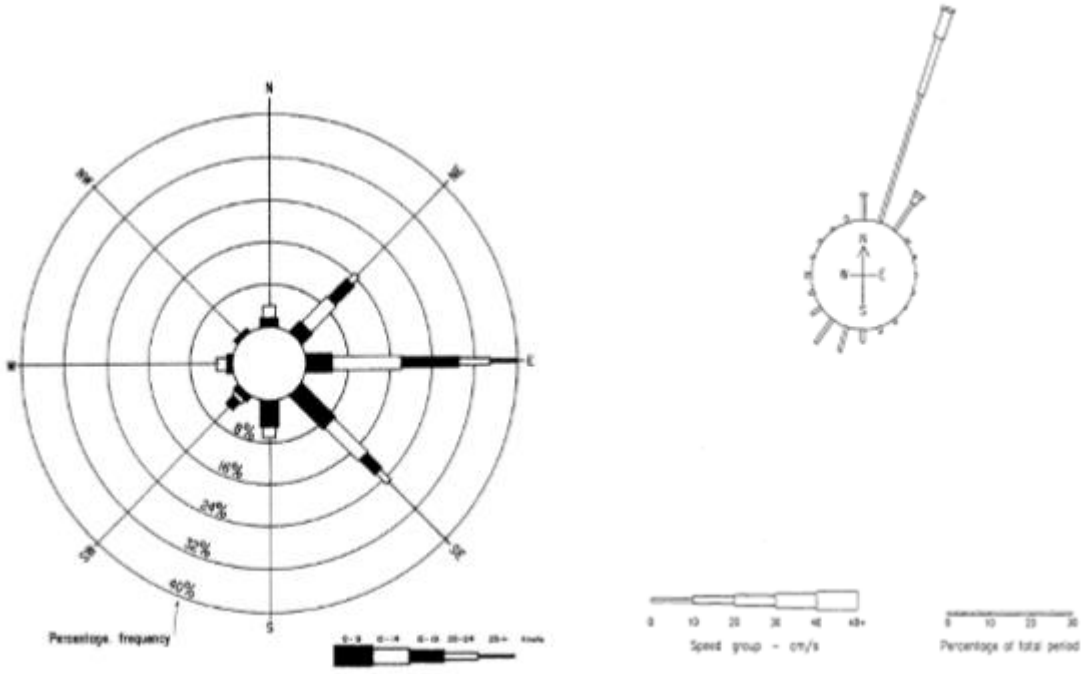


Figure 4.6: Wave and Current Rose for Southern Cook Islands (from Holden 1982 and Muri Water and Sanitation Project 2010 (AusAid and MMR 2010)

4.2.3.2. Tsunamis

Since its installation in 1993, the SEAFRAME tide gauge at Cook Islands has detected 15 separate tsunami events. The largest trough-to-peak tsunami signal recorded by the SEAFRAME at Cook Islands since installation is 63cm, which followed a magnitude Mw8.1 earthquake near Samoa on 29th September 2009.

4.2.3.3. Currents and Water Levels

The Lagoon has a semi diurnal lunar tide with an approximate range of 1 m (Tait *et al*., 2013, 2014). The current circulation and flushing of Muri Lagoon and Ngatangiia Harbour (also known as “Avana” Harbour) is influenced by wind derived wave direction and hence are primarily wave induced (not tidal induced) currents. This movement of water within the lagoon (inner and outer zones) does vary with tidal cycles, with current speed increasing more readily during high tide and decreasing during low tide.

The current flow exiting Muri Lagoon is primarily caused by super elevated water levels which are caused by wave overtopping (setup) from the reef crest. Climate Change Consultants (2016), as part of a separate study to support the Muri Lagoon EIA (Lyon 2016), similarly concluded that there is a linear relationship between wave height in Muri Lagoon and current speed within Avana passage, as originally stated by Holden (1992). Therefore, larger waves overtopping the reef crest can cause a hydrodynamic 'set-up' in the lagoon, subsequently increasing current speed at the location of the Avana fish trap (see Figure 4.7).

Figure 4.7 Avana "fish trap" and inner lagoon flow (north eastwards) out through the Avana Passage (photo taken in 2008 – fish trap to the right of the image is now removed though scattered boulders do exist within the same footprint)

Figure 4.6 also displays a current rose for Muri Lagoon which demonstrates the predominant north easterly flow out of the lagoon through Avana Harbour. Flow rate out of Ngatangiia Harbour was estimated at 35.2 m3/sec during a study in 1992 (SOPAC, 1992), and an approximate lagoon volume of 650,000 m3 at mean water level. Utilising this data, Holden (SOPAC, 1992) calculated that for an average wave height of 2.2 m, Muri Lagoon flushing time is approximately 15 hours. Flushing time would be expected to increase with lower wave heights and corresponding lower current speeds; conversely higher wave heights and higher current speeds would decrease the flushing time (SOPAC, 1992).

4.3. Coastal Form Parameters

4.3.1. Lagoon Geology

Notable geological assessments have been carried out by the New Zealand Geological Survey (NZ DSIR, 1970) and Thompson *et. al* (1998). These studies have informed the fundamental understanding of the geological properties and stratigraphy on Rarotonga. The island is an extinct Pacific basin volcano which was created between 2.3 – 1.1 million years ago (Hein *et al.,* 1997). It is suggested that there have been two episodes of volcanic activity on the island; initial eruptions of basalt, followed by a later event of phonolitic eruptions and lava flows.

The Muri Lagoon catchment is one area that experienced the secondary phonolitic eruptions, producing flows of alkaline phonolite (volcanic rock). Phonolite deposits are likely to directly overlie the older basaltic rock, and extend from the catchment ridge down to the Lagoon. The phonolite is overlain by alluvial deposits in the coastal region, but it only outcrops at the shoreline in the southern extent of the Lagoon. It also extends beneath the current lagoon floor, and outcrops within the Lagoon. The motu "Taakoka" is comprised of phonolite however the spatial extent of phonolite rock beneath Muri Lagoon is unknown (GHD 2017).

Adjacent to the coast, a coral sand and gravel beach ridge rises up to 9 m above sea level (NZSB, 1980). Depressions are present between the colluvium terraces and the beach ridge, thought by Hay and Wood (NZ DSIR, 1970) to have resulted from fresh water dissolving carbonate based beach deposits. These depressions are characterised by low-lying, poorly draining soils, where water commonly ponds creating swampy conditions, which are utilised for growing taro (NZ DSIR, 1970).

The coastal flat is comprised of cemented and unconsolidated beach sands and pebbles, beach ridge deposits and raised reef and beach rock. The Holocene fringing reef and reef flat, surrounding the majority of Rarotonga, balances coral growth with degradation, with coralline reef sediments being deposited on the reef flat, and up onto the beach ridge during storm events (NZ DSIR, 1970; Hein *et al*., 1997). Cemented coral limestone underlies the sediments of the lagoon floor and beach ridge. The thickness of these deposits, the extent to which they extend inland and to the south and the potential for karst conditions within the limestone is unknown.

Sediments within the Muri Lagoon comprise erosion deposits from the reef crest and fore reef with a smaller component of terrestrial volcanic material. Sources of volcanic sediments include transport by streams during flood events.

4.3.2. Soils, Alluvial and Colluvial Deposits

Alluvial and colluvial deposits at the coastal margin originate from the eroded volcanic interior of the island, with deposition of terraces, flood plains and fans occurring in phases due to changing sea levels during the Pleistocene (NZSB, 1980). The colluvium terraces that have formed from these periods of erosion form a thick sequence of highly weathered soils and boulders, inferred to overly volcanic rock. Recently deposited alluvium sediments are present in flood plains, where the streams have truncated a number of the older terraces (GHD 2017).

Mapping of the soils of Rarotonga was documented by the New Zealand Soil Bureau (NZSB, 1980). The sandy soils present at Muri are deemed ineffectual in filtrating nutrients (compared to other types of loam soil), thus increasing the amount of nutrients flowing to the lagoon. Furthermore, the shallow groundwater table around the lagoon means there is less soil to remove nutrients before the effluent merges with the groundwater.

Figure 4.8 identifies the mapped nitrogen levels within the soils for the area. It can be seen that recorded amounts of Nitrogen are highest in the coastal soils area close to Pacific Resort moving north past the sports field (corresponding with classified Muri Soils – stony phase). It has to be noted that Rarotongan streams will have naturally higher concentrations of phosphorus contained within them due to the volcanic nature of the island.

Figure 4.8: Published Soils Map - Muri Soils (from ICI)

More recent soils mapping (completed by SPC in 2010) is presented in Figures 4.9 and 4.10.

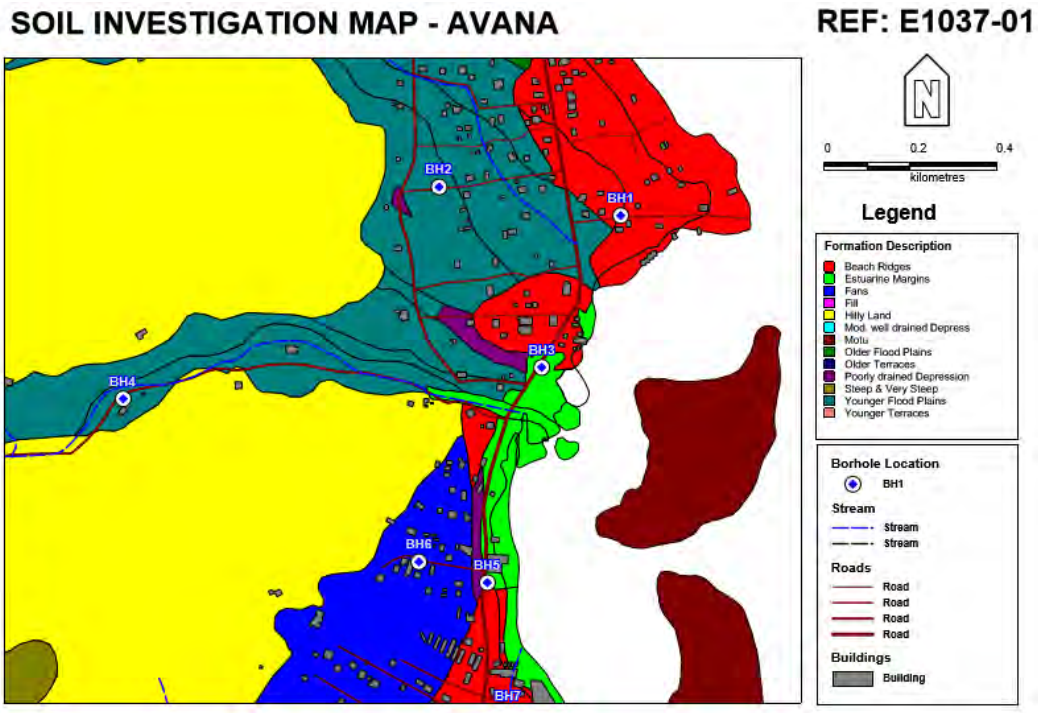


Figure 4.9: Soils Map for the Muri Lagoon area (north)

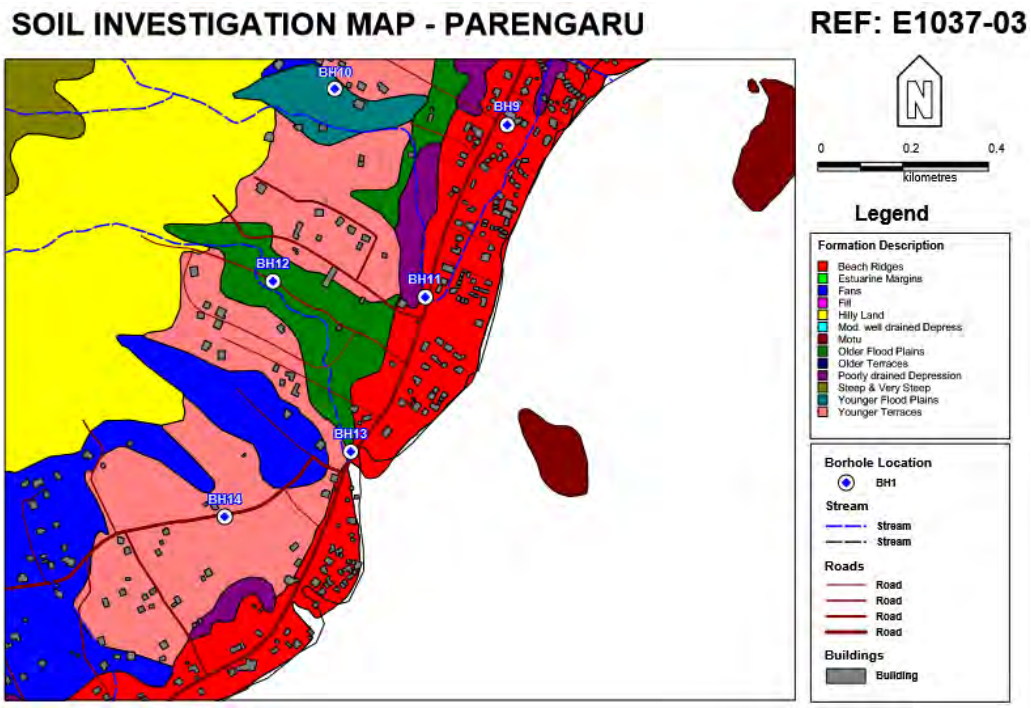


Figure 4.10: Soils Map for the Muri Lagoon area (south)

4.4. Conceptual Coastal Model

4.4.1 Background

The flushing and water quality of Muri Lagoon and Ngatangiia has been of concern for several decades and a number of studies have been completed in an attempt to better understand coastal hydrodynamics of the Lagoon. This is often linked to having a better understanding of the types of natural sources and sinks within the Muri Lagoon area. Sediment sources (inputs) can include river transport, coastal erosion and longshore drift (throughputs) into an area. Sediment sinks can include longshore drift of sediment away from an area and sediment deposition. Anthropogenic activities can also influence sedimentary budgets; in particular "outputs" such as stream mining of an alluvial fan which can reduce the sediment source to adjacent coastal areas.

The historical sand budgets in Muri Lagoon have been altered due to a number of reasons:

- The removal of sediments for construction purposes;
- Filling in the wetland areas for residential business and hotels;
- The placement of poorly designed ad hoc sea defence structures, designed only to protect the land directly behind them, causing an erosion scar on both the up-drift and downdrift sides;
- The modification of streams to accommodate wastewater and overland runoff for both hotels and commercial properties contributing to coastal erosion along the Muri Lagoon shoreline.

Holden (1992) first published information describing the oceanography and flushing of the lagoon. More recently Sharma (2011) described habitat related information (and production of a baseline habitat map) to help track the development of algae in the lagoon. These studies agree that limiting the nutrient load from the groundwater, creeks and untreated sewage "outflow" is necessary to improve the water quality in Muri Lagoon. The recent findings from Tait *et al*. (2014) suggest that despite such effort, the nutrients input via groundwater may continue to increase in the future decades due to the latent response of the aquifer to changes in land use. This suggests that short to medium term mitigation options to Muri Lagoon poor water quality should primarily focus on improving lagoon flushing.

In addition to inputs from terrestrial sources, the slow deterioration of the barrier coral reef (which represents an important "input" of reefal beach sediment material) is significant in terms of reducing the contribution and production of new marine sands over time. From the terrestrial perspective, the streams represent a major source (input) of sediments along the coastline. Modification of stream flows, such as the clogging of culverts (barriers in the form of fallen trees and rocks in the river etc.) can all have an effect on sediment loads and volumes reaching the lagoon. In addition, the removal of wetlands, the clearing of stream vegetation and the

construction of ad hoc stream structures all contribute negatively to the health and clarity of Muri Lagoon.

4.4.2 Published Work on Sediment Budgets

Kirk (1980) illustrated an early, yet useful understanding of a conceptual sediment budget for Muri Lagoon (Figure 4.11). One key point declared by Kirk (1980) is that sediment deposition within the Lagoon channel, such as from the Aroko, Aremengo and Parengaru Streams (as deltas), has the potential to reduce water velocity (current speeds) in localised nearshore areas. A net reduction in water velocity may influence lagoon flushing and potentially increasing lagoon temperature characteristics (increasing temperature when current speeds are reduced) whilst also increasing sediment deposition (especially fine terrestrial sediments or organic matter). The development of alluvial fans around stream mouths has also been demonstrated following a review of Google Earth images and site observations, with this potentially influencing lagoon flushing (see Appendix C Section C4.2).

Sediment samples taken as part of the 1993 study indicate that, at the time, lagoon sediments contained only approximately 1% terrestrial material and less than 2% mud. Sediment analysis within the Ngatangiia Harbour indicated that on average less 20% comprise of volcanic clasts (SOPAC, 1993).

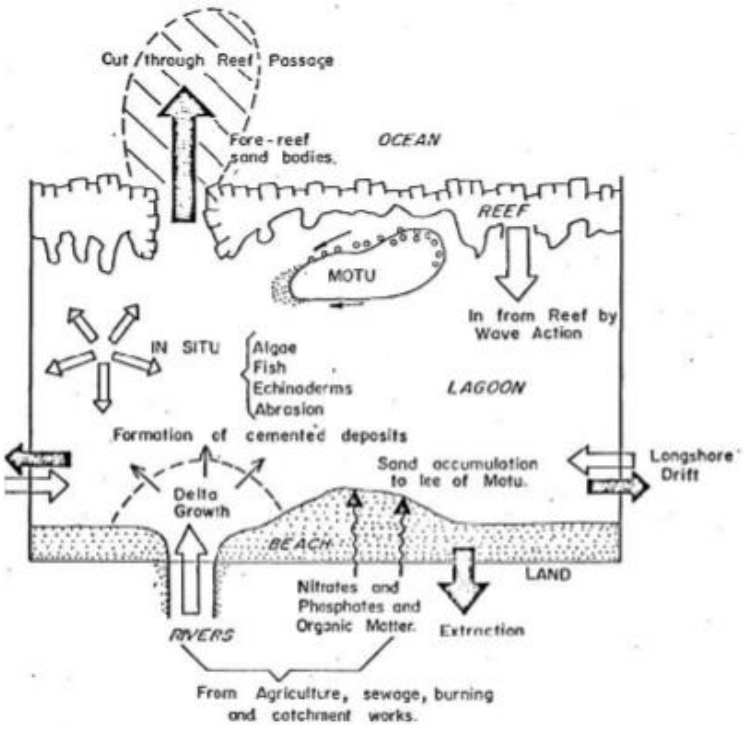


Figure 4.11 Muri Lagoon conceptual model for the sediment budget (Kirk, 1980)

Additional work relating to the hydrological baseline for Muri Lagoon was undertaken by SOPAC Muri Lagoon Desktop Survey by Sharma, and Jens Kruger as part of the Ocean and Island Program (2012). This work produced a conceptual circulation model using previously observed bathymetry information, and satellite

image interpretation to derive a crude bathymetry of Muri Lagoon. Three mitigation options were modelled to help better understand how to improve lagoonal flushing. These options were:

1. Option 1: Dredging of a distance of about 500m from the passage to the big fish trap at Oneroa. The dredge would be about 8m wide and 1m deep. The mouth of the fish trap will be opened to allow more flow.

2. Option 2: Remove the large fish trap at Oneroa;

3. Option 3: Remove debris from the passages on the reef to allow more fresh seawater to flow into the lagoon.

SOPAC stated that the tide averaged currents calculated for the conceptual model representing the present condition shows current velocities between 0.1 and 0.3m/s in between the islands of Oneroa and Koromiri. The current speed at the Oneroa fish trap being between 0.4 and 0.6m/s. Apart from in the Ngatangiia passage, the tide averaged current is flowing out of the lagoon (Figure 4.12).

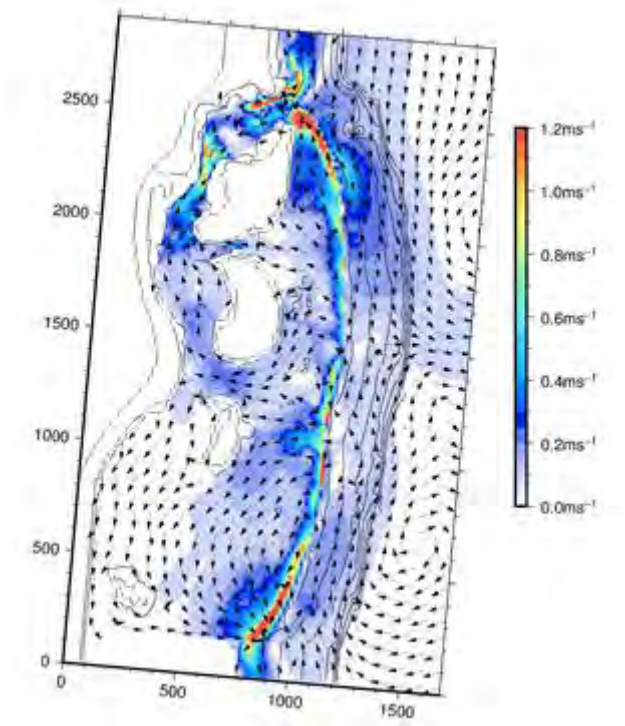


Figure 4.12. Tide averaged current speed (shading) and direction (arrow) for Muri Lagoon, present conditions.

The tide averaged current for option 1 is generally faster than in the present condition model. Specifically, the model show higher velocity in the vicinity of the channel and as far as 500m upstream of the Oneroa fish trap. The difference in currents ranges between 0.1 and 0.2m/s. The option seems to reduce current velocities in the South of Muri Lagoon (Figure 4.13).

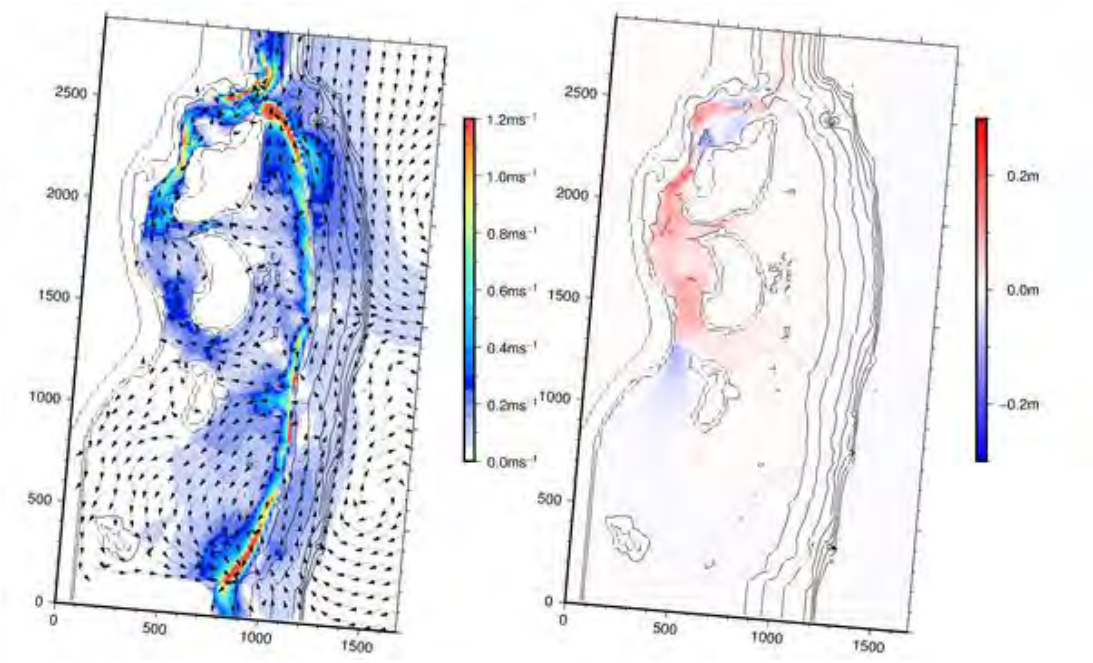


Figure 4.13. Tide averaged current speed (shading) and direction (arrow) for Muri Lagoon, Option 1 (dredged channel) and difference in current between option 1 and present condition.

The tide averaged current speed for option 2 are only little different from the present condition. The changes are localised around the Oneroa fish trap (Figure 4.14).

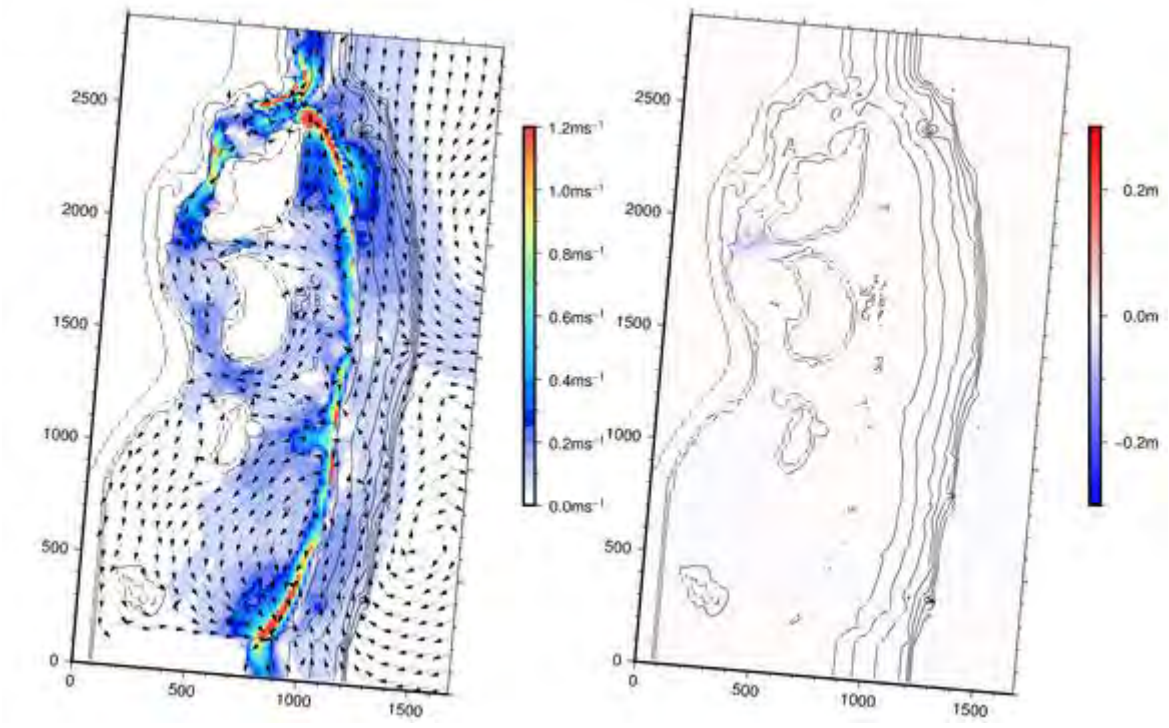


Figure 4.14: Tide averaged current speed (shading) and direction (arrow) for Muri Lagoon, Option 2 (Removal of the Oneroa fish trap) and difference in current between option 2 and present condition.

The tide averaged current speed for option 3 is different from the present condition in the area where the debris were removed but have little effect in the area affected by the high nutrient load (Figure 4.15).

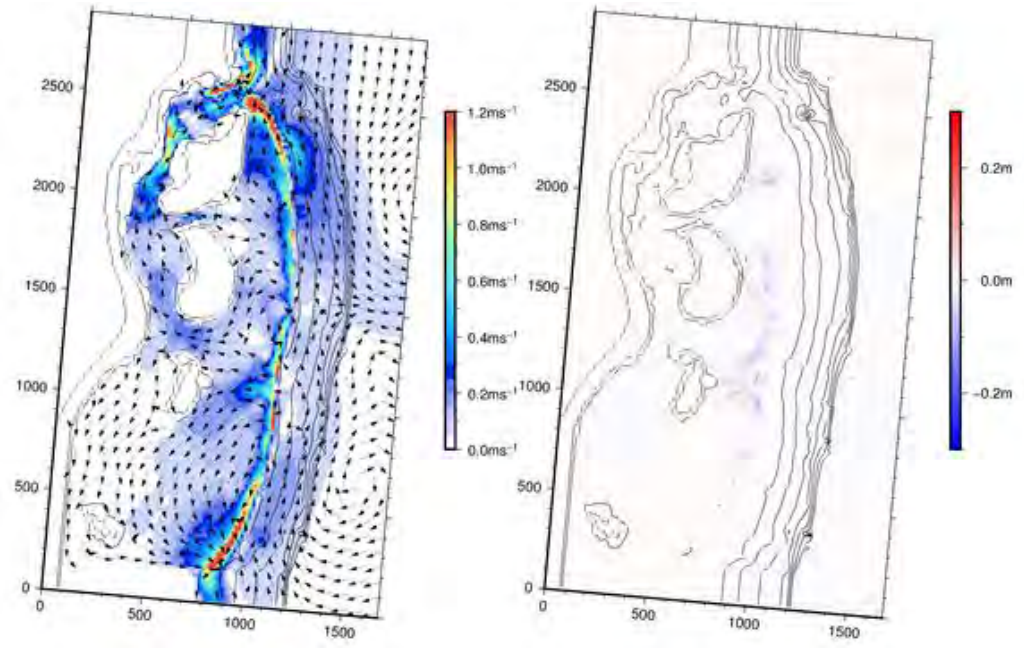


Figure 4.15. Tide averaged current speed (shading) and direction (arrow) for Muri Lagoon, Option 2 (Removal of the Oneroa fish trap) and difference in current between option 2 and present condition.

Despite model inaccuracies, Sharma *et al* (2011) concluded that the tide averaged current simulated near the fish trap and Ngatangiia Harbour passage is in the order of magnitude of current measured by Holden (1992) and unpublished current data collected by SOPAC in 2011 (Sharma *et al*. 2011). On the other hand, the current simulated south of Koromiri is suspicious and inconsistent with drogue measurements from Holden (1992). This is probably because the conceptual bathymetry does not accurately represent the channel that exists in this part of the lagoon toward Ngatangiia passage. As a consequence the values of current changes south of Koromiri are very likely to be underestimated for all 3 options.

The model results suggest that option 1 should provide a greater flushing than the other options. This is because the channel between Motutapu and the mainland restricts the drainage of the whole lagoon. This is somewhat at odds with previous studies reporting that the fish traps are more important at restricting the flow. The calibrated accuracy of the fish trap (option 2) and the removal of debris (option 3) were not high enough to be able to give any accurate interpretation of findings. However, a valid point made is that the removal of debris is likely to have little impact because they often are located outside of the wave breaking zone during mean conditions. Although they are locally restricting the flow, they do not have a significant impact on the volume of water transiting in the lagoon and therefore had little impact on the flushing.

Appendix C fieldwork by AECOM develops the coastal model concept further and explain whether any new field information will help to confirm (or refute) some of the observations presented above.

4.5. Coastal Hydrodynamics Findings

4.5.1. Sediment Budget and Hydrodynamic

Based on the satellite and aerial photographs, numerous reports and data collected, ground truthing during the field mission (including snorkelling on different part of Rarotonga – see Appendix C), the following observations are noted:

- Currents in Muri Lagoon and Ngatangiia Harbour (both direction and magnitude) are dictated by the size of the waves breaking on the fringing reef. Large breaking waves result in wave dominated currents running toward the north and out of the harbour. During periods of smaller waves, both tides and wave conditions impact the overall direction and magnitude of currents that occur in the lagoon. Hence, the circulation and flushing of the Muri Lagoon and Ngatangiia Harbour is primarily wave driven.
- Water levels on the fringing reef and within the lagoon at Muri are significantly influenced by wave setup and gravity surges. These will also have a significant impact on currents.
- Tides at Muri lag the tides along the north coast and at the site of the permanent tide gauge at Avatiu Harbour (and the previous gauge at Avarua).
- The current flow out of Muri Lagoon is primarily caused by super elevated water levels which are caused by the wave setup at the reef crest.
- The presence of the motu (islands) at the eastern side of Rarotonga (Muri Lagoon) is likely to have a sheltering influence to the predominant wind direction (easterly direction) which is likely to be one major differentiator to other parts of Rarotonga where tidal exchange (flushing) is likely to operate at a faster rate.
- Sediment particles are primarily calcareous algae with Halimeda being dominant. Secondary constituents included Mollusca, echinoderms, foraminifera and coral fragments. Information (monitored) on suspended sediment transport regimes is poor and as part of the new modelling work being proposed, it is recommended that new sediment traps are installed to help capture this valuable information for model calibration purposes (see part B Section 7).
- There may be enough suitable sediment for beach recycling to assist towards re-establishing a sediment budget equilibrium within the Muri Lagoon (additional sediment depth surveys are still required within the outer and inner lagoon zones).The stream alluvial fans could be a source of sediment reservoirs which can be used for beach renourishment and beach creation (see Figure 4.16, Part B Section 7 and Appendix C).
- The construction of two fish traps (and other structures) in the Muri Lagoon and the dumping of chemicals, sewage, and garbage into the rivers combined with uncontrolled overland runoff during time of heavy rains and tropical cyclones have all contributed to the increased presence of algae and seaweed in the Muri Lagoon and the loss of marine biodiversity.

Figure 4.16: The sediment outwash delta fans observed around Rarotonga are possible sources of good quality beach sand

More detail is presented in Appendix C regarding sediment outwash deltas and the AECOM coastal field assessment findings.

4.5.2. Future Coastal Modelling Requirements

While the hydrodynamics and bathymetry of Muri may have adjusted since the time of the earlier investigations, it is prudent to build on the previous knowledge identified within this Section and to ensure that the current investigation captures the most important data sets to inform future model calibration.

The following tasks need to be included within the Terms of Reference of any future coastal model design for Muri Lagoon.

- the core monitoring program would have a duration of 1-2 months of data collection, adjusted to fit in with the timing requirements of the broader project and to ensure that a range of environmental conditions are captured (tide ranges and wave events).
- Measure wave transformation across the reef to the Muri Beach area using an array of up to four wave gauges (situated as a single gauge in deeper water on the reef rim (outside of the wave break zone); a single gauge in the 'outer lagoon zone'; and two gauges in the 'inner lagoon zone).
- Water level data should also be measured outside of the reef and in the lagoon by the wave gauges. A single water level gauge should be deployed at the northern end of the lagoon, in the vicinity of the Avana Harbour area to provide further water level data for calibrating the numerical model, and an understanding of water surface gradient throughout the lagoon.
- Continuous current data at a fixed location just inside the harbor entrance channel/passage at the northern end of the study area – this would be the same location as was previously measured by Holden (1992);

- Continuous data at a fixed location either between Motutapu and the mainland or Koromiri and the mainland – this would be the same location as was previously measured by Holden (1992);
- Current profiles across the channel/lagoon between the various motu and the mainland.
- Measure currents using drifting drogues with in-built GPS loggers.

The model needs to determine a number of factors including the following:

- Will cumulative or separate option dredging activity impact on coastal erosion and sediment movement within the inner lagoon area?
- How frequent will cumulative or dredging separate taking place in the inner lagoon require undertaking?
- Will current speed changes (either through cumulative or separate option dredging activities) be influenced by the presence of existing/traditional fish traps in the inner lagoon area?
- Will cumulative or separate option dredging activity impact on current speeds which may increase bathing safety risks?
- Will flushing rates and current speeds be influenced by artificially encouraging improving "flushing channels from the reef crest, through the outer lagoon to the inner lagoon areas?

When completed, it should be MMRs responsibility (in partnership with others such as ICI) to analyze the coastal model findings and produce a "Muri Lagoon Conceptual Model" which can be used for updating the Integrated Monitoring Programme (see Part B Section 8) and also to fine tune the possible field interventions/data collection instrumentation site locations (e.g. sand traps etc.) in Muri Lagoon (see Part B Section 7).

NB: at the time of writing, MFEM recently (24 November 2017) reached a decision to award the coastal hydrodynamic model project for Muri Lagoon to University of New South Wales (UoNSW). The programmed completion of this work is anticipated to be June 2018.

5. PUBLIC HEALTH SAFETY ASSESSMENT

This Section addresses the following project objectives (already defined in Part A Section 1.2)
Review public health safety concerns surrounding ciguatera, bacteria loads and other noxious agents and the current techniques for monitoring these such as enterococci and the development relevant public health standards.

5.1. Ciguatera Concerns

5.1.1. General Description

Ciguatera Fish Poisoning (CFP) is the most common seafood illness reported in travellers and locals in Rarotonga. It is caused by eating fish contaminated with ciguatoxins which are produced by dinoflagellates – small marine organisms living on or near coral reefs, belonging to the species *Gambierdiscus toxicus*. Ciguatoxins are mainly concentrated in the fish liver, intestines, heads, and roe. The toxins do not affect the taste, texture, or odour of the fish and cannot be destroyed by cooking, smoking, freezing, salting or any other method of food preparation. Outbreaks can occur seasonally or sporadically, though research implies that its frequency increases after cyclone or storm events (physical disturbance of sediments etc.). This issue is elaborated upon in Section 5.3.

5.1.2. Ciguatera in the Cook Islands

The key authoritative guidance document of ciguatera is produced by SPC (Laurent, Dominique et al. Ciguatera: a field reference guide 2005). According to this guide (referred to as SPC 2005 from hereon) the incidence of CFP in the Cook Islands varies from 5 to 8/1000 (as of 2005 recordings). Most cases are due to eating surgeonfish *Ctenocheatus striatus* (maïto), long-snouted unicorn fish *Naso unicornis* (ume), Bermuda catfish *Prometichthys prometheus* (manga), moray eel *Gymnothorax javanicus* (a'a pata), red bass *Lutjanus bohar* (anga-mea) and various cod and grouper such as *Cephalopholis argus* (roi).

Of interest, Rarotonga, reports the highest incidence of cases globally. As a consequence, research into CFP has been a key focus for a few decades. In collaboration with the Conservation Service and the Ministry of Health (MoH), MMR set up a ciguatera monitoring programme on Rarotonga in 1994 and James Cook University (JCU) provided training in the collection and analysis of ciguatoxic algae (SPC 2005). The number of cases of ciguatera poisoning in the Cook Islands per year from 1994 to 2017 is shown in Figure 5.1.

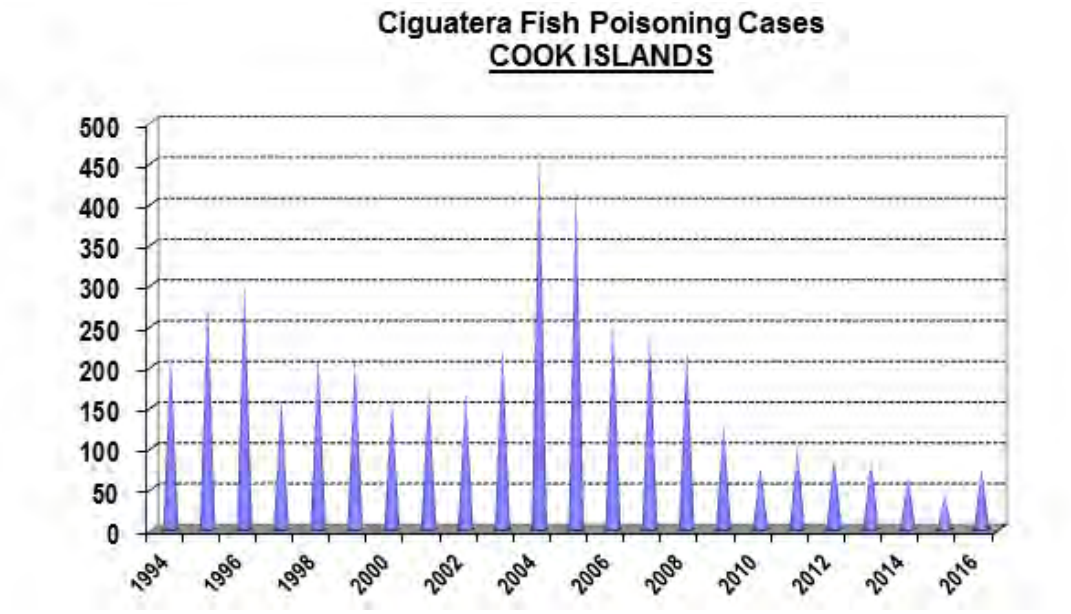


Figure 5.1: CFP Poisoning Cases (from Min of Health)

In most parts of the world where CFP is recorded (including the Cook Islands) the natural environment is a major factor in ciguatera outbreaks (SPC 2005). The dinoflagellate *Gambierdiscus toxicus* is a largely immobile species that is an endemic inhabitant of most reef ecosystems. In habitats containing a high proportion of living coral, its density is often low and the small amount of microalgae consumed by grazing and herbivorous fish is of no great consequence and has no influence on the toxicity of carnivorous fish. Conversely, when large areas of dead coral form, mixed macro-algae beds develop (filamentous and calcareous algae, unicellular algae and macro-algae) and these provide very favourable breeding grounds for opportunistic toxic microalgae.

Original hypotheses from *M*MR (2006) linked ciguatera outbreaks to cyclone frequency and this appears to be a valid line of thought. The space created in reef bank and fore reef systems after the passing of a cyclone (break up of reefs etc. – implying a less healthy reef as stated above) is sufficient enough to encourage dinoflagellate species to grow (cyclones having killed off healthy dinoflagellate species in the process). Fish that graze off reef floors are subsequently more at risk that those grazing off plankton. In addition, MMR believe that El Nino seasons (low rainfall and cooler seas) are more conducive conditions for dinoflagellates to grow and develop. During La Nina periods, fewer fish appear to be poisoned as reef disturbance/damage (fewer cyclones) to open up reef space. Of interest, 2017 is a year that is at a start of the latest La Nina episode (Rongo 2017) and this is evident from hospital records in Rarotonga which show a reduction in the number of ciguatera cases to an all-time low in the southern Cook Islands since the five major cyclone events in 2005.

Of interest, any bare substrates are therefore likely to cause mass proliferation of *G. toxicus* and consequently an outbreak of ciguatera. These disturbances may be natural (tsunamis, cyclones, seismic activity, submarine volcanism, coral bleaching, etc.) or artificial (coastal development, construction of dykes or wharves, channel dredging, etc.). Ciguatera risk zones may therefore be quite localised, occurring in only one section of reef, one passage, or even around a stranded ship. Research by Rongo (2013) reaffirms the theory proposed by SPC

(2005) and Evans (2006) and concluded that reef disturbance and density of herbivorous fish were good predictors of ciguatera poisoning. Both of these factors increased following major cyclones, thus they suggested that high numbers of cyclones affecting Rarotonga are responsible for the high number of ciguatera cases. Furthermore, he suggested that the decrease in frequency of cyclones is responsible for the decrease in cases of ciguatera poisoning. During the El Nino years, there is also an increase in cases of ciguatera poisoning. During this time, the cyclone would disturb the reef, opening up space on the reef for these microscopic algae that produce the toxins to colonise. However, during La Nina periods, when fewer cyclones occur, the risks for fish poisoning appears to reduce.

MMR have been undertaking seaweed cell laboratory analysis sporadically since 2011 to determine the presence of dinoflagellate *(G.toxicus).*Findings from MMR (2011) stated that *G. Toxicus* was found at all sites in Muri Lagoon (see Figure 5.2). Samples were collected from four sites (Aroko, Nukupure, Eco Tours, Sir Geoff's Residence) in Muri and at two control sites at Little Polynesian and CICC, Titikaveka. Collections were made once a month for six months from July to December 2010. Host algae collected for dinoflagellate counts during surveys also included *Halimeda spp, Turbinaria spp, Jania spp* and mixed turf algae.

Figure 5.2: Map of areas where macro algae was collected to be examined for *Gambierdiscus toxicus.* Macro algae were collected at four sites, with two areas (inshore and outer lagoon) in each site (take from MMR 2011)

Of interest, dinoflagellate counts made at all measured sites (including control sites) in the months of July and December 2010 recorded zero counts of the dinoflagellate *G. toxicus*. The month of August had the highest average *G.toxicus* count of 4±1.3/100g of host algae, with dinoflagellates being found in both the inner lagoon

and outer lagoon samples. The months of September, October and November all had low counts of *G.toxicus*. Experts now believe that there is an increasing number of dinoflagellate species that have the capacity to harbour the ciguatera toxin. Originally, it was originally believed that only 1 species of dinoflagellate was the cause though the list presented in SPC (2005) suggests that the following species appear to co-habit with *G. toxicus* in ciguatera-prone regions. The other species of the *Gambierdiscus* genus for future assessment and consideration within the Cook Islands include *G. yasumotoi, G. pacificus, G. australes* and *G. polynesiensis*. All these microalgae can produce ciguatoxin or maïtotoxin-type toxins. Other genera of toxin producing dinoflagellates can also co-exist, such as *Prorocentrum, Ostreopsis, Coolia* or *Amphidinium* (SPC (2005).

A total of 24 fish were collected by MMR (2011) from four sites to test for ciguatera poisoning. Of the 24 fish, 11 tested positive for ciguatera. Of the 11 fish that were tested, 8 of the fish are classified as being at high risk of having ciguatera poisoning (patuki roi, pakati, maito and tangau). Since this time, MMR has largely discontinued monitoring of this program as there are questions over how to put in place effective counts of micro-algal species associated with toxicity as well as reliable tests to quantify toxicity levels within fishes themselves.

It is of interest that if the above theories are proven valid (with better monitoring results, that there is a negative correlation link between preferred seaweed growth conditions (during La Nina wetter and warmer conditions) compared to the colder and more stormy conditions linked to El Nino conditions which appear to favour the increase in CFP cases. This is a useful observation that dilutes the popular belief that seaweed outbreaks are linked with increased in CFP cases.

5.1.3. CFP Reporting Procedures

At present, if any CFP case gets reported to doctors, the procedure of reporting and monitoring is as follows:

- A patient arrives at a doctors surgery and a case is reported then (by the doctor) to the Event Surveillance and Response Unit (ESRU) which (comprises of a series of separate officers).
- ESRU Officers then inform the Heath Protection Manager and his Director at the Community Health Services (Ministry of Health) and a statistical analysis is then made to assess whether a number of cases are being reported and if so, where the cases are occurring.
- Should the need arise, the MoH embark of a specific short term awareness campaign which may include radio, newspaper and TV coverage and related information events.
- MMR can ask for data on CFP on an “as needs” basis only. There is no formal dissemination of this data in place between Ministries and departments.

Improvements are proposed to this approach. At the outset, however, improved Ciguatera Risk Assessment procedures and forms should be followed/produced (see Section 5.4).

5.2. Bacteria (Bathing Water) Concerns

Stream water quality monitoring results that have been gathered from MMR (2007 – 2015) declare some concerning results with regards to bacterial (enterococci numbers) in streams. Table 5.1 provides the average enterococci numbers in cells/100ml per month for the streams reaching to Muri Lagoon for this time period.

Months	Enterococci (cells/100mL) within Streams feeding Muri Lagoon	Enterococci (cells/100mL) in Muri Lagoon (inner lagoon zone)
January	3944	98.9
February	1187	63.0
March	5843	290.0
April	4534	122.4
May	1992	79.3
June	1691	76.0
July	2597	55.2
August	2856	58.1
September	2907	298.2
October	1865	23.5
November	1945	27.2
December	1196	51.2
Average	**2713**	**103.6**

Highest level of enterococci spp.is recorded during the months of January, March and April which coincides with the identified rainy season (see Figure 2.11 and 2.12 in Section 2 and Table 5.2). This implies that the source of the pollutant is within the Muri catchment area (transported via streams or groundwater). It is shown that high volumes of enterococci are transported to Muri Lagoon via this medium. Indeed, enterococci cell numbers in the lagoon are highest during these high rainfall months.

Table 5.1 presents the level of average enterococci recorded within Muri Lagoon per month. This shows that enterococci levels are high during the months of January, March and April which is complimentary to the same recordings taken within the streams. The statistical correlation between the existence of enterococci in streams and enterococci recorded within the Lagoon shows a positive (correlation =0.16).

From the above analysis, although bacteria measurements within Lagoon fall within the acceptance limits defined by WHO, the level of existence of bacteria in Quarter 2 is close to the upper limit of acceptance. Bacteria level recordings coincidently are highest (from stream recording) during Quarter 2 (see Table 2.8 for steams flow recording into Muri).

Table 5.2: Stream measurements for water quality, oceanographic and climate parameters

	DRP (µg/L)	NH4-N (µg/L)	NO3-N (µg	DIN	TSS (mg/L)	Entrococci (cells/100mL)	pH	DO Satura	Temperature (ºC)	Salinity (‰)
Quarter1	27	28	107	126	3	2,109	8	85	26	3
Quarter2	36	65	129	209	6	4,123	8	75	25	2
Quarter3	25	35	152	199	4	2,381	8	76	23	3
Quarter4	29	38	164	175	4	2,239	7	89	24	3
Avrage	**29**	**42**	**138**	**177**	**4**	**2,713**	**8**	**81**	**24**	**3**

As recorded in Section 2 (nitrates and phosphorus) water quality (from a public health perspective) reduced within Muri Lagoon during Quarters 1 and 2.

An important observation with regards to bacterial laboratory test results for enterococci is presented below and of which AECOM recommends immediate review. MMR continue to conduct enterococci tests during 2017. However, according to the results of these tests, average level of enterococci number in Lagoon show recordings of **731 in per 100ml** . This figure is much higher than previous years (average is 103 enterococci per ml – see Table 5.1). Average enterococci readings are recorded (from MMR results) as being **368 in per 100ml** in all beaches of Raratonga. Consequently. This implies that public health risk from bacterial infection from lagoon water recreation is dangerously high with leveld of enterococci far and above the acceptable upper limits of standars (200 enterococci per 100ml).

In support of the above observations, it maybe opportune to introduce E-coli measuring, which currently does not take place in the lagoon (or stream) waters of Rarotonga. Considering enterococci testing takes place by MMR already, it would appear sensible to introduce E coli testing as well and carried out (in terms of measurements) at the same time. New equipment is recommended to be introduced within the MMR monitoring programme during 2018. It is recommended that the same company that supply the equipment for

enterococci should be approached for a quotation for this additional assessment to help support public health related monitoring “early warning” systems. Specific information regarding field and laboratory procedures for this are proposed in Part A Section 6.

5.3. Public Health Observations

5.3.1. Ciguatera Observations

The following observations have been taken from specific meetings with MMR staff, key scientists on Rarotonga and officials of the Ministry of Health (MoH) during May, June and November2017.

- In habitats containing a high proportion of living coral, densities are often low and the small amount of microalgae consumed by grazing and herbivorous fish is of no great consequence and has no influence on the toxicity of carnivorous fish. Conversely, when large areas of dead coral form, mixed macro-algae beds develop (filamentous and calcareous algae, unicellular algae and macro-algae) and these provide very favourable breeding grounds for opportunistic toxic microalgae.

- At present, no formal procedure is in place to process and analyse the information being collated on CFP. An improved reporting and analysis “arrangement” should be set up between MMR, MoH and also Cook Islands Tourism that is based on a risk assessment approach. This is necessary as capacity to undertake this (from MMR etc.) is currently and will continue to remain low and consequently, it is important that any reporting system is kept simple and easy to use. It is recommended that a review is needed of the specific questions being asked within the existing MoH database “patient examination form” to include a new parameter to determine where the fish was either caught or bought from (see proposed questionnaire in Appendix F). Figure 5.3 displays the current patient examination form that is used to collate ciguatera related illness information.

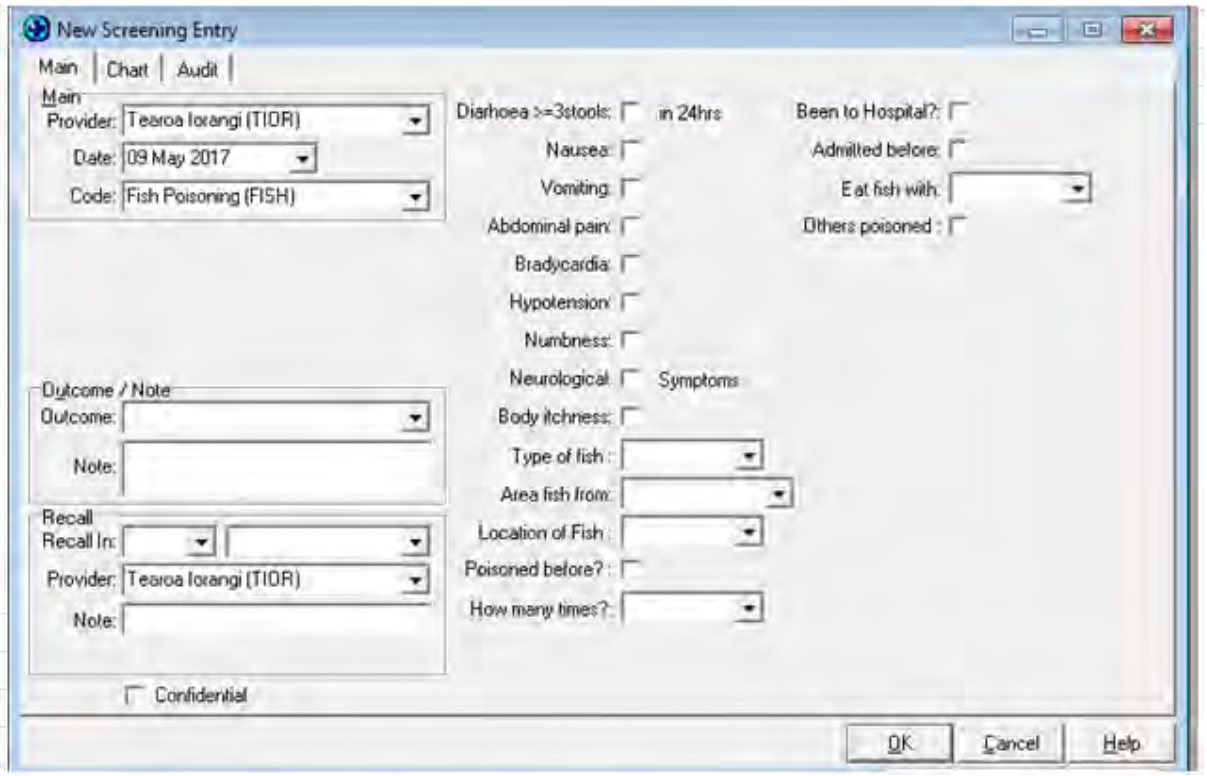


Figure 5.3: Patient Recording Database Screen for CFP cases

5.4. Public Health Recommendations

5.4.1. Ciguatera Monitoring

Further to consultation with the Ministry of Health (November 2017), it is proposed that that following actions are required:

- It is recommended that some MoU is set up between MoH, MMR and the Cook Islands Tourism to ensure the necessary technical support is embraced and communicated on ciguatera events. The focus of the MoU should be centred around MMRs initiation of a Ciguatera Risk Assessment procedure (similar to the SPC "approach" defined in Figure 5.5). The risk assessment process should be used to help convey seasonal "risk" increases of ciguatera cases, which do statistically suggest cases increase 1-3 months following a cyclone (resulting in coral break up etc. – See Section 5.2). This is recommended to be used as an "early warning" post cyclone internal awareness programme. This reporting mechanism, especially to Event Surveillance Response Officers (ESRO's), may prove valuable to help ensure that a formal monitoring and reporting system approach is adopted.

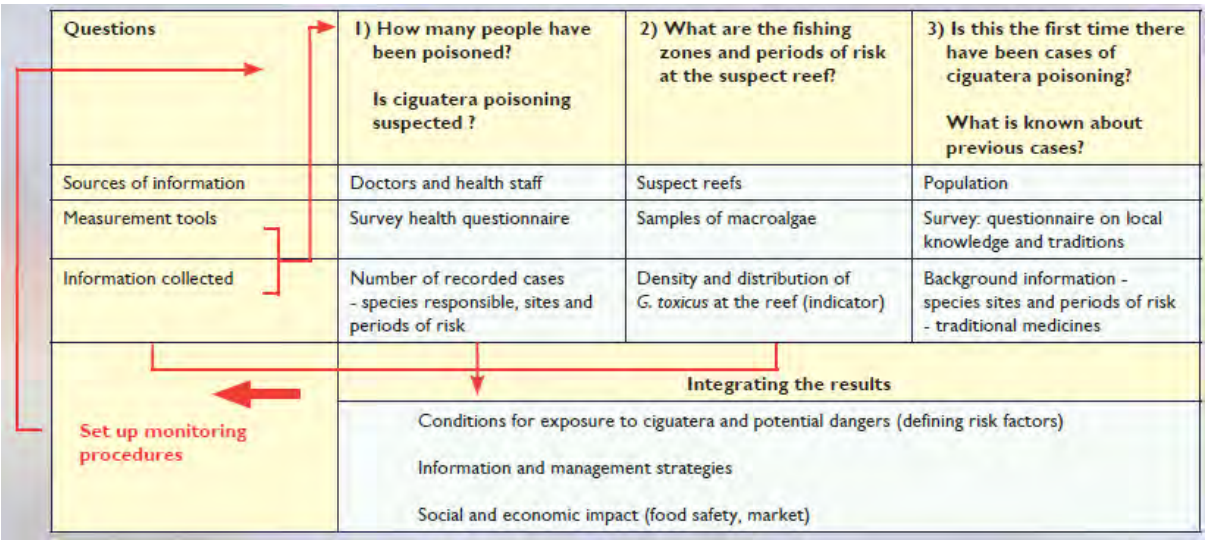


Figure 5.5: Ciguatera Risk Assessment Procedure (taken from SPC 2005)

- Specific monitoring sheets /health questionnaires need to be prepared, communicated with MoH and updated by MoH as part of their Query Builder (Access Database) system. This should be updated to include aspects of the proposed SPC questionnaire presented in Appendix F. Following the completion of the Ciguatera Risk Assessment process by MMR, they shall be responsible for communicating whether the risk if ciguatera may potentially increase as a result of climatic conditions (see Part C Section 11 – Ciguatera social post examples). The existence of the revised health questionnaire shall be made known by MoH to all district health officers to assist in them being completed by a doctor or other health worker. It is vital as it is the first link in the data collection chain. It is important that the person who fills out the questionnaire emphasizes that the information given by the patient will be invaluable in increasing our understanding of ciguatera and thus useful for preventing other cases of poisoning.

- Linked to the above proposed arrangement, the Muri Lagoon "Health Card" initiative (see Part C Section 10.3) needs to be more widely used by MMR to help convey the health of both the outer and inner lagoon systems (or monitored presence of *G.toxicus* as an indicator). One suggestion is to improve the recording of increasing areas of "open sand" or "coral boulder" that may have occurred after cyclone or repetitive storm events. These new barren areas are often populated opportunistically by specific dinoflagellate species and consequently ingested by reef fish (e.g.; parrot fish etc.). The alternative is to use *G.toxicus* as a specific indicator species of dinoflagellate to record via the Health Card.

- The role of the church and local community groups is important in reporting local cases that often are never reported to the MoH. It is proposed that local village leaders should help to collate this knowledge (as required) possibly with support from the local churches leaders. This would be a simple way to better record cases that otherwise may go unnoticed and unreported. Likewise hotel/guest house managers should be encouraged to assist in reporting cases to MoH (ESR Officers). This (coupled with the point

raised above with church / community surveillance) would all help to fine tune any specific outbreak, the culprit "location" (if known) and indicator species (Trevally etc.).

- Enforcement of "no take" zones within the Ra´ui at Titikavika (currently a voluntary code) needs to be improved upon through the regulatory support of MMR and NES under current regulations (or possibly through the pending Marine Resources Bill 2017 currently being debated through Parliament). The lack of a legal mandate for enforcement (as well as a lack of regular review and follow up) limits the efficacy of the Ra'ui so that support and management of these sites has diminished over time. Traditional leaders remain interested in finding ways to provide legal authority and backing to the Ra'ui system in a way that will not disempower them as the traditional authority.

- Closer links with research counterparts in the Pacific is recommended (Tahiti and Hawaii) to determine appropriate toxicity testing and selection of appropriate dinoflagellate species as potential bio-indicators of CFP. Undertake some pilot research on the use of healing medicinal qualities of plants to heal CFP cases (as undertaken in Tahiti). Further discussion should be encouraged with MoH and ESR Officers on the use of the "stick test" to assess CFP cases (adopted in Hawaii).

5.4.2. Bacterial Monitoring

AECOM do not believe that bacterial measurement figures are correct (between 2007 to 2017) and that it is very likely that the test results include some errors as there is evidence of some records that are well above 200 enterococci per 100ml recorded within the MMR database for 2017. AECOM believe bacterial samples should be taken again. Procedure for assessing data recording "anomalies" is described in Part A Section 6.In the meantime, any effort to communicate bacterial health of lagoons (see Health Card in Section 10) should be delayed until accurate information is attained.

6. CURRENT MMR FIELD MONITORING PROCEDURES

This Section addresses the following project objectives (already defined in Part A Section 1.2)

Develop a resource monitoring programme to assess the health of the marine ecosystem and developing it into an indicator for marine ecosystem health. This monitoring program is essential as it will complement ongoing sanitation upgrades and provide a basis to assist decision makers to decide whether to (1) continue with the current sanitation on-site treatment or (2) commission the construction of a reticulated system.

6.1. Field Monitoring Procedures

6.1.1. Current Sampling Approach

Monitoring sampling approaches and protocols are clearly outlined within the MMR (2011) "Water Quality Monitoring Network for the Cook Islands" (Version 5) document. According to MMR laboratory staff, this remains the key document that should be adopted/updated by staff when undertaking field or laboratory work.

Currently MMR is collecting data only from streams whilst NES collect the inner lagoon water samples ((Figure 6.1). MMR are currently not sampling or collecting ground water samples either in the terrestrial, inner, outer or reef crest zones.

Figure 6.1: Water Quality Monitoring Sites at Muri Lagoon

Once a month, teams from MMR and NES collect data for streams (MMR) and lagoon locations (NES with MMR support) all around the island (12 lagoon sample sites and 9 stream sample sites). Teams collect the water samples only along the shore in very shallow locations (though no samples are currently taken in the outer lagoon zone). Samples are collected very close to the shore area between 2-5 meters away from the coast (see Figure 6.2), which mirrors the MMR (2011) protocol recommendation to take samples at "knee deep depth". Figure 6.3 represents the current field monitoring form that is used by both NES and MMR Sample collection teams fill the form for all test sites. This form includes information on the following;

- Distance to shore; Time; Cloud Cover; Wind Direction; Tide; Current; Surface Condition; Clarity; Algae Observations (at beach and in Lagoon).

Figure 6.2. Water Quality Sample Collection

MMR Laboratories
Ministry of Marine Resources
Govt. of Cook Islands

Water Quality Field Sampling Form
Record Ref: MMRL/IMS/F-55
Revision: 02

Rarotonga Lagoon Water Quality Field Sampling Form

ECOWATCH FILENAME: RR081117

LEGEND: **Tide:** 1=Low; 2=Med; 3=High **Current:** 1=Slow; 2=Med; 3=Strong
Surface Conditions: 1=Rough; 2=Choppy; 3=Smooth **Clarity:** 1=Low; 2=Med; 3=High

Air Temp (°C):	Wind Speed (knots):	Low Tide/Height:	High Tide/Height:
Date:	Sampler:	Field Recorder:	Probe Recorder:

Site, Location, GPS	Site #	Lab Serial #	To Collect	Probe Order	Time	Distance to	Cloud Cover	Wind Direction	Tide	Current	Surface Conditions	Clarity	Algae Observations on beach	Algae Observations in Lagoon	Lagoon & Weather Observations
Punaru Rua Hydrometry S21 15'821 W159 45'842	RAM 03	11D1838	TN/TP												
Avana Mud Hole Hydrometry S21 14'864 W159 45'738	RAM 04	11D1839	TN/TP												
Paringaro Hydrometry S21 15'855 W159 44'885	RAM 05	11D1840	TN/TP												
Tikioki Packing Shed Tikioki S21 15'914 W159 44'788	RAM 06	11D1841													
Tuhakaia Station Tikioki S21 15'976 W159 45'578	RAM 08	11D1842													
Papua Tikioki S21 15'744 W159 47'851	RAM 09	11D1843													
Arorangi School Arorangi S21 15'583 W159 45'728	RAM 11	11D1844													
Social Center Nikao S21 15'855 W159 45'285	RAM 13	11D1845													
Muri Bung Hydrometry S21 15'914 W159 45'577	RAM 16	11D1846	TN/TP												
Bokola Drain Arorangi S21 14'743 W159 45'522	RAM 17	11D1847	TN/TP												
Avatiu Avatiu S21 15'223 W159 45'858	RAM 18	11D1848													
Muri Trail Site Hydrometry S21 15'224.1 W159 45'48.1	RAM 19	11D1849													

*FIELD TEAM PLEASE COMPLETE **ALL** COLUMNS.

MMR Laboratories
Ministry of Marine Resources
Govt. of Cook Islands

Water Quality Field Sampling Form
Record Ref: MMRL/IMS/F-55
Revision: 02

Rarotonga Stream Water Quality Field Sampling Form

ECOWATCH FILENAME: RS300517

LEGEND: **Tide:** 1=Low; 2=Med; 3=High **Current:** 0=None; 1=Slow; 2=Med; 3=Strong

Air Temp (°C):	Wind Speed (knots):	Low Tide/Height:	High Tide/Height:
Date:	Sampler:	Field Recorder:	Probe Recorder:

Site, Location, GPS	Site #	Lab Serial #	To Collect	Probe Order	Time	Cloud Cover	Wind Direction	Tide	Flow Type	Current	Clarity	Algae Observations on stream bank	Algae Observations in stream	Weather Observations
Avana Hydrometry S21 14'734 W159 45'835	RAS 01	05D1688	X											
Paringaro Hydrometry S21 15'838 W159 44'135	RAS 02		X											
Ohapuna Tikioki S21 15'274 W159 44'836	RAS 03													
Tuhakaia Vaimaanga S21 15'338 W159 45'535	RAS 04													
Bokola Arorangi S21 14'735 W159 45'462	RAS 06		X											
Avatiu Avatiu S21 15'342 W159 47'842	RAS 08													
Waterfall Vaimaanga S21 15'227 W159 47'252	RAS 09													
Pacific Resort Health Hydrometry S21 15'574 W159 45'812	RAS 10		X											
Averii Hydrometry S21 15'42.87 W159 45'45.42	RAS 11													

*FIELD TEAM PLEASE COMPLETE **ALL** COLUMNS.

Dispatch Time:		Entered into Database By:		COMMENTS:
Dispatched By:		Date Entered:		
		Checked By:		
Receipt Time:		Date Checked:		
Receipt By:		Verified/Validated By:		
		Date Verified/Validated:		

Figure 6.3: Field (Lagoon and Stream) sampling forms used by MMR and NES

One key observation on this form is that there does present the opportunity to capture broader environmental parameters at the same time as the water quality samples are taken. AECOM staffs experience of the field inspections observed that the capture of such additional parameters would not add significant time to the field process, yet could add considerable value to the types of factors that could/or should be captured at the same time as the water samples are taken. Field monitoring teams, for example, do not carry out an observation (and hence laboratory sampling) on sediment change (accretion, erosion, type of sediment, color, quality etc.). This addition to the form (in Figure 6.2) would prove a key issue for future development and support based on observations of sediment quality (surficial and at depth) as recorded in Appendix C.

The future recommendation to adopt tablet monitoring data collection systems should be encouraged. Any Android based tablets which have GPS and SIM card capability is proposed to be suitable. MMR may either prefer to use the ARC Collector software or another software or develop its programming by using open source codes (through engagement of a qualified programmer).In addition, there is an excellent opportunity through this technique to formalize photographic monument points (at the existing water and stream sampling sites) so that routine beach profile images and lagoon condition photographs could be taken. This issue is developed further in Part B Sections 6 and 9 (geo-database platforms and supporting software).

A useful article that analyses a suite of new products on the market can be found at this site:

http://online-journals.org/index.php/i-jim/article/view/3645

6.2. Field Monitoring Recommendations

Based on two separate missions to the Cook Islands (May and November 2017), AECOM have made the following observations with regard to sampling methodologies undertaken in the field:

- Sample collections are made generically for the “Lagoon” and “Streams”. No differentiation is made between samples within the inner or outer lagoon areas which (based on observations made and presented in Sections 2, 3 and 4) could be considered as an addition / update to the MMR (2001) manual. It is therefore recommended that a review of sampling locations (adding new sites within the outer lagoon) is carried out, keeping existing sites, but also considering improving the spatial coverage of field data coverage that perhaps now should be undertaken. It is also recommended to collect regular samples from the outer lagoon zone as well as the reef crest area (the latter on less frequent intervals), as far as practical and as budgetary resources allow.

- Testing and sampling procedures need to be improved to obtain reliable nitrogen, phosphorus and enterococci concentrations more frequently than once a month. Water quality testing should instead be carried out on a fortnightly basis and after any major storm event (see Emergency Protocols in Appendix F4).

- It is essential to collect samples from ground water in order to understand the contribution of settlements (groundwater nutrients levels) in the inner lagoon zone. It is anticipated that the MTVKTV project (undertaken by GHD for MFEM) shall be gathering new borehole groundwater information into February 2018. This information will only provide information within the "terrestrial zone" and future analysis of the implications of this information on the inner and outer lagoon may have to be assessed once the Muri Lagoon Coastal Hydrodynamic model is completed by June 2018 by UoNSW).

- As observed and presented earlier, the lagoon samples collected within the inner lagoon are taken very close to the shore. It is proposed that additional samples are taken from locations from within the inner lagoon that extend circa 75m from the shore (accessed via kayak etc.) to better assist with the knowledge and relationship findings that link to lagoon water circulation, salinity changes, mixing and current circulation impacts (linked to the Muri Lagoon Coastal Hydrodynamic model is completed by June 2018 by UoNSW).

- It would be recommended (as budgets allow) to collect samples from beyond the reef crest (ocean zone) twice a year. This is important to help compare the salinity and sea temperature between inner lagoon, outer lagoon and ocean "zones".

- Seaweed monitoring and recording, at the time of the surveys, appears sporadic and not consistent. Collection teams only report seaweed presence exactly where they stand to collect the water samples. It was the case that during both AECOM observations that seaweed patches were present only a few meters away from the sample collection site, though this was not recorded in the form. Collection teams should take the photos of the existence algae / seaweeds for recording purposes as opposed to relying just on an observation card. It is recommended that data collected on seaweed existence and spatial coverage requires a new approach (in addition to existing ground truthing) that uses aerial drone technologies to better record coverage.

- The recording form includes no opportunity to record important marine ecological bio-indicators of health such as coral juvenile recruitment, coral bleaching and *holothuria* (sea cucumbers). These are all important bio-indicator and should be introduced into the lagoon sampling form (as presented in Figure 6.3). An adapted survey approach for such invertebrates could be proposed during these more informal yet regular monitoring periods as part of the Health Card reporting approach (see Part B Section 10.3).

- It would be very useful if the data is collected by using tablet / mobile applications. By this way, time allocated for data entry can be saved in real time and easily downloaded when back at the office. It is also possible to avoid the possible data entry mistakes as Tablet / mobile data collection can also include the recording of pH, salinity and temperature measurements as soon as it is measured in real time. The use of a tablet could also assist with regular fixed photographic recording of each site and beach profile by introducing a formal monitoring fixed point "stand" (or similar) whereby the tablet can be exactly and

consistently positioned to help gather a time series set of images at each sampling point. This should be similar to the "TUFMAN" or "TAILS" application software approach being adopted by the offshore fisheries division of MMR (developed by SPC for recording fisheries catch data).

- It would be useful if there is a staff rotation and organisational rotation between the MMR and NES teams every month for an initial period to help identify "kinks" in the program. By this way, it would be possible to monitor and compare the sample test results between the teams. This will help to understand if there is any possible human factor on collected data or not. It is learned that new staff are being trained to "shadow" existing experts (from NES and MMR), however, should staff leave/die etc. there is no "manual" that could be subsequently used to train up new staff. This is remiss and needs addressing as a specific action (i.e.: updating the MMR (2011) Manual.

- Whilst potentially outside of the remit of MMR, more routine monitoring is needed to better understand changes to the physical environment (littoral beach and nearshore systems). MMR do not carry out laboratory sampling on sediments (size of quality etc.). This is a key issue for future development and support based on observations of sediment quality (surficial and at depth) as recorded in Appendix C. A consistent approach to sediment monitoring and analysis is recommended on Muri Lagoon sands intertidal and lagoon floor). This is needed as changes to sediment conditions can be exacerbated by development of seaweed algae and cyanobacteria mats, with anoxic conditions leading to the accelerated retention of nitrogen creating a positive feedback loop for increased seaweed growth. The installation of sediment traps (see Part B Section 7), as a new addition to the monitoring programme, could be considered. Details and outcomes of the pending UoNSW coastal hydrodynamic modelling exercise are needed to help determine the location and strategy for this (modelling approach presented within Part A Section 4). Physical environmental parameters that could be included in future routine monitoring may include the following:

    - Beach and lagoon profile surveys;

    - Motu and sand bar migration (GPS or drone surveys of Motu toe of beach and sand bar extension).

- One key addition to the routine monitoring undertaken by MMR is to recommend that sediment and invertebrate sampling analysis is undertaken at key parts of the Muri Lagoon monitoring strategy. This is important in the short term, to support the MTVKTV project (GHD 2017) particularly at the stream delta mouths, the "channel" within the inner lagoon area, the inner lagoon south of Pacific Resort and also within Avana harbour area (to determine the wider ecological impact of any dredging event). This information shall be needed to feed directly into any future EIA that is likely to be required to assess potential seawater outfall locations etc.

- An institutional recommendations relates to the fact that in reality, MMR staff should take ownership of the inner and outer lagoon sampling whereas NES should be responsible for stream monitoring (not the other way around as it is at present). Samples should be collected from streams, ground water and lagoon at the same time.

- Some errors are observed in MMR lab data collected in 2017. This includes observations such as, salinity being recorded as 14.3ppt within the lagoon plus (more alarmingly, that the amount of bacteria recorded as being 24,196. It is vital to re-test these samples or to be certain whether such values are outliers or these measurements represent technician or instrumentation error. Should such abnormalities be observed in the field recording, the test should be immediately repeated (or sample should be re-collected) before leaving the test site.

- Minor name change to Site 18 should be considered. Currently named as “Avatiu” it perhaps is more appropriate to be named “Avatiu- BSP” as the monitoring site is directly opposite the BSP office.

In conclusion, it is important to note that monitoring represents the ‘consistent, regular, long-term gathering of quality data. Therefore samplers must operate and abide to standard operating procedures (SOPs), use accredited laboratories where sampling result quality could be jeopardised and subsequent quality assurance. To achieve this, data quality checks should be undertaken by nominated and trained staff. It is essential to ensure that trained staffs regularly review the database to assess if there are any abnormalities within the data set before conducting further analysis. Should abnormal observations be detected (e.g.; bacteria), it is necessary to find out if these are real observations or if there is any mistake made during the data collection and laboratory analysis. This is vital as Implementing data analysis and producing health cards without making any quality control may cause serious misinterpretation of the results or water quality statistics.

Figure 6.4 summarizes the suggested MMR revised sampling data collection system to help improve the statistical monitoring of water and sediment quality in Muri Lagoon and across the Cook Islands.

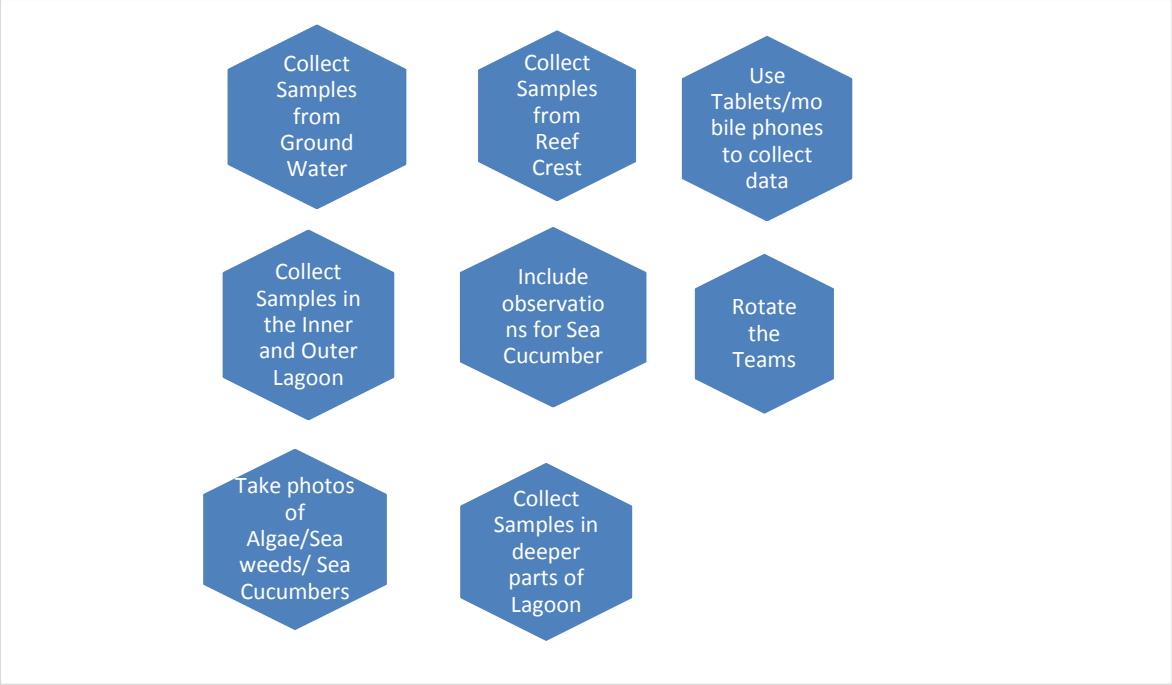


Figure 6.4 Suggested Sample Data Collection Approach

Details of monitoring frequency for individual environmental parameters are tabulated in Appendix F.

PART B: PROPOSED RECOMMENDATIONS

7. PROPOSED INTERVENTION MEASURES TO REHABILITATE MURI LAGOON

This Section addresses the following project objectives (already defined in Part A Section 1.2)
Investigate sites for establishing coral gardens within Muri Lagoon that may be used to supplement tourism snorkelling and other marine tourism related activities
Investigate options for the removal of the re-occurrence of benthic algae outbreaks.

The following sub-sections represent the proposed short term intervention measures that could be introduced to address the seaweed proliferation problems at Muri Lagoon (and elsewhere on Rarotonga as appropriate). The interventions have been consulted with appropriate parties in terms of practical implementation though each intervention is likely to be subject more detailed community consultation and/or environmental regulatory consent compliance (EIA etc.). The interventions range from engineering to environmental, strategic planning support, institutional and capacity building related measures. They are all primarily aimed at delivering engineering or scientific interventions that will either reduce the input of nitrogen or phosphorus into the marine environment, restore marine ecosystem services back to Muri Lagoon or seek to improve the natural flushing capability within the lagoon (as recommended in Part A Section 2). They are also introduced as possible interventions that seek to provide short term (or supportive alternative) solutions that support the long term reticulated waste water approach that is being planned for Muri Lagoon through the MTVKTV project (GHD 2017).

The proposed measures are based on the observations presented in Part A though (as stated in Part A Section 1), have been proposed in the absence of more detailed environmental monitoring results which are pending from the MTVKTV project during the first half of 2018.

7.1. Engineering Related Measures

The following recommendations put forward by AECOM for "hybrid toilets with mini treatment plants" and "composting toilets" are more of relevance for inland areas of Rarotonga away from the proposed reticulated sewage system being advocated for Muri Lagoon or for Pa Enau (outer islands). Efforts to reduce nutrient input into streams (as indicated from results in Part A Section 2) are of particular value here.

7.1.1. Hybrid toilets with mini treatment plant

A hybrid system is based on the flush toilet and tank system, in which the volume of water needed is drastically reduced. Solids are separated and the liquid goes into a smaller septic tank; organic matter is broken down through bacterial action. The hybrid system operates in a manner similar to aeroplane toilets, in which a partial vacuum suction is used to clean the pans. The volume of water is reduced to 770 l per year.

Such a system would still, however, need to be linked to a sewage treatment system however the design involves linking three to four households together to a mini treatment plant which separates solids from liquids. The treated solid waste can be used on Pa Enau for composting, while the nutrient-rich liquid effluent can be sprinkled on grasses. This is a highly capital-intensive option for outer islands where water resource management is a critical climate change adaptation strategy.

One environmentally friendly approach to wastewater treatment, currently being marketed in the Cook Islands (by GRAF Ltd) is the E-Clean 20 system which can accommodate 2,000 litres/day. It is a system that has tested to NZ OSET requirements and has achieved advanced secondary results. The single tank system is extremely simple with no electrical or moving parts in the tank. In most instances a gravity outlet is often achievable for many Island situations. This can be used in conjunction with an infiltration tunnel for the effluent disposal field. Without the need of an electrical pump for a disposal field, one can achieve an additional 18% saving on power consumption reducing the power requirements to below 0.5kwh/d (GRAF 2017). The 2,000 litre E-Clean has sufficient capacity to treat 11 people/ household (based on ICI requirements of 180 litres per person per day).

7.1.2. Composting or waterless sanitation system

Composting toilets constitute an above-ground, dry (waterless) sanitation system. Many different designs and off-the-shelf composting toilets are available, and they vary in cost depending on the material used and the local cost of labour (Del Porto and Steinfield 2000).

Composting toilets are usually built with the pan sitting on a high platform and the collection container or tank fitting under the platform. The waste collection container or tank can be either removable or fixed, depending on the technology; easy access to the container or tank is needed for removal of the dried compost. The system relies on the use of carbonaceous material, such as dry leaves, untreated softwood shavings or coconut fibres to balance nitrogen in human excreta and provide aeration. Any type of organic material can be used for

personal cleaning and then dropped in the toilet. The decomposition process produces a soil-like humus or compost, which can be used as a fertiliser after sufficient time has been allowed for the destruction of disease-causing organisms and pathogens (usually about a year). The compost material is emptied from the end of the chamber every 6 to 24 months, depending on the size of the chamber and the frequency of use.

Composting toilets can be easily incorporated in the design of a new house. Any composting toilet design can be applied, but the entire component must be included in the building design (hence a consideration for future Building Regulation updates in the Cook Islands). The tanks or containers should be easy to access so that it is easy to remove compost from the tanks or containers. New compost toilets are more cost effective because the need to construct an outhouse is avoided).

7.1.3. Dredging Channels and Stream Deltas

Part A Section2 and 4 (and Appendix C) all identify the possibility that increasing the natural flushing ability of Muri Lagoon not only reduce sedimentation and hence siltation within the lagoon (encouraging seaweed to colonise and the lagoon to raise its temperature) but also it would encourage natural flushing and maintain salinity levels throughout the lagoon (which is deemed as a critical parameter in influencing seaweed growth). In support of this proposal, (though subject to the results of the hydrodynamics model and supporting EIA work), GHD (2017) proposed the following 4 sediment removal options for the Muri frontage:

- Option 1: Dredging of Stream Delta/fans;
- Option 2: Dredging of Inner Lagoon “sands” (the new hydrodynamic modeling project shall determine exact location see part “ Section 4);
- Option 3: Dredging of the inner lagoon “channel” sands landward of Oneroa and Mototapu Motu Islands;
- Option 4: Dredging of sediment at the mouth of Ngatangiia Harbour.

Option 1 is believed to represent a “quick win” and can be implemented using machinery and equipment that exists already on Rarotonga (with support from ICI). This option will require land agreement on the temporary storage of dredged materials for dewatering and future re-use. One possible suggestion is to establish a location close to Avana Harbour where machinery and trucks can easily access the material for future use. Options 2, 3 and 4 cannot be implemented until the outcomes of the pending coastal hydrodynamic model for Muri Lagoon is completed (UoNSW) and results clearly understood and digested which is unlikely to be available until June 2018 . Option 4 would result in creating a deeper channel that may assist with the flushing sediment from the inner to the outer lagoon and beyond the reef crest to the ocean.

Importantly, all 4 options above potentially offer the opportunity to collect accreted/dredged sands which (if of a clean acceptable quality) may be used for beach replenishment purposes within the Muri Lagoon area. Appendix C has undertaken an assessment of stream delta accretion rates over time. Throughout August 2017,

GHD have been progressing the removal of sediment at the stream outlet near Pacific Resort by liaising with land owners and developing design options and a new EIA is being lodged with NES to extract sediment from these areas for possible re-use in riparian planting schemes along the shoreline. If this EIA is granted, then dredging lagoon sands and gravels would need to be initially be "stockpiled" either on adjacent areas or in submerged "sheltered" locations for future redistribution. It is anticipated that the EIA shall identify this detail when completed during January 2018.

7.1.4. Stream and Drainage Management

7.1.4.1. Storage Ponds

A retention or detention pond is a basis used to manage storm water runoff to prevent flooding and downstream erosion and improve water quality in the adjacent stream and the ocean. It is often recommended to use an aerator in the larger ponds to keep the water circulation (Figure 7.1).

Figure 7.1. Typical man made retention pond

7.1.4.2. Water Conveyance

A system of drains, channels and water conveyances could be constructed starting on the hillside within the Muri catchment to help convey the carrying the storm water into the streams and then empty into newly constructed setting ponds or basins where the topographic features allow for their construction. Depending on the site specific conditions stepping ponds could be constructed (see Figures 7.2). Ditch Beam using "Geo-ridges" could be another option depending on the site specific condition.

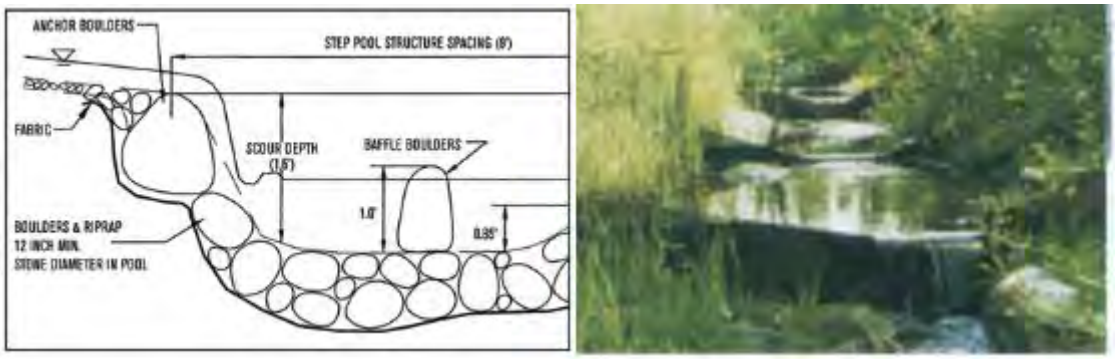


Figure 7.2 Cross section of a typical stepping pond. Photograph of a ditch beam made by "Geo-ridges"

The key challenge within the Muri catchment is that for much of the year, the stream courses run dry and overland flow only occurs after persistent and continual precipitation episodes. As a consequence, significant investment into this type of engineering intervention is more likely where infiltration rates are slower than those experienced at Muri.

7.1.4.3. Trash Traps

Appendix C clearly identifies (through photography) that a core problem experienced along many of the observed culverts in Muri is their constant blockage by trash. It is therefore proposed that some type of strong grating could be used on the intake side of the culverts to trap debris from clogging up these culverts. Due to the site specific conditions it may be recommended to encourage communities to custom make such a trap. These can be simply constructed comprising of a set of screen or grills varying in size and strength. The outer screen should be made of strong ½ to ¾ inch steel. Spaced at 2 inches apart, this will stop the logs and large tree branches and litter etc. The second screen spacing could be 1 inch spacing made with at least ½ inch steel. The third screen spacing could be ½ to ¼ inch apart to stop the debris that has passed through the first two screens. Sometimes a forth screen is used with spacing at 1/8 of an inch catching the reaming debris. Each screen is set into a slot on the bottom of the trap with a large handle at the top so it can be easily removed and cleaned. All of this would require a maintenance schedule budget. The more expensive alternative option is to purchase commercial trash traps. The key for the trash trap to work effectively is maintenance checking and removing all collected trash on a monthly basis and after every heavy rain event (Figure 7.3).

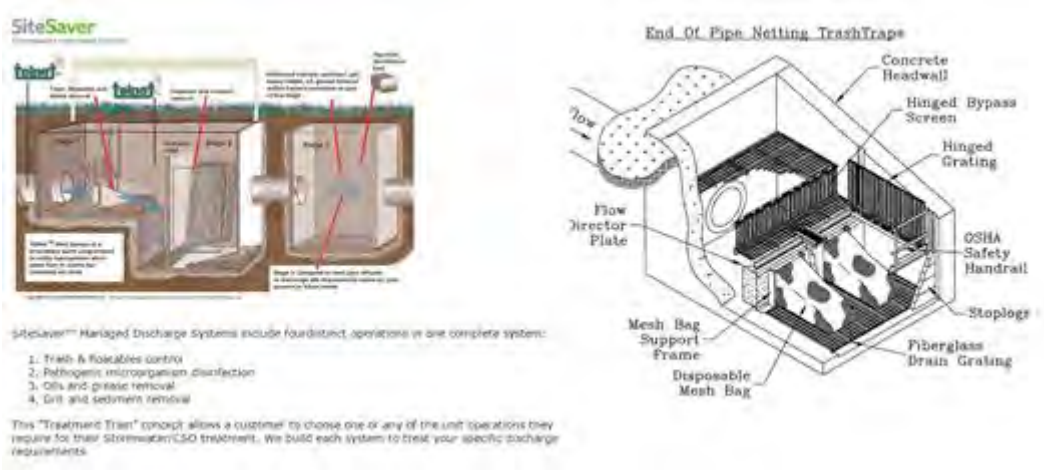


Figure 7.3 Trash Trap Maintenance Options

NB: there are a range of additional low cost alternatives that maybe considered. Some good examples are presented in the Auckland Councils "Sediment and Erosion Control Manual (1999) amongst other techniques.

7.1.4.4. Diversion of Streams

Field assessment work by GHD (2017) was undertaken to develop a conceptual understanding of the Muri catchment which was described in the GHD "Literature Review and Gap Analysis". This work concluded that one possible stream engineering option for consideration is to encourage the "channelling" (diversion) of two streams into one. Figure 7.4 presents a 2009 map of the Muri, showing Areiti Stream (stream on the top/north with outlet at Kura's Kabana) flows into the Pacific Resort boundary.

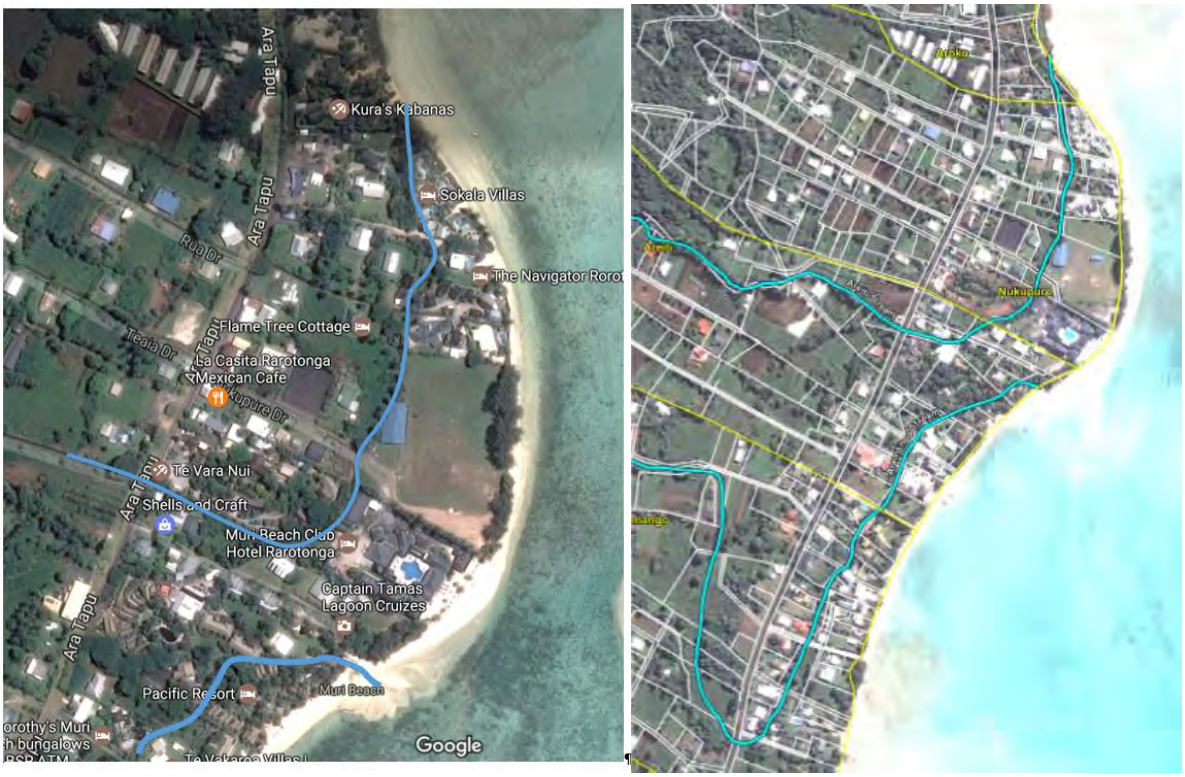


Figure 7.4: a) Field Observations of stream flow options (GHD 2017)

The Aremango Stream outlet at the Pacific Resort beach is contributing to the sediment accretion being noticed at the delta area at the stream mouth, nevertheless, the implementation strategy to divert this stream will face the following challenges:

- The stream flow through Pacific Resort is a major feature of the hotel as the Resort also has underground water galleries/wells, where they pump/use ground water to maintain pond levels, gardening etc. without using the reticulation water mains. Consequently, the proposed stream diversion will likely impact this area and not be supported by Pacific Resort Hotel.

- Gaining stream easement through an already highly dense developed area, shown by the white boundary lines (Figure 7.4) will represent a considerable challenge. It is likely to prove an expensive option.

7.1.4.5. Reticulated Roadside Drainage

The Cook Islands National Roads and Road Drainage Policy (2017) clearly state that there are no current restrictions on the discharge of surface water onto roads from adjacent land. There can also be difficulties in obtaining the necessary easements to discharge water off the roads. The tourism industry raised concerns about contaminants in storm-water running off into the lagoon. This issue is relevant to this project at Muri Lagoon as some storm water runoff from road surfaces contains contaminants from vehicles. Currently the 'first flush' of storm water contaminants following rainfall is generally managed by the use of swales, grassed drains, wetlands, and grassed basins. More advanced treatment methods may be required in sensitive areas such as in proximity to the Muri Lagoon.

It is strongly recommended that in tandem to the MTVKTV project currently underway, that a reticulated storm water drainage system is introduced and integrated within the proposed sewage reticulation system for the Muri Area, focusing specifically on the main road running through Muri village. The Cook Islands are currently updating their Building Regulations (BECA 201&) and this work must be integral to any new storm water roadside reticulation system. Another key challenge is that the Cook Islands do not have any regulations which govern land use planning. Due to the land ownership model in the Cook Islands, this is a sensitive issue with regards to roadside drainage easements etc.

7.1.5. Coral Rubble Clearance

It is understood that 3 natural passages had existed through the existing outer reef crest close to Muri Lagoon however; these are mostly blocked as a result of natural storm processes. The exact location of the “gaps” (believed to be up to 20m wide) is not exactly known at the time of writing, though similar “gaps” are noticed in the reef system around Rarotonga (Figure 7.4a). In 2005, five cyclones hit Rarotonga and Muri reef flat was inundated by coral rubble and boulders which reduced diversity and live coral coverage. It is believed that these “gaps” represent existing coral spur and groove systems that are common in all reef systems (see

Figure7.5b and c). These “grooves” are accentuated in size following cyclone events when coral boulders are broken off reef edges and strewn into the fore reef areas of lagoons.

Figure 7.5a: Reef “gaps” found in Rarotonga reef crest zones; Healthy spur and groove systems (b) and (c) showing clear flushing spaces for divers

The intervention proposal for Muri Lagoon is to encourage a feasibility study (possibly involving an EIA) that encourages local communities to use local equipment to reinstate the spur and groove systems by removing and re-positioning dead coral boulders (often caused following the 2005 cyclone events) to better naturally reinstate natural flushing “routes” within the lagoon. The positioning of boulders, in such a way as to encourage tidal flushing and inhibit sediment transport routes is to be encouraged. The implications of this intervention, on current speeds are proposed to be modelled as set out in the new hydrodynamic model (see Part A Section 4). This is important as periodic openings to the sea may generate more saline conditions on a semi-permanent basis providing an improved water circulation and consistent salinity recordings within the Lagoon. However, if the openings are short lived then the reverse may hold true (i.e. a reduction in water

quality through the generation of scum and vegetative mats as a result of vegetation die-off brought about by salinity changes).

Despite this valid uncertainty, the AECOM team believe that efforts to improve flushing from the reef crest, through the outer lagoon and into the inner lagoon should be supported and that beneficial outcomes should be realised as a result. Efforts have been made to progress this option during August 2017. Local community leaders have taken environmental scientists out to the edge of the reef, following the suggestion made by community members that reinstating reef gaps could increase water flushing of the Lagoon. The proposed bathymetric modelling (due to commence through UoNSW in January 2018) will test what effect removing these debris from the reef gaps will have on increasing the rate of flushing of sea water through the Lagoon, diluting nutrients in the Lagoon and changing the salinity of the Lagoon.

Issues relating to increased current speeds between the motus' may be a consequence of such an activity which may require further beach safety control features (hazards signs/lifeguards etc.) to better ensure visitor safety in the Muri area. Training on beach safety may be an important secondary activity (see Part C Section 13), especially since recent deaths were reported in Muri Lagoon in November 2017 when local police reported the deaths of two men drowned after their kayak was swept over the reef and capsized in rough seas (the most dangerous water hazards are the channels linking the lagoon to the ocean).

https://www.radionz.co.nz/international/pacific-news/344559/two-tourists-drown-in-cook-islands

7.1.6. Remove Traditional Fish Traps (Avana)

Previous studies have shown that Avana Harbour area has consistently experienced adequate current flow compared with other areas in the Muri Lagoon (e.g., 0.16 m/sec recorded at Koromiri in 1990; Holden, 1992). In support, flora and fauna generally found in habitats with constant water movement were noted within the vicinity of the fish trap. For example, crustose coralline algae, *Turbinaria ornata (rimu tara)*, and invertebrates such as *Actinopyga mauritiana (rori puakatoro)*, that are normally found in surf zone habitats were observed around the Avana fish trap.

The difference in current speed noted within and outside the fish trap is likely the result of increasing water depth from the motu towards the mainland, causing water to gravitate towards the deeper area in the direction of the mainland as it moves towards Avana passage (Figure 7.6).

Figure 7.6: Avana Fish Trap (a) in 2008 and b) in removed in the 2017 image

Average current speed reported by Holden (1992) at the fish trap area was around 0.7 m/sec, which is consistent with those reported in the present study (0.4 to 0.8 m/sec). However, the 1990 study and this assessment are unlikely to determine variability over time (particularly with relation to climate variability and change) given that this parameter has not been consistently monitored over the years.

The AECOM team believe that efforts to improve flushing by removing any residual fish trap boulder should be assessed in some detail in the pending coastal modelling study (University of New South Wales). If modelling results suggest that the removal of the remaining Avana fish trap should be adopted, the rocks from the trap can be used for separate coastal engineering interventions along the shoreline is appropriate and subject to an acceptable EIA.

7.2. Environmental Related Measures

7.2.1. Seaweed Removal

7.2.1.1. Extraction using Machinery

Muri Lagoon Action Group (Lyon 2016) trialled the removal of algal mats on sandy areas by hand. This task proved difficult as the algae has well-established roots systems anchoring to as deep as 75-100 mm in the sand. A second trial was conducted, this time using machinery to scrape the top layers of the sand containing the algae showing more promising results. However the area occupied by the algae (at the time) was significant and continuing this exercise would have proven costly and there were concerns raised from public onlookers about the amount of silt generated during the process. MMR monitored the water quality during this trial and recorded photo quadrants where the algal was removed.

It is clear that manual techniques failed to work due to the rhizomes of the caulerpa remaining in the sediment. However, mechanical extraction methods were not supported by local groups in Muri due to the excessive sediment turbidity the process caused in the short term.

Recently a GEF Small Grant Facility application has been lodged by the Muri Action group to purchase a 1 x Cherrington Model 800 Beach Cleaner/Screener 1 (circa NZ$40,000) which has a has a cleaning width of 36 in (910mm) and depth of 3in (76mm).The GEF application was, however, not successful and further efforts to purchase such a machine have not been taken forward.

7.2.1.2. Osmotic "Shock" Techniques

Salinities below 10 ppt and above 38 ppt prove lethal to *Caulerpa spp*. Therefore eliminating or controlling the spread of *C. taxifolia* with osmotic shock techniques (application of salt or the use of freshwater in South Australia) has been shown to be reasonably effective and cost-efficient (Creese *et al*). Any control technique, however, will be scale dependent – things that work well at small scales may not be feasible at larger scales. Thus, in small situations, the application of salt can be very effective at scales up to a few hectares. In Lake Macquarie, single applications of salt to numerous outbreaks have resulted in the apparent removal of almost 5200 m2 of *C. taxifolia*, whereas repeated salting of a 3000 m2 infestation in Careel Bay in Pittwater has led to a considerable reduction in the density of the alga, but no overall change in the boundaries of the invasion. If natural phenomena assisted with the removal of *C. taxifolia* from Lake Macquarie, as seems likely, a focus of future research needs to be on patterns of change in established populations of *C. taxifolia* and the causes of those fluctuations.

Caulerpa spp. worldwide often undergo patterns of rapid expansion followed by dramatic declines (Jaubert *et al*. 2003 and references therein), and it may be that local species will show the same phenomenon in Muri Lagoon. Until the reasons for any 'natural' fluctuations are known, however, work on elimination or controlling the further spread of the alga is imperative.

AECOM suggest that a trial area could be tested (during the months of December and January or February when natural salinity levels are low and rainfall levels are high) to assess whether the introduction of increased saline conditions (salinity in excess of 38ppt) has a positive impact on reducing algal cover (for caulerpa).

7.2.2. Re-use of Seaweed for Fertilizer

Attempts have been made to promote the use of collected seaweed as a local fertilizer with a degree of success. The local Growers Association have set up an area in Muri where seaweeds can be stored, dewatered and re-used as fertilizer to hotels, guest houses and locals alike. Whilst the use of seaweed is likely to only re-use a small percentage of the overall amount, its wider benefit for local home owners and hotels/guest houses for garden product growing should not be underestimated. The challenge remains in terms of retrieving the seaweed off the beach in a cost effective manner and storing it in the most socially acceptable way possible. In light of the seasonality of this option needing to be implemented, no firm advice is provided at this time except that should a seaweed outbreak occur again soon, there will be a need to identify a suitable storage location should blooms are significant and action to extract the seaweed need to be swift.

7.2.3. Coral Gardens – Pilot Trials

Should water quality results indicate that the heath of the lagoon is improving, then feasibility studies should be initiated for the most suitable "coral garden" design and approach to be trialled (as set out in Appendix D).

The key question linked to this is associated with the ambient water conditions in Muri Lagoon being suitable for a future coral garden, and if they are suitable, what is the most resilient coral species to focus on within such garden. In 2006, a large number of small colonies of *Leptoria phrygia* that would be considered recruits were recorded in the Muri locality (remnants of what used to be larger colonies which are key to planning species "focus" within a coral garden). Recruits often belong to several key species of *Acropora, Favia* and *Pocillopora*. Based on observation from the pre-COTS period in the 1990s, large plate-like colonies of *Acropora* were among the most dominant coral on the reef slope (T. Rongo, pers. comm.). The increase of acroporid species in the larger size classes clearly indicates a shift towards the pre-COTS conditions of the 1990s. These findings suggest that there are perhaps 4 key species of coral that should be considered in the future:

- *Porities;*
- *Pocillopora sp;*
- *Acropora. sp. and*
- *Montipora sp*

The location of such a trial is debatable, though it is important to ensure that the site exists within the "outer lagoon" zone (less visitor swimming/snorkelling/kayak traffic) but in a location that has sufficient depth at low tide. An indicative location is identified in Figure 7.7 (see pink area).

Figure 7.7: Possible Coral Garden Trial location

Should the trial coral garden prove a success, there is the possibility of introducing/designing a "snorkel trail" in a similar area. This should be managed directly by private sector groups under some type of private public partnership (PPP) which encourages monitoring, education, maintenance and research all together. Appendix D2 (specifically see Phase 4) refers to the possible approach that could be adopted for this.

A procedure for setting up such coral gardens should be piloted using coral transplanting techniques as appropriate to the species selected. This action should be closely linked to marine conservation practices being undertaken or proposed. With coral recovery occurring on Rarotonga, establishing new *Ra`ui* or enforcing the management of the current *Ra`ui* around the island should be considered and introduced as possible key indicators within any new State of the Coast reporting system put in place (see Part B Section 11).

Appendix D outlines the possible types of approaches that could be undertaken around the Cook Islands. This also includes a draft Work Plan methodology for the approach required in order to set up a "Coral Garden" in Muri Lagoon (should water quality conditions dictate this to be suitable).

7.2.4. Riparian Planting

Local fast growing, deep rooted robust, trees, scrubs, and vines along the stream bank and roadway should be considered as a strategic intervention option if this is feasible and accepted by stakeholders.

The Ministry of Agriculture are working alongside local experts (Gerald McCormick who hosts the Cook Islands biodiversity database) and the experts from GHD to help identify the most suitable range of plant species for consideration for riparian and beachside stabilisation. Of note, GHD have lodged a pre-application form (October 2017) with NES to undertake dredging of the Aremango stream delta (near Pacific resort, Muri). The NES Terms of Reference for the EIA provides generic guidance, though omits any detail on possible riparian planting approaches and so GHD seek to include in their EIA scope the planting of the riparian margins of the stream and also at any area along the Lagoon margin where dredged sand may be placed (i.e.: along the foreshore of the Ngatangiia sports field).

The focus of any riparian planting programme should be on the use of native plants (not introduced plants such as *Menemene* or sea grape). It is better to also select perennial, prostate sprawling vines and low sedges and shrubs that have high saltwater tolerance. Very vigorous plants that might create greater maintenance issues for the land owners (such as the umbrella plant) should be avoided as well as any large plants and trees that are more than a couple of metres height.

Figure 7.8 identifies a list of possible riparian plant species that could be considered (*pers comm* Murray Wallis of GHD, Nov 2017).

SPECIES A		The sprawling vine on the beach front in photo. This is common in undeveloped areas of Rarotonga but in many areas it has been cleared. Photo taken in Titikaveka. Legume with a yellow flower. Widely used including in current times for medicinal purposes (sprains etc.)
SPECIES B		Attractive flowers open in the morning. Can be found near Parengaru stream.

SPECIES C		A shrub that tends to be found somewhat back from the beach. Will grow among the groundcover vines. Small white flowers
SPECIES D		Shrub that grows to circa 2 metres. Now uncommon on Rarotonga. Disadvantage - Very slow to propagate and slow growing. Cultural significance – was used to make fishing rods and hooks
SPECIES E		A sprawling vine with red flowers and large pods. Silky stem and leaves

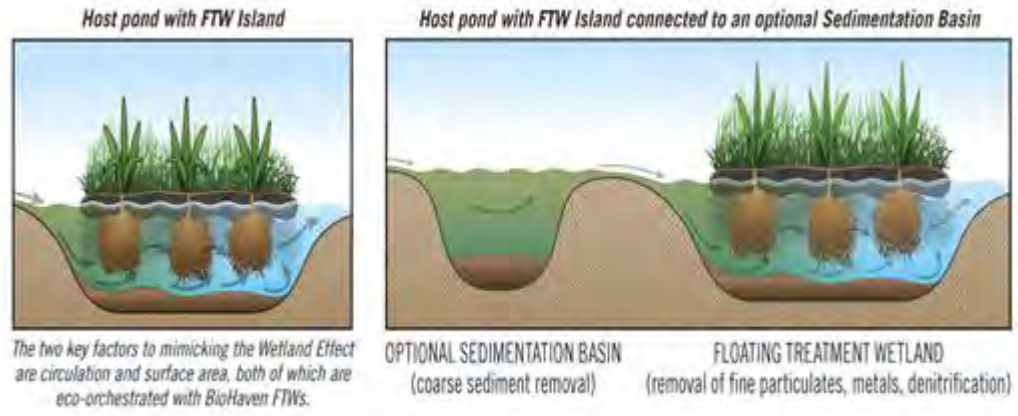
Figure 7.8: Local Plant Species for riparian stream/shoreline planting

7.2.4.1. Creation of Wetland Nurseries

It is recommended that the Government should consider developing further the concept of a wetland nursery as a top priority. The existing nursery (exact location unknown) is not likely to be sufficient enough to accommodate the potential role of vetiver grasses in the future, and so more discussion with landowners and the MoA is required to develop this interesting concept further. For example, a private public partnership (PPP) approach could be considered in order to set up the nation's first wetland plant nursery. In addition to operating as a nursery, it could also be used as an integral part of MMRs and MoAs education and research endeavours. Of course, the nursery would focus on wetland plant species that are native to the Cook Islands and which have the ability to propagate more species as required. Research at the facility may concentrate on horticultural questions, and the benefits of certain horticultural activities in Rarotonga and the Pa Enau.

In addition to a wetland nursery project, one possible strategy to assist in the creation of wetland systems would be to use appropriate vegetation - possibly vertiver grass) which are trialled to grow hydroponically on

"floating platforms", which could be moved to the worst affected parts of the lagoon (Figure 7.9). The advantages of this innovative floating platform method are that vetiver tops can be harvested easily for stork feed or mulch and vetiver roots can also be removed and re-used for fertilizer.



Figures 7.9: Floating island as an alternative to constructed wetlands

Linked to this work, there is a need to make effective use of the ongoing NES work to map 'current' wetland areas which seeks to capture the spatial delineations of all swamps, depressions and streams in Rarotonga. This work should build on the existing NES championed 'Sustainable Land Management Program' which originally created the baseline maps for wetlands around Rarotonga, with the purpose of tracking changes and identifying vulnerable areas.

In addition, ICI have undertaken topographic survey of existing streams, drains and bridge/crossings; for the general Muri area, though this work remains in progress. The purpose of this work was to address flooding within the Muri area and to compliment the proposed road widening and upgrade work. It is understood that ICI are currently in the process of engaging consultant to develop a 'Muri Concept Master Plan' focusing on transportation, road safety, streetscape and community/tourist areas. At the time of writing, no further information has been made available on this aspect.

7.2.5. Installing Sediment Traps

Installing coastal sediment trap units may need to be constructed at select locations along the Muri coastline including the *motus,* to facilitate with the removal of sediment from the lagoon. This approach would likely deepen the Muri Lagoon over time, and allow the reefs in this area to recover. Ultimately, this approach would be less dramatic than conducting dredging operations that disturb reefs.

An interesting example to possibly mimic or replicate (to a smaller scale) is a lagoon project undertaken recently in Wainono Lagoon, Canterbury, New Zealand. The project (total funding of NZ$2.1M) was to design to improve water quality in Wainono Lagoon and minimise further contamination of the lagoon by reducing sediment inflows. In other words, the project objective is very similar to that of Muri Lagoon. The main observation from this project was that a number of interventions need to be undertaken in order to attempt to achieve the intended outcome of the project. For example, bby the end of the project in December 2015, the following had been achieved:

- fencing of 49 kilometers of stream;
- reinforcing 21 kilometers of stream and river banks;
- *installation of 31 sediment traps;*
- 4.8 km of stream planting.

With reference to the installation of sediment traps, MMR need to determine the rate of accumulation taking place in specific areas. The exact location of these “traps” cannot be determined at this time, and MMR should await the results of the UoNSW Wales coastal hydrodynamic model to take this further. Nevertheless, the approach is to use sediment traps which commonly consist of four cylindrical traps fixed to a single rod at a depth of about 0.5 m above the seabed. The traps are often made from 50 cm long PVC pipes with an internal diameter of 9.5 cm, i.e. an aspect ratio of 5.3 (see Figure 7.10). Specific laboratory procedures required to test turbidity ad sediment volume can be provided should this option be taken forward.

Figure 7.10: Example of a sediment trap instrument (taken from Szmytkiewicz *et al* 2014).

7.3. Strategic Planning Related Measures

7.3.1. Lagoon Management Plans

Government agencies within the Cook Islands, in general, need to be persuaded to take forward initiatives to develop a national Coastal and Lagoon Policy Framework (similar to that already drafted for Mangaia in 2014 (Sustainable Seas Ltd 2014)). There are a number of key recommendations that should be addressed as a next stage:

The Ministry of Finance and Economic Management (MFEM) together with the Office of the Prime Minister (OPM) play an important role in the delivery of strategic environmental planning in the Cook Islands and together are influential to the process of lagoon management plan delivery under the new Marae Moana Act (2017 – see Appendix E).

National Cabinet in the Cook Islands need to have an interest in Lagoon Management Plans (LMPs) for Pa Enua and Rarotonga and their high influence on matters nationally is critical. To ensure that this influence is a positive one, Cabinet officials must be made central to the process or this could lead to delays and poor LMP implementation at a later date.

Efforts through the R2R project for the Cook Islands are seeking to undertake LMPs for Aitutaki (ALMP). The overall objective of the ALMP is "*To preserve the quality of the environment of the lagoon of Aitutaki*" which is linked directly to risks caused by land-based activities, lagoon use activities and environmental changes; thereby mitigating the risks to tourism, food security, public health and the environment. This overall objective is in line with Te Kaveinga Nui (NSDP 2016-2020) Goal 12 Sustainable management of oceans,

lagoons and marine resources and indirectly linked with 9 of the remaining 15 goals. It is also consistent with the Aitutaki Island Community Sustainable Development Plan (2016-2020), and the business plans of the National Environment Services (NES), the Ministry of Marine Resources (MMR) and the Ministry of Health (MOH). In addition, as part of the new Marae Moana Act (2017) there is a request for Pa Enau and Rarotonga to produce LMPs. To this end, Muri Lagoon should seek to produce, with immediate effect (through R2R funding) a participatory LMP that embraces the requirements of NSDP and also the new Marae Moana Act (2017 – see Appendix 7) whilst also embracing the 2017 Water Policy (see Appendix E).

Within each LMP, a clear easy to interpret set of zones usage maps are required to help decision makers to manage lagoon space and who is responsible. This (for example), can help to identify whether pproviding a lifeguard service is needed or not (which has proven of urgent need following the drowning of two American tourists in November 2017). The development of draft **Beach Risk Management Standards** ("beach product") for the CI tourism sector to adhere to is now regarded as one step towards ensuring sustainable development on the coast in order to improve the competitiveness of CI beaches to all those who wish to visit the country as a tourist destination of choice. The ISO 13009, "Tourism and related services — Requirements and recommendations for beach operation", has just been published by the International Standards Organization (ISO). This is the first standard that provides beach operators with the information and guidance needed to manage beaches effectively, anywhere in the world. As well as general beach management, the ISO 13009 includes initial guidance on beach safety, beach cleaning and waste removal, beach access, infrastructure, beachfront planning, stakeholder communication, beach promotion and commercial services (vendors etc.). Therefore, assisting the tourism sector to comply with ISO 13009 is likely to help significantly towards generating both media and public interest within resorts and beach fronted hotels. This in turn may help secure public funding for future improvements to the surrounding beach area. The ISO13009 therefore brings a range of important elements together that could offer guidance to tourism to help sustain a hotel or resorts economic future.

7.3.2. Environmental Guidance Manual

It is recommended that donor / CIG budget is allocated towards assisting in the improving Guidance Manuals for sustainable development within catchments and coastal areas. Effort is needed to produce a bespoke set of planning and support guidelines, rules and policies for the management of development within sensitive areas such as Muri Lagoon and also within Ra'ui. In Rarotonga, this means both development that currently exists or is planned on the landward side of the coast as well as any new reclamation of new land seaward of the current shoreline position (or offshore island). The guidance will enable regulators and government (namely ICI) to ensure that new coastal and stream developments are designed in an appropriate sustainable manner (adhering to ecosystem based adaptation principles) though ensuring that they are consistent with environmental and land related policies, laws and regulations (see Appendix E). It will help to reduce the possibility of new developments having adverse effects on the coastal environment and other users of the

coast and marine area. It also will provide consistency and transparency for decision makers and enables them to support their decisions with auditable evidence.

The guidelines will need to address the current and future different coastal characteristics found (or to be found) at Muri and will consider the setting of appropriate “rules” or “standards” for coastal development within defined boundaries. Clear implementable advice is required (through a series of planning development guidelines to help with the implementation of issues such as developmental “Setback” (i.e.: the distance behind (landward) the current coastline before any new development should occur). Currently, the regulation distance of 30m and 5m buffer for streams needs to be adhered to, though this is very difficult to implement and requires further update based on land ownership constraints and latest climate change predictions for the Cook Islands. The existing local definition of “setback” as considered within Ra’ui regulations is proposed as a sensible definition to adhere to within a stream situation. The outcome of the guidelines should be to establish a set of development controls for buffer and setback areas for streams and development behind mean high water. It also needs to be written in partnership with all Ministries, Departments and Traditional Leaders as well as the specific responsibilities placed on developers.

The proposed Guidelines shall also provide clear advice on how to complete a climate change risk assessment as part of existing environmental regulations or EIA procedures. This should include identification and modelling of water flow paths (for example). Such studies would be facilitated by more accurate topographic information such as can be gathered by LiDAR (in the future). Development that could be considered vulnerable to flooding because of the nature of the users (e.g. young people, older people, people with illnesses / injuries) or because the services they provide are considered vital to health and safety (e.g. fire service, police facilities, etc.) should not be located in areas at risk.

Auckland Council produced a useful “model” report that could be adapted to the Cook Islands situation. The Erosion and Sediment Control Manual (1999) represents a good example of a similar type of guidance manual that needs to be considered for the Cook Islands. These Guidelines focus on the principles and practices of erosion and sediment control recommended for various Land Disturbing Activities. Conveying the message within these manuals is the most important exercise, with particular time and effort needed to ensure that all land owners with stream easements within their land are willing to learn and change their ways with regards to the clearing of vegetative cover on their land.

7.4. Capacity Building Related Measures

7.4.1. Training

There is a priority need to identify donor support (possibly through future GCF funds) on capacity building and training on a range of aspects. Identifying additional resource, especially on outer islands, is critical yet remains a constant delivery challenge for the Cook Islands and MMR in particular.

One suggestion is to encourage institutional links between the CIG and institutions in French Polynesia, such as the Institute of Research and Developments (IRD). Despite the obvious language difference, there appears to be a growing missed opportunity developing between the two nations. There are obvious climatological and cultural similarities between the two, and there appear to be many examples of good practice which could be developed and nurtured over time. This includes the use of natural herbal remedies to deal with ciguatera as well as lessons associated with riparian planting close to streams etc.

Recommendations for web based GIS training is urgently required. Within this training, efforts to introduce new innovative UAV data collection (drones) could be introduced to help with marine habitat mapping amongst others. The current proposals being put forward under the R2R project to use UAVs (using new 3D correction software such as PIX4D (circa NZ$50/month to purchase) should be brought into this consideration (see Part B Section 8 for more information on data capture using UAV technology).

Finally, it is recommended that in partnership with ICI and GHD, that a series of training events are arranged into 2018 (July 2018) to focus on best practice guidance on sediment control measures and catchment “soft engineering practices”. These events should formalise the production of specific Guidance manuals on riparian planting, soft engineering solutions and ecosystem based adaptation solutions.

8. INTEGRATED MONITORING PROGRAMME FOR MURI LAGOON

This Section addresses the following project objectives (already defined in Part A Section 1.2)
Develop a resource monitoring programme to assess the health of the marine ecosystem and developing it into an indicator for marine ecosystem health. This monitoring program is essential as it will complement ongoing sanitation upgrades and provide a basis to assist decision makers to decide whether to (1) continue with the current sanitation on-site treatment or (2) commission the construction of a reticulated system.
Develop statistical sampling methodology and biometric standards for routine and intensive monitoring programs to ensure accurate and precise reporting relevant to ranges for survival of marine species.

8.1. Purpose of this Section

Integrated monitoring, when planned and implemented effectively will provide MMR with two primary benefits. The first is a better understanding of cause-and-effect relationships within social-ecological systems and the response of these systems to management actions (represented by a Driver-Pressure-State-Impact-Response model). The second benefit of integrating is cost-effective use of available resources for monitoring the status of Key Ecological Features" (KEF) and "Matters of National Environmental Significance" (MNES), which is achieved through building on, and enhancing existing monitoring efforts and clearly setting out the priorities and gaps to be addressed by any future monitoring. Other important benefits of integrated monitoring include better insights into the effects of cumulative pressures and impacts on MNES values and how to respond to fluctuations in resources available for monitoring (e.g. reductions and increases in monitoring budgets).

AECOM have reviewed strategic work carried out by Hedge *et al* (2013 and 2017) and have adapted that work to create an "Integrated Monitoring Programme (IMP)" for MMR to formalize and implement into 2018. Appendices G, H and I are generated to help support this IMP approach though additional work is required to formalise the concept being put forward at this time. Muri Lagoon is nevertheless proposed as a "pilot" implementation site for the identification of future "Ecologically and Biologically Significant Areas" (EBSA) and Particularly Sensitive Sea Areas (PSSA's) *(which are specifically defined as being of relevance to the Cook Islands within the Marae Moana Policy (2016)*), however, the IMP framework is designed to help develop an efficient

and effective monitoring and reporting system nationally to embrace Rarotonga and all Pa Enau islands. The IMP approach is also structured to be used as a template for future iterations of the "State of the Coast" reporting system (see Part C Section 11) but also important national reporting requirements which have recently been defined within Part 6 of the Marae Moana Act (2017) (see Appendix E) .

Importantly, the framework of this consultancy is designed to ensure that all findings deduced are closely intertwined with the goals of the Cook Islands government National Sustainable Development Plan (NSDP) "Te Kaveinga Nui'' 2016-2010 and the indicators for the marine and health sector take from the following national policies:

a) National Water Policy (2016);

b) Marae Moana Policy (2016).

To ensure this is achieved, close consultation and engagement of all key stakeholders within the Cook Islands is required. This consultancy has started this process, though formal acceptance of the ideas put forward in this section will require more formal engagement and consultation to ensure its integration into sector policies and Ministerial work plans.

NB: The IMP approach being put forward will require appropriate governance to be in place and adequate and sustained funding and resources to be established. The monitoring program remains as a draft framework due to the incomplete nature of the environmental investigations under the MTVKTV project. Consequently, whilst the framework is designed to complement that project, AECOM are unable to finalise the exact parameters to determine whether to (1) continue with the current sanitation on-site treatment or (2) commission the construction of a reticulated system. Only upon acceptance and adoption of the Integrated Monitoring Framework (IMF) for the Cook Islands can a detailed statistical sampling methodology and biometric standards be created for routine and intensive monitoring programs. This shall be a recommended action as set out in Part D (Section 13).

8.2. Integrated Monitoring Programme for Muri

8.2.1. Overview

An IMP outlines a clear purpose and set of priorities for integrated monitoring for Muri Lagoon and provides details on how the program will start, be developed and be reviewed. It identifies the existing monitoring programs that will participate in integrated monitoring and the infrastructure, initiatives, processes, standards and protocols that will be used to integrate monitoring in the focus area(s). It seeks to identify the actions that need to be completed over the short, medium and longer term, and who will be responsible for actions, to commence, develop and review the IMP. Specific aspects of the IMP are identified and costed in Part D Section 13.

NB: A detailed and formal IMP cannot be established at this time and for general acceptance, will require a considerable amount of national consultation to make the design acceptable. What is presented in Section 8.3 represents a framework for later update and broader consultation with teams from NES, MoA, CCD, ICI, MFEM and Marae Moana (OPM) amongst others. This procedure is adapted from Hedge et al (2013) and presented in Figure 8.1.

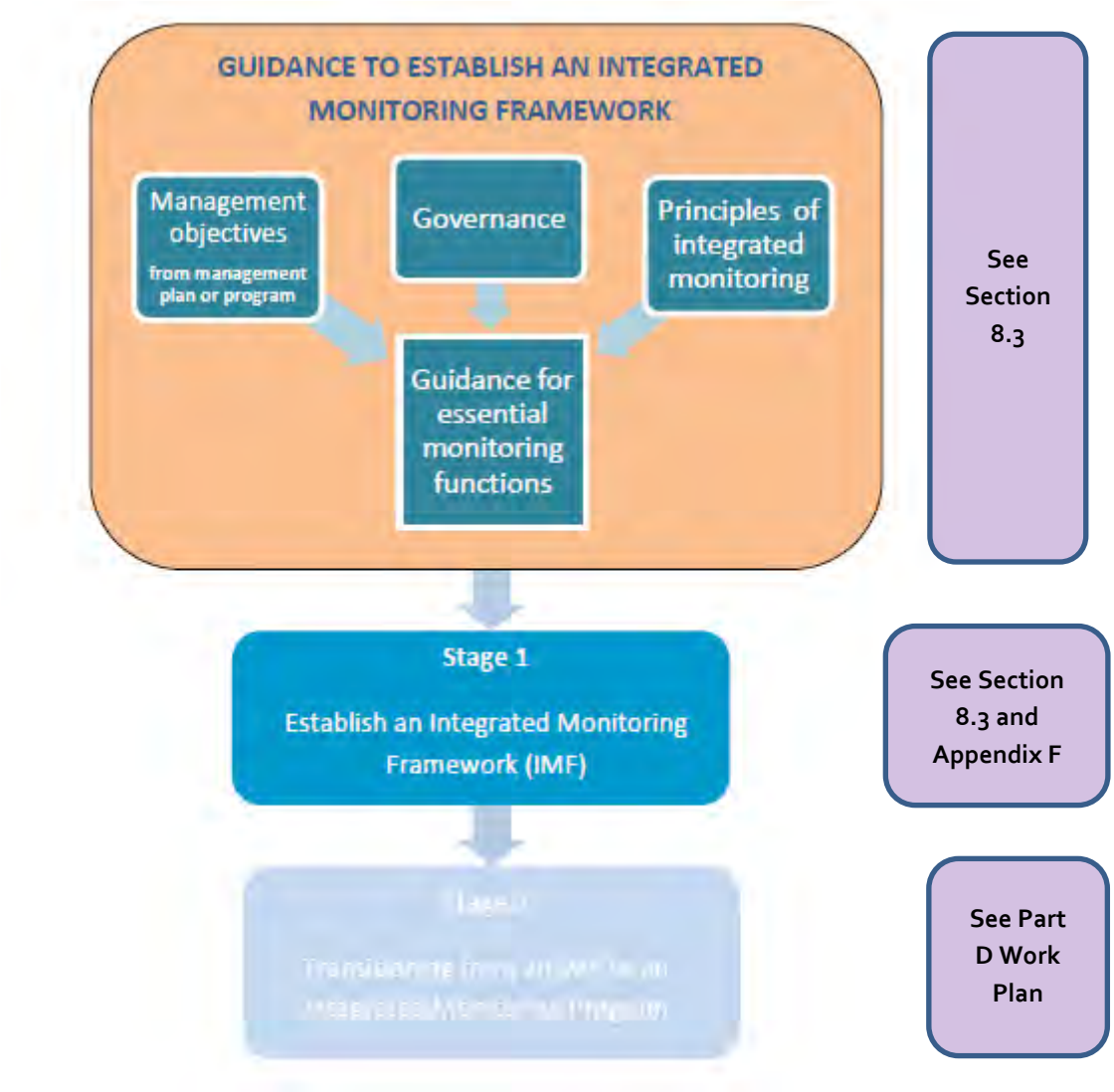


Figure 8.1: An overview of the guidance relating to establish an IMF for Muri Lagoon to support the adaptive management arrangements of programs being assessed under the Ridge to Reef (R2R) programme for Muri Lagoon. Stage 1 represents the stage that AECOM "departs" this process. Stage 2 can only commence once Stage 1 is endorsed by all relevant stakeholders in the Cook Islands (adapted from Hedge et al 2013).

8.2.2. The need to integrate interests

Within the Cook Islands, the integration of interests across policy, management and science sectors will prove to be the cornerstone to successful integrated coastal and marine monitoring. Arguably the most important

aspect for future consideration will be the crafting of realistic, specific and measurable monitoring objectives and directly linking these to management objectives for Muri Lagoon (and nationally under the Marae Moana Act 2017). Within the Cooks, agencies need to work together to input collectively into a national marine monitoring program and this is something that MMR are currently working towards as a priority that includes the integrated monitoring protocols for water quality, fisheries, habitat health, invertebrates, so that key government line agencies can collaborate together on.

The challenge facing the Cook Island agencies is to ensure that collectively the management and monitoring objectives are structured hierarchically to provide clarity on the mandate of policymakers and the priorities for resource managers, and are scientifically testable. This represents a transition from Stage 1 to Stage 2 (as defined in Figure 8.1).

8.2.3. The need to integrate data

There are two important considerations for integrating data and analyses: firstly, integrating similar data streams to build understanding about marine environmental change and trends at a range of spatial scales (local, regional and national) and over time; secondly, integrating different types of data (e.g. economic, social and environmental) to produce understanding and insights to determine the effectiveness of management for maintaining and enhancing marine environmental values. Coral monitoring, as an example, is a national priority for the Cook Islands though datasets are dispersed amongst a number of organisations, many of them are not Government bodies and therefore a need to organise collection within government "bounds", to attract donor funding if nothing else, is important as this remains a government mandate to look after the marine resources and to protect and conserve the marine environment.

The design of any IMP requires data collection protocols and data management standards to be agreed upon, formalised and collectively implemented. These are all important mechanisms to ensure the facilitation and integration of marine ecological monitoring data and improve understanding of marine environmental change or trends in Muri Lagoon across spatial and temporal scales. For example, these mechanisms are critical for ensuring future data collection at local scales (e.g.: the current RAPCA process being undertaken at Muri Lagoon through the R2R project can be discovered, stored, accessed and used to make confident inferences at regional and larger scales). They are also important for integrating new monitoring programs with existing programs, where required. This is certainly something that has come apparent with regards to coral surveys around Rarotonga (and elsewhere) as identified in Part A Section 3 (coral survey work undertaken by NGOs, Climate Change Department and others).

The use of conceptual models (as included for Muri Lagoon in Part A Section 4 for coastal hydrodynamics) provides an important means for understanding how the diverse components of natural lagoon systems and humans interact. Simple graphical conceptual models can also provide a mechanism to integrate the beliefs of diverse groups of scientists and stakeholders into a coherent and scientifically testable structure, and they

guide the analysis and interpretation of data from monitoring programs. Conceptual models also complement the "Driver; Pressure; State; Impact; Response" (DPSIR) framework that seeks to link indicators to pressures, and subsequently management response (R2R Cook Islands RAPCA approach towards creating the State of the Coast methodology). The learning that accompanies the design, construction and revision of the conceptual models (including 3 dimensional Participatory Models – see Part C Section 12) contributes to a shared understanding of system dynamics (e.g.: Muri Lagoon as a "system"), and the process of developing conceptual models is often more important that the model itself. Using DPSIR to convey the issues and challenges at Muri Lagoon is a useful way to communicate and prioritize monitoring needs (see Figure 8.2).

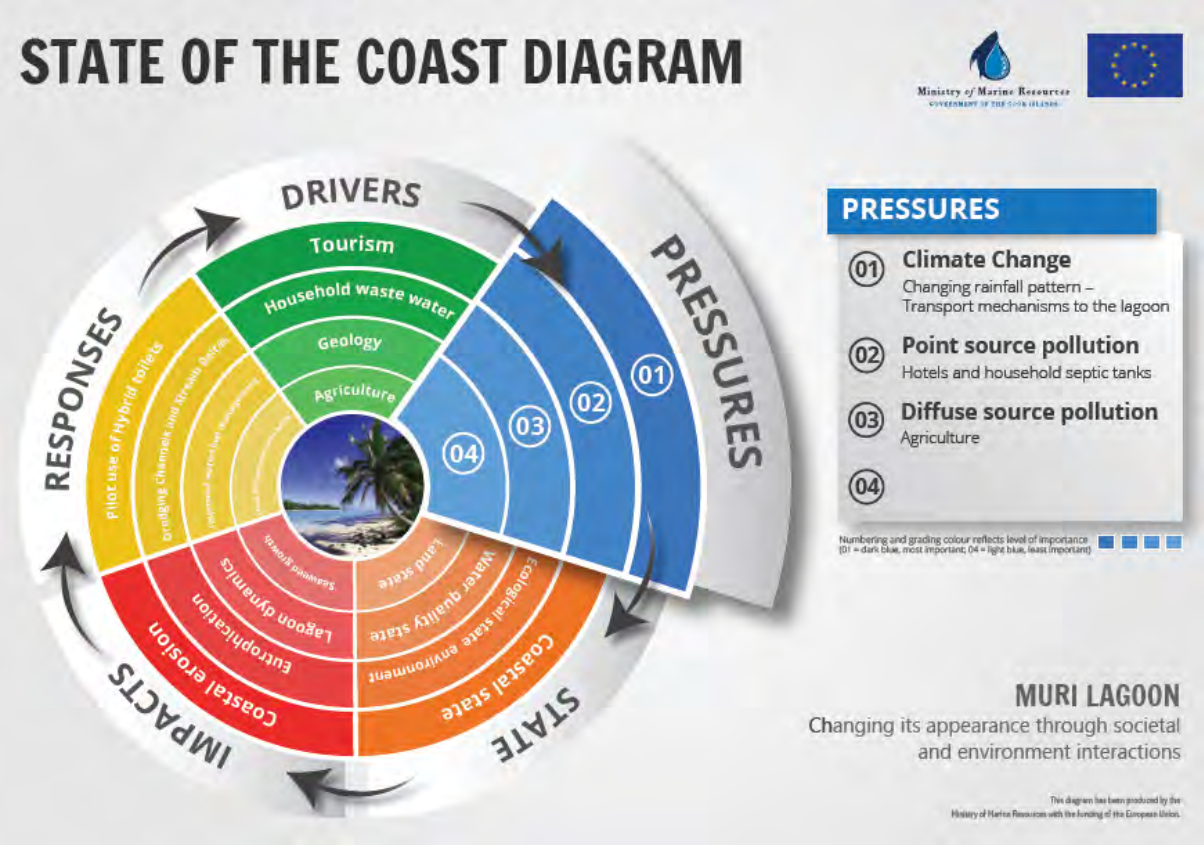


Figure 8.2: DPSIR "State of the Coast" Diagram being drafted by AECOM/MMR to convey pressures at Muri Lagoon

8.2.4. The need to integrate new information and knowledge

It is essential that mechanisms to integrate new information and knowledge into existing monitoring programs are designed into an integrated monitoring program for Muri and the Cook Islands. Important mechanisms for integrating new information and knowledge into existing monitoring programs are regular program reviews and the identification of research priorities designed to improve performance monitoring. A good example of this is the use of latest technologies that involve UAV systems ("drones") which provide great opportunities for marine habitat monitoring as well as the rapid ability to assess the extent of seaweed plumes (see Figure 8.3).

UAVs are also a great asset for monitoring the stability of a coastline and for carrying out a rapid initial survey after storm or pollution events. UAVs can quickly survey large sites with a very high level of detail.

It is apparent that drones exist within ICI (personal use *pers comm* Paul Maoate 2017), the NES (recently purchased equipment) plus proposals are in place for a drone to be purchased for the MMR. It is recommended that instead of separate departments/ministries purchasing such kit, that a clear strategy is adopted towards the purchase of one system (plus potentially a back-up system) that can capture information that is needed by a range of institutions. More information on drones is presented in Part A Section 6.

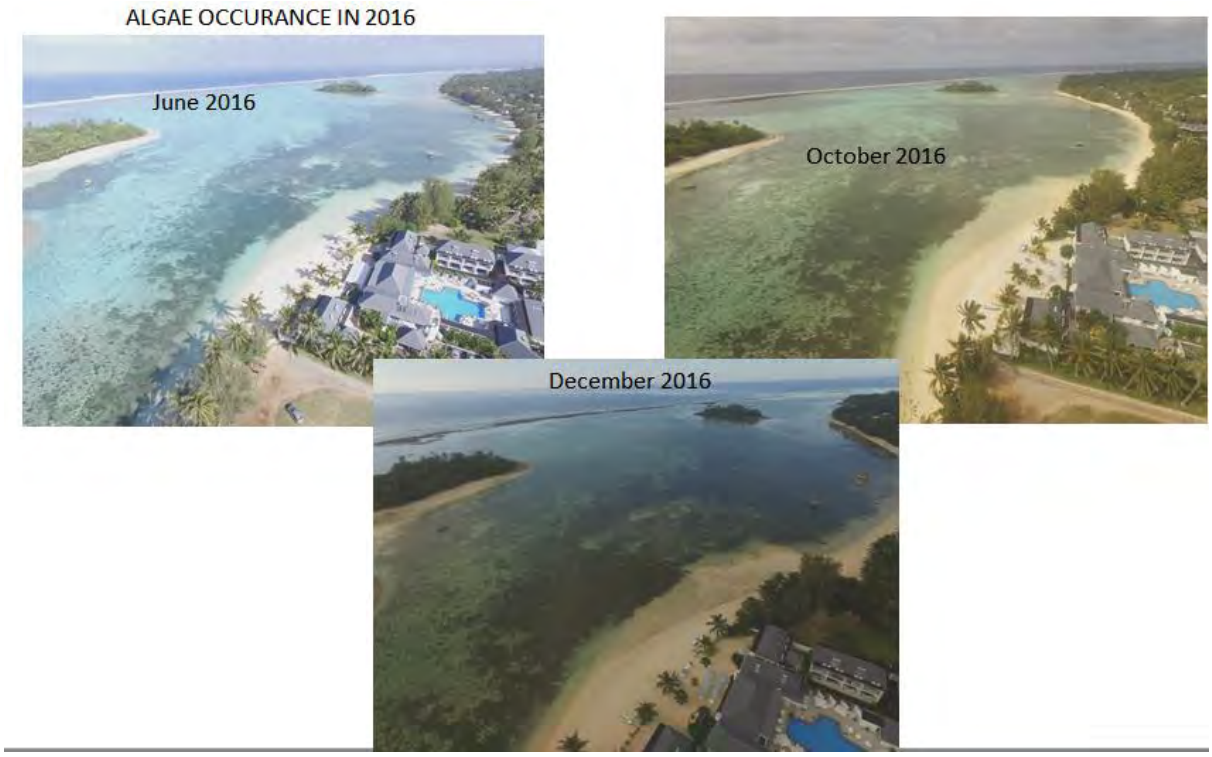


Figure 8.3: Drone footage showing algal coverage in Muri Lagoon during 2016.

8.3. Key Programme Functions

Figure 8.4 diagrammatically presents the 9 key Programme Functions (PF) that need to be adhered to and implemented for a Muri Lagoon monitoring programme (as a pilot area), and later the approach is hoped to be up-scaled to a national scale.

The code "A" represents the existing conceptual models and known gaps for Muri Lagoon; code "B" denotes existing monitoring programs and known gaps for Muri Lagoon; code "C" represents existing monitoring protocols and known gaps defined by MMR/others within Muri Lagoon; code "D" denotes existing infrastructure, processes or protocols and known gaps; and code "E" suggests that update and Iteration may be required as sampling design informs, and is informed by, selection of monitoring programs for Muri. ***(NB:***

much of the above exercise is being carried out by the R2R team as part of the Integrated Coastal Management work for Mur Lagoon which is scheduled to commence early into 2018).

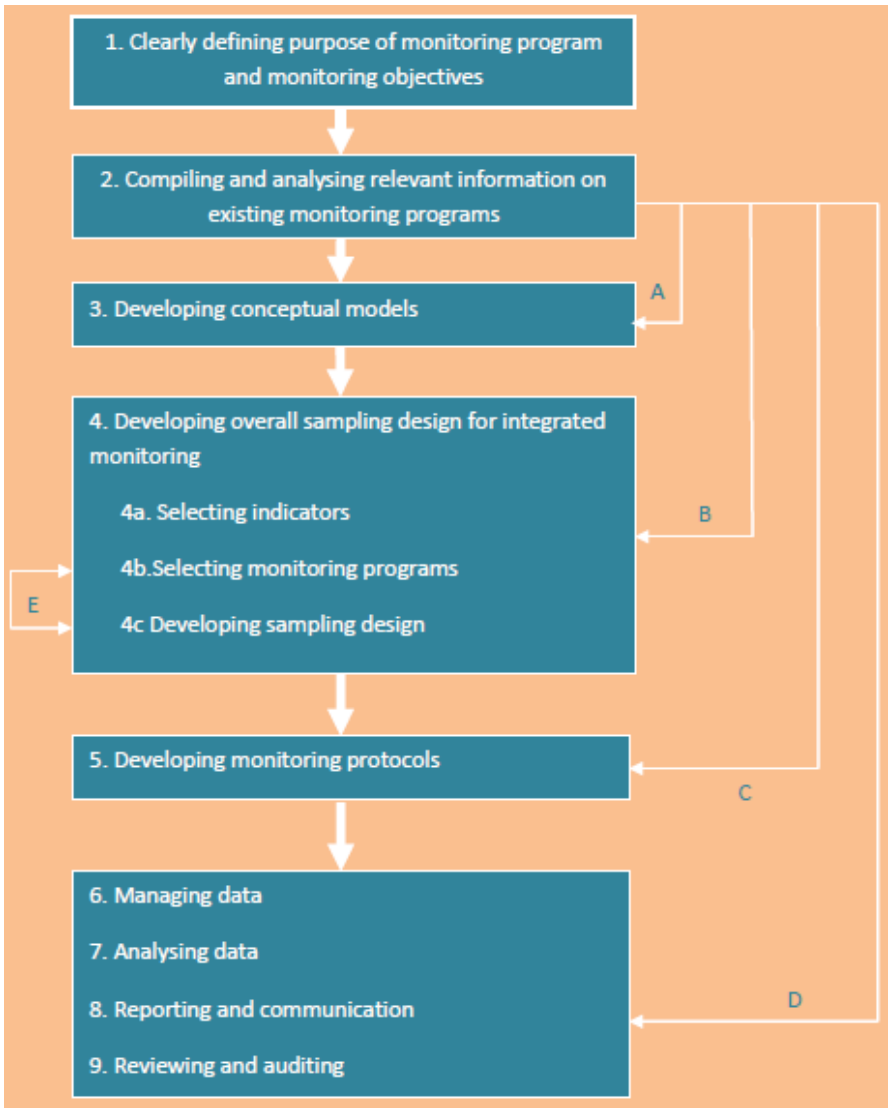


Figure 8.4: An overview of how to apply the guidance for Key Programme Functions identifying the relationships, links and need for iteration between them.

8.3.1. Defining the integrated monitoring program and monitoring objectives

This PF must clearly articulate the purpose of the integrated monitoring program for Muri Lagoon and provide a prioritised list of monitoring objectives.

8.3.1.1. General Description

Clearly defined management objectives are a fundamental prerequisite to successful management. Management objectives are mostly defined by policymakers and managers during the process of planning and

management. It is important that management objectives are defined early in the process to inform an IMF as they are essential for focusing effort and prioritising. Any objectives set should be specific, measureable, achievable, results-oriented and applicable over relevant time frames (i.e.: SMART). Failure to set SMART indicators may severely limit the capacity of the monitoring program to inform adaptive management. The management objectives hierarchy begins at the broadest level with the organisation's vision, mission statement or strategic objectives (hereafter referred to as the high-level management objectives). These high-level objectives are then broken down into a suite of lower-level statements which have increasing focus, rigour and achievability. The lowest level of the management objectives hierarchy provides on-ground managers with realistic, specific and measurable direction that is delimited in space and time.

8.3.1.2. Muri Specific Recommendations

Example "High Level" management objectives for the future of Muri Lagoon are drafted below. These reflect the intentions of NSDP (2016-2020), the Sustainable Tourism Development Policy (2012) and the MTVKTV project.

Option 1 – "Maintain genetic, species and ecosystem diversity plus restore degraded habitats within Muri Lagoon so that they become resilient and biologically productive whilst providing the opportunity for ecologically sustainable use" (adapted from Marae Moana Policy Objective 1 (2016)).
Option 2: "Ensure sustainable management of both inland and coastal water resources within the Muri Catchment and defined lagoonal space" (adapted from National Cook Islands Water Policy - Objective 5 (2017)).

Example "Operational" management objectives for the future of Muri Lagoon are drafted below.

Option 1: "To increase the live coral cover and condition in Muri Lagoon by 5%, from baseline current conditions, within 5 years of implementing the IMP".
Option 2: "To improve the health card scores for Muri Lagoon by 5%, from baseline current conditions, within 5 years of implementing the IMP".
Option 3: "To halt and reverse the decline in water quality within Muri Lagoon within 3 years after implementing the IMP"

Specific actions following this current AECOM contract (possibly as part of the R2R Muri Lagoon Integrated Coastal Management exercise due to start in early 2018) are as follows:

- Baseline condition surveys of any outstanding lagoonal environment parameters must be collected within 6 months of this AECOM report (by July 2018).

- Test high level management and operational objectives to determine if they provide the correct direction at the operational level (i.e. are they realistic, specific and measurable). If they meet the test, organise objectives into a management objectives hierarchy diagram (see Figure 8.5) for inclusion within the MMR Strategic Action Plan (2017-2021), Laboratory Strategic Plan (see Appendix G) and insert within the MMR Business Plan (2018-2022).

- Circulate management objectives hierarchy to appropriate governance committees (Muri Community Action Group etc...).

- Define the indicative monitoring parameters and programmes required to help management achieve this objective). Using Option 3 (above) as a pilot example, monitoring programmes may include the need for data provision that:

  i. tracks trends in sediment transport within Muri Lagoon catchment to receiving lagoonal waters;

  ii. Quantifies change in the extent of land use (clearing and agriculture) in the Muri catchment

  iii. Monitors trends in concentrations of pesticides in receiving waters and compliance with water quality standards set by MMR

  iv. Traces the sources of nitrogen and phosphorus entering Muri Lagoon.

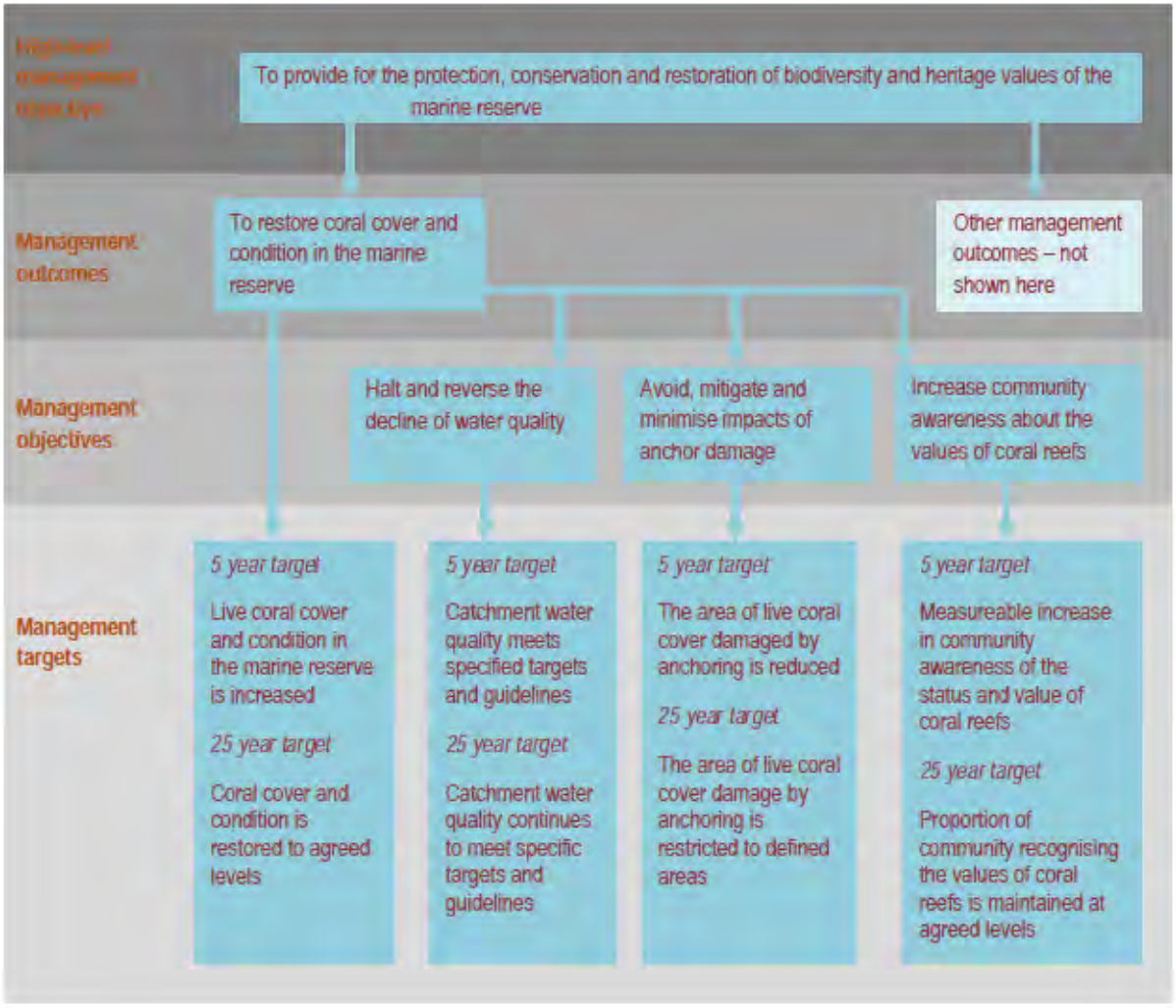


Figure 8.5: Management objectives hierarchy diagram (taken from Hedge *et al* 2013).

8.3.2. Compiling and analysing relevant information on existing monitoring programs

This PF must clearly articulate a review of existing monitoring programs taking place, or historically have taken place within Muri Lagoon.

8.3.2.1. General Description

It is important that integrated monitoring builds on any old or existing programmes (i.e.: a legacy of monitoring) if any new programmes that generate monitoring data can prove of any added value. This function is essential from the perspectives of pragmatism and cost-effectiveness from a Government of Cook Islands perspective.

There are a number of ways to go about compiling information on existing monitoring programs. In some cases there may be existing reviews of monitoring programs that could provide a sound basis to start this work. Another approach is to search metadata within institutional, or ideally national, data centres, such as

the Australian Ocean Data Network etc. Completing this step requires very little time and expertise if relevant metadata records are provided to central data repositories of internet related searches. If structured well, the findings of the analysis should provide important inputs to complete the remaining steps on the IMF, particularly in terms of identifying existing infrastructure, resources, protocols and standards that are already supporting monitoring.

With specific reference to Muri Lagoon, a databank of information already exists within the MMR and other organisations. In parallel to this, detailed consultancy studies have recently been engaged to collate and compile a literature review of environmental information regarding the state of the lagoon. MTVKTV project (undertaken by GHD) are carrying out environmental investigations in Muri that are designed to fill the gaps in the current understanding of the Muri catchment area and help identify the optimal technical solution for improving the water quality of Muri Lagoon. There are two phases of the environmental investigations: preliminary investigations (August 2017) and main investigations (November 2017 onwards). Details can be found at the MTVKTV website (http://www.vaikitevai.com/enviro-monitoring) plus also recent work undertaken by AECOM for this consultancy (see references listing at the end of Part D of this report.

In addition, as part of the current R2R project, a task is about to commence in 2018 to undertake a Rapid Coastal Assessment (RAPCA) for Muri Lagoon. It is understood that during early preparatory stages of the R2R project, that a Diagnostic Workshop has already been held and preparatory stages of a RAPCA already completed which involved meetings with stakeholders in Muri that were designed to assist in the RAPCA.

Specific actions following this current AECOM contract (possibly as part of the R2R Muri Lagoon Integrated Coastal Management RAPCA task that is due to start in early 2018) are as follows:

- Produce a project outline for compiling, analysing and summarising information on existing monitoring programs for Muri Lagoon defining purpose of review, spatial boundaries and required outputs (being competed for Muri under the R2R project during December 2017).
- Seek endorsement of the Muri Lagoon RAPCA process findings from the appropriate governance committee(s).
- Appoint a suitably qualified analyst(s) to complete project and produce the RAPCA report (budgeted under R2R).
- Provide copy of report to appropriate governance committee(s).

8.3.3. Developing Conceptual Models

This PF must clearly identify any existing conceptual models that would support the integrated monitoring plan for Muri Lagoon, gaps in conceptual models required for integrated monitoring and opportunities to address gaps.

8.3.3.1. General Description

Conceptual models are an essential component of successful monitoring programs because programs that are not motivated and supported by clearly stated conceptual models risk being insufficiently focused or relevant to management objectives (Lindenmayer and Likens 2010). Furthermore, whether recognised or not, all monitoring programs are implicitly based on a conceptual model of the system. Some forms of conceptual modelling also provide an opportunity to identify indicators, and thereby assist in completing another essential function of the IMF. Conceptual models also provide a pragmatic insight into how to integrate monitoring data, particularly the interpretation and synthesis of numerous monitoring data streams.

Conceptual models represent a working hypothesis about how the ecosystem works. They should: a) identify the important components and processes in the system; b) document assumptions about how these components and processes are related; c) identify the linkages between these components/processes and anthropogenic pressures; and d) identify knowledge gaps or other sources of uncertainty (see Figure 8.6). It is important that the formulation of a conceptual model occurs at the beginning of a monitoring program, as it drives the collation of system knowledge and understanding about how the system works and how it might respond to anthropogenic pressures, and thereby ensures that relevant components are included in the project design.

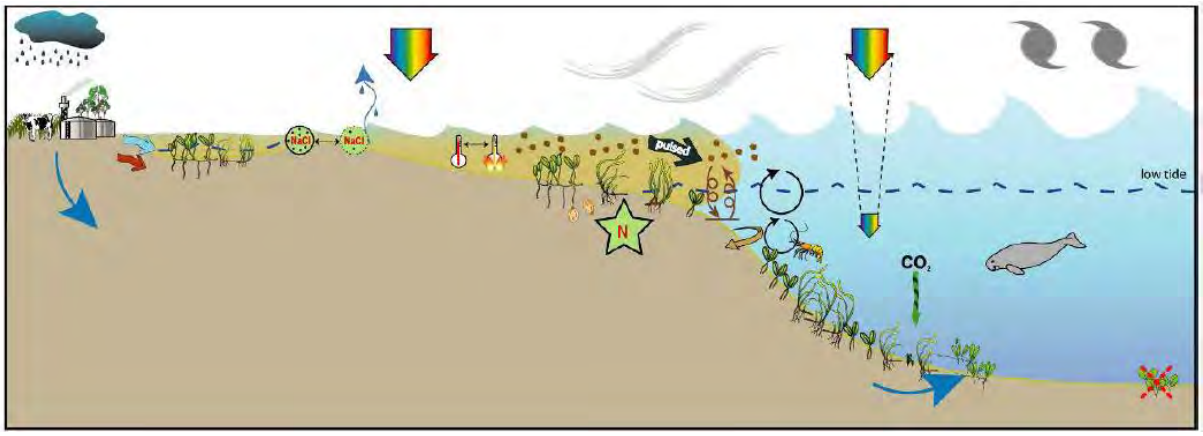


Figure 8.6: Conceptual diagram of coastal habitat in the Burdekin region—major controls are wind and temperature extremes, general habitat, seagrass meadow processes and threats/impacts (taken from McKenzie *et al*. 2012)

With regards to Muri Lagoon, conceptual models have been prepared and these have already been discussed in Part "Section 4 plus Appendix C (see Section 4.4). Updated conceptual models for Muri cannot, however, be

finalised until the completion of the environmental investigations currently underway as part of the MTVKTV project (MFEM), have been completed in tandem with the details hydrodynamic coastal "model" being produced by the University of New South Wales (due to start in January 2018). As a consequence, specific actions following this current AECOM contract are as follows:

- List all existing conceptual models (building on the list already provided by AECOM in Part A Section 4) to assist with the analysis of existing monitoring programs).
- Update and produce a coastal model based on outstanding information pending from MTVKTV project and University of New South Wales and circulate to participants in the process and the appropriate governance committee(s).

8.3.4. Develop the Sampling Design

8.3.4.1. Selecting indicators

This PF must select high-level indicators to support priority monitoring objectives agreed for Muri Lagoon.

8.3.4.1.1. General Description

Indicators will be the backbone of the proposed IMP to help demonstrate progress towards the SDGs at the local, national, regional, and global levels. Specific indicators can be set for these (reflecting those already established within the Marae Moana Policy (2016) as included within Appendix E). Importantly, the supporting Marae Moana Policy (2016) recognises the connectivity between the terrestrial and marine environment and supports the management of activities on land which may adversely impact the marine environment. This recognition is critical for delivery of any IMP.

Clear links from management objectives to monitoring objectives (see Section 8.3.1) to selected indicators are required. Well-defined indicators are also an important means for communicating monitoring results to a wider audience A sound indicator framework (as part of the IMP) will turn the SDGs and their targets into a management tool to help countries and the global community develop implementation strategies and allocate resources accordingly. They will also serve as a report card to measure progress towards sustainable development and to help ensure the accountability of all stakeholders for achieving the SDGs. The indicators (when set and agreed) need to serve two purposes: management (to stay on course) and accountability (to hold all stakeholders to the SDGs). For management purposes, the indicators need to be accurate and frequent, reported at least once per year. The SDGs also require annual reporting of high-quality data from all countries, including the Cook Islands. This, in turn, will require much greater investments in building independent, impartial national statistical capacities and strengthening statistical quality and standards.

The Cook Islands (through its NSDP 2016-2020) has chosen its national SDG indicators that are best suited to track its own progress towards sustainable development. It is proposed that each goal (set within the NSDP) is

tracked by a small number of global "Global Monitoring Indicators" that will be monitored systematically by the UN. In order for the SDGs to be successful, every level of government will be counted on to benchmark and assess progress on each target (Figure 10.1). A sensible approach for the CIG to continue to develop is the need to design cross-cutting indicators. For the marine environment, this creates a few challenges in the absence of an effective integrative policy for land and sea (although the new Water Policy does embrace ICZM and Lagoon Management Plan objectives throughout – see Appendix E). Effective indicators must be measurable, relevant, reliable and comprehendible (see Figure 8.7 and Table 8.1).

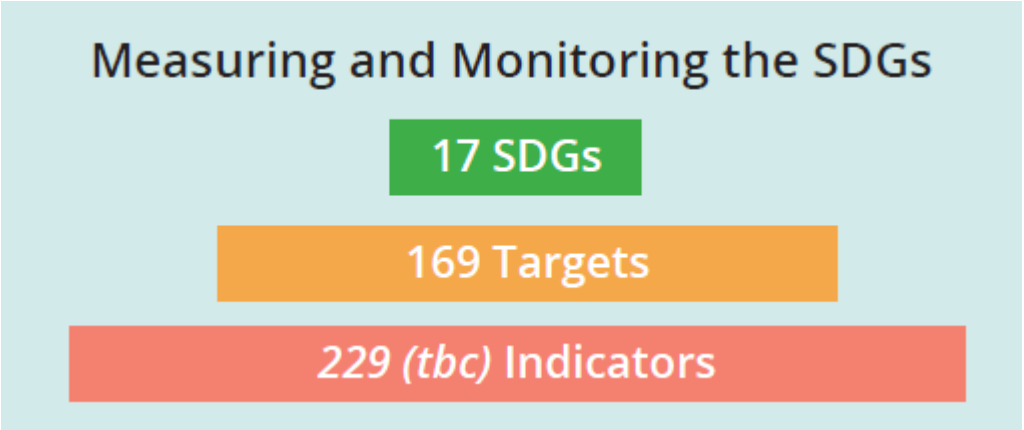


Figure 8.7: Measuring and Monitoring SDGs

To ensure national compliance, an important link needs to be made between the NSDP (2016-2020) indicators and those set for SDG14.

NSDP Indicator 12.1 "State of the Reef" focuses specifically at the state of reef including coral coverage and other indicators of reef health. Monitoring of biological parameters needs to focus on a host of organisms to assess the extent of damage to coral reefs from natural and human induced disturbances. Mayfield *et al* (2016) prepared an interesting study that focused on Cook Island reef systems that focused on the role of *pocilloporids* as a possible bio-indicator for Cook Island reef systems. They declared that an ideal biomarker for proactive coral health assessment would be a molecule (e.g., gene mRNA, protein, or metabolite) whose concentration and/or activity signifies a future physiological change. Therefore, it seems logical to target macromolecules involved in the cellular stress response, such as heat shock proteins. AECOM believe however that this bio-indicator is not an easy one to regularly monitor, and so whilst technical it may provide a sound suggestion, the practicality of adopting this far outweighs its impact. Instead, AECOM propose (in Section 10.3) that the most frequently measured and more practical "indicators" for reef systems (marine ecological parameters) should include the following:

- Percentage cover of corals (both live and dead), algae and non-living material;
- Species or genus composition and size structure of coral communities;

- Presence of newly settled corals and juveniles;
- Numbers, species composition, size (biomass) and structure of fish populations;
- Frequency of Crown-of-Thorn Starfish, sea cucumbers etc.;
- Extent and nature of coral bleaching through use of UAVs; and
- Extent and type of coral disease.

Indicator 12.4 focuses on “Lagoon water quality” as the health of lagoons has come under threat due to unsustainable land use practices as well as poor management (see table 8.1 – SDG 14.2). It remains very important to regularly test lagoon waters to identify potential environmental or health risks, and make timely interventions to address the situation. Specific parameters identified for indicator measurement are set out in Section 10.3.

Table 8.1: SDG, NSDP and Marae Moana Policy Indicators of relevance to Muri Lagoon

SDG14 Indicator Title Heading	Why is this relevant within the IMP for Muri Lagoon	Relevant link to NSDP Indicators and Marae Moana Policy Objectives (2016)	Relevant Marae Moana Policy Indicator (2016)
10.3: Number of reported biosecurity threats	Eradication of an invasive marine alien species is a very long process and requires the support of partnerships working together as much as possible with other government ministries and community groups. Issues linked to ballast waters from ships are of relevance here (including recent observations of Australian droplet tunicate *(Eudistoma elongatum* in October 2017*)*	1: Enhance Conservation and Ecological Sustainability	Number of established marine invasive
14.1. Eutrophication of major estuaries:	The increased levels of nutrient runoff and untreated sewage resulting from human activities, are leading to eutrophication, harmful algal blooms (HAB) 228 and "dead zones." The levels of eutrophication need to be monitored in all major estuaries. NSDP states that CIG needs to regularly test lagoon waters to identify potential environmental or health risks, and make timely interventions to address the situation.	Goal 12: Sustainable management of oceans, lagoons and marine resources Indicator 12.4: Lagoon water quality	Lagoon water quality (NSDP Indicator 12.4)
14.2. Ocean acidity (measured as surface pH):	The chemistry of the ocean is not constant and variables such as water temperature affect the dissolution of CO2, making pH differs from the global average. Consistent measurements will allow better understanding of the processes and impacts of CO2 absorption.		
14.3. [Indicator on the implementation	There are a growing number of uses of the marine environment potentially leading to increasing spatial conflicts between users. Marine spatial planning is a strategy to distribute (spatially and temporally) human	6. To coordinate use of the Marae Moana through zoning and a management plan.	6.1 Establishment of a zoning and marine spatial planning

of spatial planning strategies for coastal and marine areas]	activities in coastal and marine areas in order to guarantee those ecological, social and economic objectives that are decided through a public and political process.		process for the Marae Moana 6.2 Establishment of the Marae Moana zoning plan 6.3 Percentage of activities in compliance with the Marae Moana zoning plan
14.4. Area of coral reef ecosystems and percentage live cover:	This indicator measures the area of live coral reef ecosystem coverage within the national waters. NSDP states the need for CIG to monitor this as reefs play an important role in protecting islands and communities from the impacts of climate change. Indicator 12.1 "State of the Reef" focuses on coral coverage and other variables, relating to the health of Cook Island reefs.	NDSP Indicator 12.1 "State of the Reef" • Percentage cover of corals (both live and dead), algae and non-living material; • Species or genus composition and size structure of coral communities; • Presence of newly settled corals and juveniles; • Numbers, species composition, size (biomass) and structure of fish populations; • Crown-of-Thorn Starfish, sea urchins etc.; • Extent and nature of coral bleaching; and • Extent and type of coral disease.	1. Enhance Conservation and Ecological Sustainability

NB: the above indicators are reflected in the new design of the Muri Lagoon health Card presented in Section 10.3

8.3.4.2. Selecting Monitoring Programs

This PF must identify existing monitoring programs (based on costs and benefits) that should be included in integrated monitoring for Muri Lagoon, and identify proposals to address any gaps.

8.3.4.2.1. General Description

Selecting monitoring programs is an essential function of integrated monitoring because it identifies the suite of monitoring programs that should collectively form the founding set of monitoring programs for integrated monitoring. Selected monitoring programs generate the relevant monitoring data (to meaningfully address the monitoring objectives and indicators), demonstrate how monitoring is integrated and provide a nucleus for integrating other transient or shorter-term monitoring programs (e.g. compliance or incident monitoring).

The costs and benefits of environmental monitoring programs are important factors in selecting monitoring programs for the IMP. Advances in technology such as automated data logging, data analyses, remote sensing and other opportunities such as citizen science have significantly reduced costs of some programs, and these approaches can be employed where appropriate (Newman *et al*. 2012). Data can now be packaged and shared with real-time or near-real-time reporting, and housed on data servers that can be accessed by dispersed analysts. Technology such as unmanned UAVs (drones) can also decrease costs while increasing monitoring capacity.

Managers and policymakers must also be aware that complex ecological systems require sustained monitoring efforts over the long term to detect changes arising from impacts or management interventions, and at a spatial and temporal resolution sufficient to detect these trends against background variation. The slow growth rates of many coral species and the decadal cycles of major disturbances such as outbreaks of the crown-of-thorns starfish mean that 10 years is often unrealistically short for assessing long-term trends in some priority values and pressures in the marine environment. `

8.3.4.3. Defining Sampling Areas

This PF seeks to identify the sampling design requirements for the integrated monitoring of Muri Lagoon and undertakes an assessment of how existing monitoring programs (identified for inclusion in integrated monitoring) will meet these requirements, and how sampling design area could be integrated across selected programs to produce efficiencies across all Cook Islands Ministries and Departments.

8.3.4.3.1. General Description: Agreeing Monitoring Zones

As a result of the uncertainties over the causes of deteriorating environmental conditions at Muri Lagoon, an integrated and comprehensive coastal monitoring strategy (ridge to reef) is required for the location, as part of an island wide strategy for Rarotonga. To support this, AECOM have proposed a series of areas or “zones” (see Figure 8.7 and Table8.2) and these definitions are used throughout this section.

Figure 8.7: Muri Lagoon – proposed monitoring zones.

Table 8.2: Definitions of the Muri Lagoon "Monitoring Zones"

	Name of Zone	Definition
1	Terrestrial Zone	The area landward of mean high water mark (non-intertidal). This area includes all streams up to their mouth entrance to the inner lagoon area.
2	Inner Lagoon Zone	The area ranging from mean high water seawards to an imaginary line that links the most easterly point of each "motu". This area includes all stream deltas. Geomorphologically, this is often referred to as the inner reef flat area.
3	Outer Lagoon Zone	The area ranging from an imagery line that links the most easterly landward point of each "motu" seawards to the outer reef crest. This area includes all "spur and groove" reef channels and associated reef boulders. Geomorphologically, this is often referred to as the outer reef flat area.
4	Reef Crest	The area representing the coral reef crest before the drop to the oceanic shelf.
5	Ocean	The area seaward of the reef crests (representing deep water shelf environments and habitats - policies in this zone to be set by Maraea Moana Act 2017).

8.3.5. Developing Monitoring Protocols

This PF shall clearly identify the purpose and scope of future Muri Lagoon specific monitoring "protocols", any existing monitoring protocols being followed by MMR and what additional work is needed to address technical gaps.

8.3.5.1. General Description

Monitoring protocols provide the necessary instructions and standards for ensuring monitoring data are collected, managed, analysed and reported consistently across space and time. They are important for integrated monitoring as they enable the development of data time series and the integration of similar data from different programs (e.g. they specify how marine invertebrate data should be collected, managed, analysed and reported to ensure data from local invertebrate monitoring programs can be integrated to provide a regional perspective – e.g.: the SPC monitoring approach). They also enable the integration of results from different types of monitoring (e.g. long-term, short-term and compliance monitoring).

As a minimum, MMR require monitoring protocol manual that details operational instructions about how data are to be collected. At present, this doesn't exist For integrated monitoring is it preferable that monitoring protocols provide operational instructions for the entire data life-cycle including how individual programs are to collect, manage, analyse and report data in a consistent and comparable fashion over space and time. Monitoring protocols must also be sufficiently well documented that different people (within MMR or staff within NES) can complete these procedures in exactly the same way.

It is recommended that a guidance "manual" is developing outlining field monitoring protocols, which should include the following:

- a narrative that gives background information on why a particular component or process of the ecosystem was selected for monitoring, together with an overview of the various components of the monitoring protocol, including the objectives, the sampling design, field methods, data analysis, data archiving and reporting, personnel requirements, training procedures and operational requirements;

- a set of Standard Operating Procedures (SOPs) that provide detailed, step-by-step instructions on how each step of the protocol is to be completed, including instructions for how any of the SOPs are to be amended (building on the MMR 2011 Water Quality Monitoring Manual).

- Supplementary materials that provide additional guidance and support, which can include items such as reports, photographs and data analysis examples.

Appendix F outlines some draft text that maybe considered for inclusion/update into a future IMP protocol "manual" by MMR to reflect their monitoring approaches currently being adopted in the field (*NB: recent staff*

field work in Aitutaki have not been assessed by AECOM as they have not be written down for review (fish/coral/invertebrate assessments).

Specific actions following this current AECOM contract are therefore as follows:

- list of existing monitoring protocols that MMR possess (or use) that could be used to support the new IMF (identified as part of compiling and analysing information on existing monitoring programs);
- develop list of selected indicators into specific details in conjunction with key partners/stakeholders;
- produce a Field Monitoring Protocols Manual (see Appendix F as a draft) that outlines an early draft for MMR to develop and build upon following results from the MTVKTV project into 2018) that includes the template options for all marine monitoring related field protocols.

8.3.6. Managing Data

This PF seeks to identify the purpose and scope of data management for discovery, storage and access to monitoring datasets, including identifying the preferred model for data management, existing infrastructure, processes and standards that could support supporting the proposed model, and what additional work is needed to address technical gaps.

8.3.6.1. General Description

Data management is an essential function of integrated monitoring because it provides the necessary infrastructure, processes and standards that enable storage, discovery and access to data generated by the selected monitoring programs and other relevant programs. Data management is fundamental to the reliable and timely flow of fit-for-purpose data from data collectors to data analysts, reporters and communicators. A properly designed and documented data management system must be a central feature of an integrated monitoring program, as the lifespan of the data set will span across the careers of many scientists, and will most likely be subject to numerous changes in information technology.

Currently MMR use an SPC created regional database entitled RFID. Updates to the current approach, to improve its value and usefulness for managing historic, present and future monitoring datasets, is addressed more fully in Part B Section 9.

8.3.7. Analysing Data

This PF shall clearly identify the purpose and scope of data analysis needed to support integrated monitoring at Muri Lagoon, together with options and preferences for undertaking and completing data analysis, examples of integrated data analysis, gaps and opportunities to address any gaps identified.

8.3.7.1. General Description

Data analysis for integrated monitoring has the important role of collating datasets from selected monitoring programs and completing analyses at regional and local scales to understand the effectiveness of lagoon management. Data analyses essentially transform ecological, social and economic monitoring data to knowledge and understanding about trends and the pressures at regional and local scales.

The IMP for MMR will require a useable data analysis mechanism(s) that meets the specific needs identified by the intended policies and actions requested (of MMR) within the NSDP 92016-202), the National Water Policy (2017) and the new Marae Moana Act (2017) (see Appendix E). More than likely this means collating a number of similar datasets (e.g. marine invertebrate cover data within Muri Lagoon) from selected monitoring programs and combining these data to complete analyses at a broader scale, subject to the survey design considerations agreed upon for local situations (e.g.: Muri Lagoon), Rarotonga specific surveys or wider Pa Enau marine habitat / fish data collection surveys. The analytical software and "tools" required need to be able to provide insight or improved knowledge that enables decision makers to better consider information on pressures, drivers and impacts to understand the effectiveness of management for enhancing and maintaining ecosystem values. For example, future monitoring programs collecting data on the die off of *E.Diadema* (sea urchin) which is being observed (Rongo *et al* 2016) may also be used to help generate knowledge and understanding at the broader island wide scale for Rarotonga and further afield (regional implications) for the Cook Islands. Multivariate analysis software (e.g.: PRIMER 6-see Part B Section 9) is a good tool to help with assessing a number of disparate ecological and meteorological/oceanographic datasets.

During this stage of IMP creation, it is important for MMR to identify the purpose and scope of the integrated data analysis that they wish to undertake and from this, the options and preference for undertaking and completing it. For example, it may be preferable to set up a specific mechanism with responsibility to undertake a periodic comprehensive integrated analysis (e.g. a specific working group that includes membership from CCD, NES if this was a coral reef survey analysis etc.). Alternatively, the whole process could be outsourced or broken down into discrete parts and completed within selected monitoring programs. Regardless of the approach, it is important that requirements, directions and standards for integrated data analysis are embedded in documented guidance (e.g. SOPs or part of the MMR monitoring protocol – see draft text in Appendix F) to ensure a consistent approach is maintained over time or that (if changes occur) they are clearly documented and communicated.

The specific requirements of this stage are quite straight forward, yet highly important and must be achieved. These are as follows:

- Collect all background information on existing data analysis arrangements for selected monitoring programs that exist in other departments/organisations apart from MMR (e.g.: NEC/MoA/ICI/CCD/OPM etc.).

- Engage the advice and participation from experts in data analysis through formal working groups (chaired by MMR) and ensure participation from organisations with responsibility for selected monitoring programs (in compliance with the Monitoring Protocol Manual – to be produced as a priority into 2018 that develops and formalises the draft "Protocol" text put forward by AECOM in Appendix F).

8.3.8. Reporting and Communicating

This PF shall clearly identify the purpose and scope of reporting and communication needed to support integrated monitoring at Muri Lagoon, sources of data and key audiences, options and preferences for reporting and communication, existing initiatives to support integrated monitoring, significant gaps and opportunities to address gaps.

8.3.8.1. General Description

Reporting and communication is an essential function of integrated monitoring because it focuses on providing key messages and the appropriate level of supporting information about monitoring results to the right people at the right time. Reporting and communicating often complex information to managers in clear and easily understood formats is fundamental if monitoring is to trigger a management response. A commitment to regular reporting is important to maintain the relevance of program objectives and data collection. Reporting and communication are a pragmatic means of integrating monitoring programs by delivering messages that are founded on the integration of monitoring data from numerous monitoring programs.

The types of monitoring reports and information products to be used may include data summary reports, trend analysis and synthesis reports, score cards, report cards, simple summary reports (annual) and in depth periodic reports (inter-annual) that synthesise long-term trends from larger data ranges.

An integrated Communications Plan (between MFEM/MoA/NES/CCD and MMR – see Part C Section 12)) is of utmost importance to help provide the necessary clarity, certainty and transparency for internal and external users. It should identify clear aims and target audiences, match reports and communication products to targeted audiences, identify any necessary standards (e.g. templates for communications or reports) and identify necessary roles and responsibilities.

8.3.8.2. State of the Coast Reporting

As shown in Figure 8.2 and mentioned in Section 8.1, the DPSIR framework has been widely used to provide a structure within which to present the indicators needed to enable feedback to policy makers on environmental quality and the resulting impact of the political choices made, or to be made in the future. It is based on describing the causal chain from driving forces to impacts and responses. In this way it is similar to the Diagnostic Analysis approach of conducting causal chain analysis of perceived problems and their societal root causes in order to identify most effective remedial actions.

The DPSIR framework is recommended to form the basis of the National State of the Coast report for Muri Lagoon.

8.3.9. Reviewing and Auditing

This PF shall clearly identify the purpose and scope of reviewing and auditing to support integrated monitoring in Muri Lagoon and propose a preferred model for reviewing and auditing performance in the future.

8.3.9.1. General Description

The proposed IMP is likely to represent a substantial investment from the Cook Islands Government and/or donors alike and therefore should be reviewed and audited periodically. Reviews provide the opportunity to formally consider how the integrated program is progressing against the program purpose and objectives and decision-making principles. Reviews also provide an opportunity to consider new opportunities such as increases in monitoring budget and advances in technology or new issues such as reduction in monitoring budget, significant change to ecosystem understanding for areas monitored or new monitoring priorities. Periodic reviews of the IMP will provide a formal mechanism for recommending changes and revisions to the program if necessary.

From a more specific technical perspective, reviews or audits that focus on specific monitoring functions, such as monitoring protocols data management, data analysis and reporting, may be needed. For example, periodic reviews of data management arrangements or data collection protocols may be required to take account of advances in technology whilst audits may be required to assess conformance with draft SOPs or monitoring protocols (see Appendix F).

8.4. Integrated Monitoring Programme Conclusions and Recommendations

8.4.1. Establish IMP Management Arrangements

Effective governance is a prerequisite for the IMP because it provides the necessary leadership, and accountability for commencing, developing and reviewing the IMP. To deliver the proposed IMP cannot be undertaken by one Department or organisation alone. It should be government led to help attract funding (not civil society led) and it is key that governance arrangements are established with immediate effect to build on the impetus being set out by the Cook Islands National Water Policy (2017) and the Marae Moana Act (2017) (see Appendix E).

Governance structures are already in place where the IMP approach can smoothly be taken forward with some slight additional mandates to ensure the IMP has wide benefits for all parties and ultimately, benefits the Govt

of Cook Islands and all Pa Enau. Existing governance or approval structures are being established within the Marae Moana Council to help to steer and progress of that legislation. Reporting and communication are key themes within that new piece of legislation and so AECOM see no reason to force the introduction of any new Steering Group/Council specifically for this IMP. Additional focus may be required on helping to specify leadership and direction in specific technical areas or specifying processes to increase collaborative reach (e.g. managers of selected monitoring programs) or experts in sampling design, data management, data analysis), reporting and communication or reviewing and auditing (see all Sections above). The governance arrangements for IMP delivery may then need to be added to existing terms of reference and participant lists and endorsed by the oversight and decision-making committee.

8.4.2. Sustained funding and resources for IMP

Viable options for long-term funding of critical monitoring programs will be needed to satisfy a number of key criteria. The following five general principles are put forward for MMR to consider (adapted from AEMWG 2012), to guide the establishment of a viable monitoring funding model (IMP) for the Cook Islands:

- Funding must be sufficient to support a science-based program commensurate with its mandate.
- Funding must be predictable, stable and sustainable.
- The funding model should strive to achieve economic efficiency.
- The funding model should be fair and equitable.
- The funding model should be administratively simple and cost-effective.

8.4.3. Prepare an Implementation Plan for the IMP

Whilst AECOM have attempted to define the “signposts” for the way forward, and attempted to deliver a “working draft” Integrated Monitoring Protocol text (see Appendix F), there is a need to await new monitoring information and modelling studies on Muri Lagoon (due from the MTVKTV project into 2018) to better formalise the specifics of any future IMP. AECOM are not in a position (due to missing data) to be prescriptive on this matter at this time.

AECOM therefore strongly recommend that once the above data is available, that a further set of analyses are carried out to better determine the exact causes of algal outbreaks at Muri Lagoon. Once this is clearly understood, an IMP implementation plan should be prepared by MMR (and partners – see Section 8.4.1 above) to help provide certainty about what integrated monitoring will achieve along with how and when this will be achieved. The draft integrated monitoring protocol text (Appendix F) should be used as a working document, and updated accordingly to help formulate a draft integrated monitoring plan which should be

submitted to the appropriate governance committee(s) for endorsement (for example the Marae Moana Council).

The actions, and timing for completion of actions, should be informed by the relative ranking of priority monitoring objectives and formal assessment of risks to, and opportunities for, successful commencement and development of an IMP. It is important to initiate the IMP with the highest priority monitoring objectives, recognising that this will inform further development of the complete IMP. Therefore, AECOM strongly recommend a "staged" approach to implementing the program as this would provide an effective means of managing any foreseen or unforeseen risks. Muri Lagoon is proposed as the "pilot" IMP as this should focus on a relatively small number of high priority monitoring objectives. This type of approach could be used effectively to demonstrate the benefits, functions and costs of a more national IMP. It would also provide a useful mechanism to test governance and integrated monitoring functions and a firm basis to develop a business case for expanding the IMP to Pa Eau (to also embrace objectives set out in Appendix G: Laboratory Strategic Plan).

8.4.4. Improve Monitoring Capacity within MMR

Another critical step for MMR must be to ensure that they are well equipped to monitor the parameters agreed upon and the bio-indicators being set, so they can serve their dual purpose as management tool (to help with national reporting on Marae Moana Act (2017) for example) and health report cards. Three priority challenges must be urgently addressed by MMR.

8.4.4.1. Filling gaps in available indicators

Developing new indicators will in some cases require major investments in MMR budget capacity to collect and analyse data. In many cases, sound indicators exist, but data is not systematically collected on a routine, harmonized, and comparable basis.

8.4.4.2. Moving towards annual monitoring

To align with national planning and budgetary processes, SDG monitoring needs to operate on an annual cycle. Ensuring annual and up-to-date data will be a major step towards achieving this. Annual monitoring on MMR progress does not necessarily mean that new data need to be produced every year. For a number of indicators this may be impossible or inadvisable. In such cases producing data every two to three years and doing robust projections, extrapolations or modelled estimates may be sufficient. But even this level of frequency will require a step change in the way data is collected and disseminated. MMR are therefore encouraged to make more creative use of modern technologies to achieve this ("collect once, use many times" strategy etc.).

8.4.4.3. Adopting innovative approaches to data collection

Monitoring marine resources requires many different types of data. Of particular importance is georeferenced data that can now be collected easily using mobile phones to provide location-specific information on government facilities, water pollution source points, and broader marine environmental challenges. The current challenge that is seeking to be addressed is the establishment of a central repository for environmental digital data for the Cook Islands. MMRs Geographical Information System is being developing in parallel with other agencies, though an integrated data strategy is still required to ensure quality assurance is brought to data collection, management and knowledge management processes for the future (see Part B Section 9).

9. PROPOSED DATABASE AND INFORMATION MANAGEMENT SYSTEM

This Section addresses the following project objectives (already defined in Part A Section 1.2)
Review and update (as required) a consolidated database that can be shared among agencies and templates for public information *(see Part B – Section 9)*.

9.1. Existing Database Challenges

9.1.1. Reef Fisheries Integrated Database (RFID)

RFID is a software package that has been developed for data entry and querying of survey data for socio-economic, fish and invertebrate surveys following SPC methodologies. The current version being used by MMR is RFID 1.6.1 and can be downloaded from the SPC website.

The overall purpose of RFID is to help SPC countries to store and monitor invertebrate & climate change related surveys. However, this database has current limitations in terms of being able to support the intended outcomes of the MMR Strategic Action Plan (2017-2021). AECOM have not been granted direct access to the whole database, nor the details of the internal files structures and contents of the MMRs IT system (for understandable reasons). Nevertheless, the approach in terms of implementing RFID within current MMR practices appears “forced” and a little outdated. It actually prevents MMR from being able to adapt its work plans, current field monitoring approaches (for invertebrates, fish and coral surveys) and documentation systems (which need to ultimately link to improved State of the Coast Reporting systems (see Part C Section 10 and 11).

Not being user friendly in its design, inflexible and non-intuitive in terms of usability, its practical application is diluted quite considerably. Most importantly, it is not possible to “future proof” the database by being able synchronize it with new field data collection techniques through the more modern use of mobile tablet technologies. MMR management and experts are willing to replace this database with a modern solution, and according to MMR, there is no continued request (by SPC) to use the database for a nations mandatory use should they choose not to. AECOM propose that a feasibility study should be undertaken to propose the required structure for a new integrated Geo-database which can serve as a platform for multiple data collection, analysis and dissemination/communication purposes in the future. Such as system can include, analyse and present laboratory data collection results, fisheries, invertebrate and coastal habitat surveys (including seaweed outbreak extent etc.). This point is elaborated in Section 9.2.

AECOM reviewed some sample analysis results that are registered to a RFID database developed by SPC (http://www.spc.int/). Although this database does have value, and in some instances can prove quite useful for policy / decision makers, its use for practitioners (e.g.: MMR) is questioned. Should RFID use be continued by MMR, the initial analysis undertaken by AECOM suggests that the RFID would benefit from the following recommended improvements;

1 It would be useful if the software used provided descriptive statistics (average, max, min, frequency, standard deviation and confidence interval) along with the capability to easily produce graphs and tables etc.

2 It would be very useful if the software could automate the production of semi-automatic reports.

3 It would be useful to add an option to add monitoring location photography;

4 Currently the software does not provide the opportunity to undertake queries between different databases. Adding this facility would improve the data presentation/analysis capacity of the MMR.

5 It would be very useful if the results can be showed on a map – based platform or GIS system.

The water quality analytical findings have not been able to take into consideration statistics relating to the following parameters.

- Changes in climate (rainfall, temperature, wave conditions, wind direction, etc.
- Changes in population and occupation/land-use.
- Review the tourism numbers (monthly occupancy and locations within the catchment).
- Software often possesses an “export to excel” option which is very valuable to wider dissemination of findings, however, there is not the current ability to import excel files (see Figure 9.1)

9.2. Data Management Recommendations

9.2.1. Web Based GIS

It is essential to develop a one single geo- database which is available for all potential users through a web platform. Benefits of such system are as follows;

1. All collected data or Laboratory test results can be uploaded onto a Web-based GIS system relatively easily from any field or office based situation. By this way, all relevant stakeholders can monitor the results on a map based system anytime. It also makes uploading new monitored data very fast and within “real time”. IT infrastructure is likely to require improvements in order to set up a web based monitoring and

information dissemination system. Such as data and internet server capacities, internet access and overall data storage and security.

2. Photos, satellite images, Google Earth images and drone images can be easily uploaded to the system. By this way, all stakeholders can overlay the analysis results on satellite images / maps easily.

3. Users can make interrogative queries and from this, develop unique and "fit for purpose" maps based on the question being raised. The approach does not need any GIS software as open sources are free and always available. That means that users can easily reach the web based system through any internet browser and from this, undertake their own bespoke analysis and produce maps. MMR currently have licenses for ESRI products (ARCGIS and ARCMAP) and so it is recommended that MMR should continue with ESRI Geo-Database systems.
4. Geodatabases have a comprehensive information model for representing and managing geographic information. MMR should consider budgeting (as referred to within the MMR Business Plan (2017)) to purchase ARCGIS Enterprise. This is of value as it has unlimited database capacity size and can include licenses for a number of users at any one time. ARCGIS Enterprise, once configured, would enable MMR to disseminate map based water quality, biodiversity (including fishery and other data – see Figure 9.1) and public health data through its existing web page (www.mmr.gov.ck).

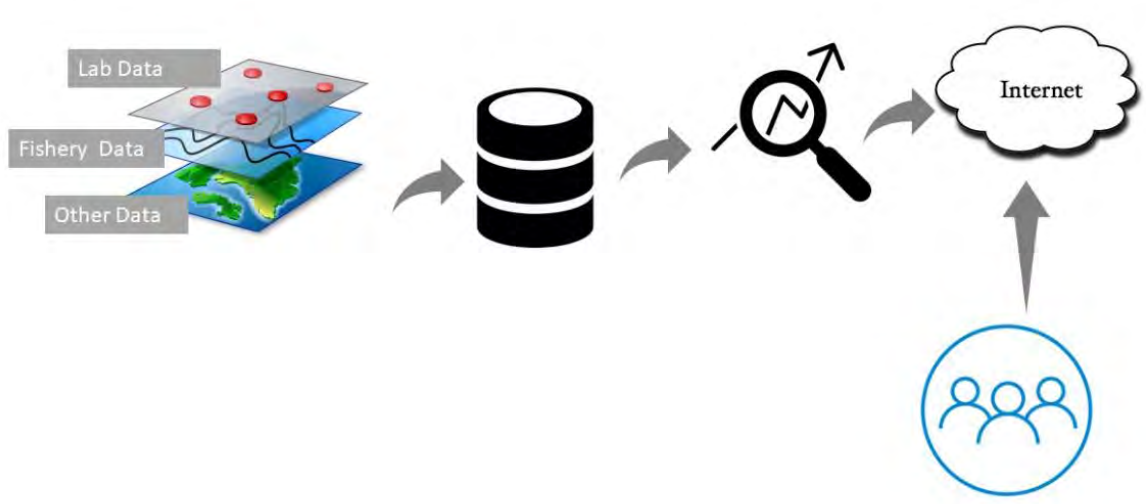


Figure 9.1: Proposed future MMR geo-database structure

5. Such a system can be developed in 3-4 months and will be cheaper than buying "off the shelf" GIS software or finding budget to train staff on GIS (ESRI related) courses on ARC GIS Enterprise using ARCGIS Collector software or similar. In addition to this, all stakeholders or users can use it very easily without depending on any software.

6. Software often possesses an "export to excel" option which is very valuable to wider dissemination of findings, however, there is not the current ability to export excel files. (see Figure 9.2)

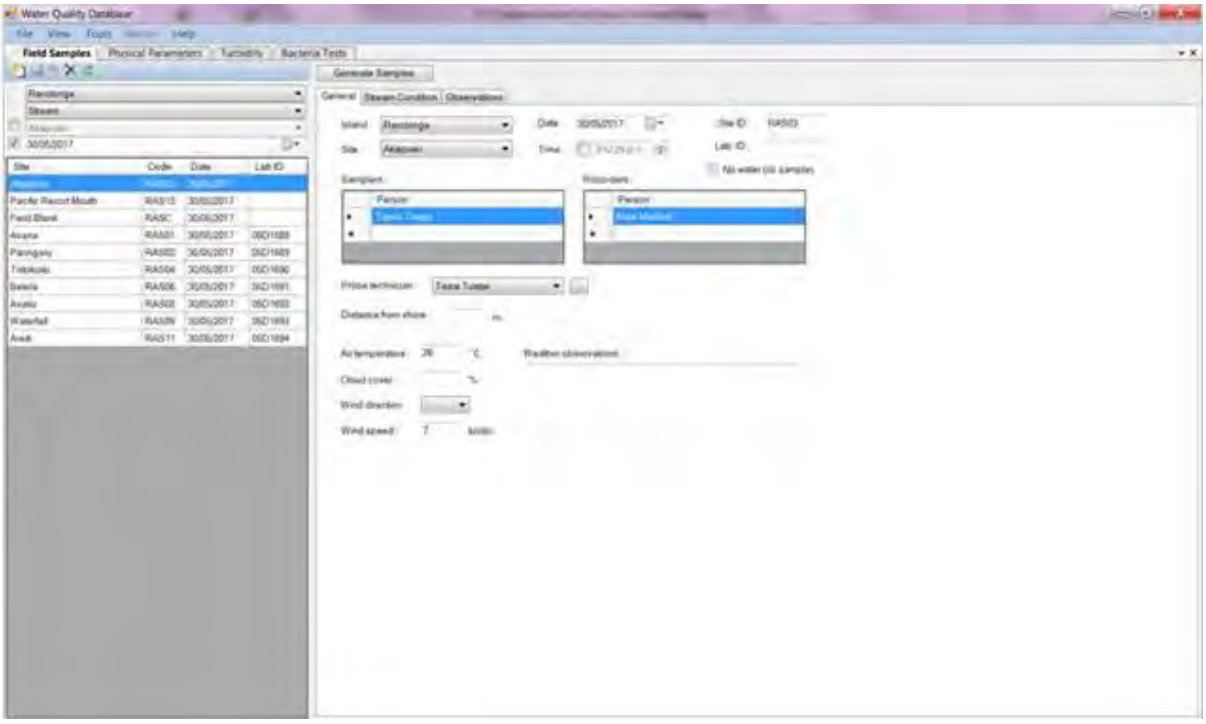


Figure 9.2: Screen shot of the current RFID database used by MMR

7. MMR may prefer to develop its own Geo-Database and tablet data collection system. Such a system can be developed in 4-6 months by an experienced programmer and will be cheaper than buying "off the shelf" GIS software or finding budget to train staff on GIS (ESRI related) courses on ARC GIS Enterprise using ARCGIS Collector software or similar. In addition to this, MMR can modify the software according to its needs.

8. It is recommended to improve data analysis capacity within MMR. For that purpose, MMR may consider to purchase / download statistical software to conduct statistical analysis (descriptive, multivariate and etc.). There are number of different statistical software like STATA, SPSS or PRIMER. Any of these software can meet the needs of MMR. Furthermore, EXCEL can be a good source for statistical analysis as well. Below are the possible type of statistical analysis needed to be carried out in MMR;

   - **Descriptive Statistics** : Mean, Meadian, standard deviation, Frequency, histogram and box plot analysis. Descriptive analysis are used to understand the data better. Furthermore , user can observe the data anomalies and its causes.

   - **Univariate and Multivariate Analysis** : MMR analysts may mainly need to correlation, regression, variance analysis and principial component analyses. Furthermore, they may need to conduct algae density analysis by using both GIS and statistical grid data analysis techniques. For Spatial data analysis, ARCGIS software spatial data analysis module can be very useful. This module can be helpful to analyze the drone collected data (at it is geo-referenced).

MMR should be encouraged to use these analyses to explain the changes in the dependent variable such as Nitrate, Phosphate and bacteria . The AECOM team support this as they separately conducted correlation and regression analysis to find the relationship between the dependent and independent variables and independent (i.e.: salinity , rainfall and temperature). It is strongly suggested that the MMR team continues to pursue and undertaken such analysis (through suitable training on its proper use is requred at the outset).

Microsoft Excel spreadsheet, Pivot Table, and Pivot Charts should be used for basic computations. PRIMER 7 and PERMANEVA software single licences were purchased through the MTVKTV project to be used to assist with graphical and comparative analysis. STATISTICA 12 purchase is also a recommended software package to help formalise the presentation of field results into a formal format.

PART C: IMPROVING OUTREACH AND COMMUNICATION

10. UPDATING MMR REPORTING TEMPLATES

This Section addresses the following project objectives (already defined in Part A Section 1.2)
Design communication and information materials related to the protection of the Muri Lagoon *(see Part C – Sections 10 and 11).*

10.1. Overview

The following outlines the reporting templates recommended by AECOM for uptake and implementation by MMR with immediate effect. It is recommended that the monitoring templates, coupled with the following reporting templates, are amalgamated into a specific MMR Monitoring and Reporting Manual. A framework structure and draft content for such a Manual is set out in Appendix F.

10.2. Updating the Scoring System

Existing reporting "cards" are included in Appendix A of NSDP (2016-2020). This is presented in Figure 10.2 below and strategically remains valid as a simple scoring approach (Figure 10.2) using 3 colours:

Description	Status
Statistically significant improvement; or consecutive years of non-significant improvements	On track
Statistically significant change	Of concern
Statistically significant deterioration	Off track

Sources of data: Marine Monitoring Reports (MMR, NES, CCCI - OPM).

Figure 10.2: Score system adopted within NSDP (2016-2020)

MMR currently produces health cards to monitor the water quality only. For that purpose, MMR defined 6 categories; A: Excellent; B: Very Good; C: Good; D: Poor; E: Very Poor; F: Extremely Poor. It is recommended that the above (existing) 6 categories are reduced to 5 categories which are used more often in statistical analysis (such as the Likert Scale). Within the Likert scale, the median point is deemed as the "standard value" and hence represents the most representative conclusion (at the time) of lagoon health. AECOM therefore recommend that the following categories are adopted within the new Health Card (see Section 10.3 below);

A: Very Good

B: Good

C: Moderate

D: Poor

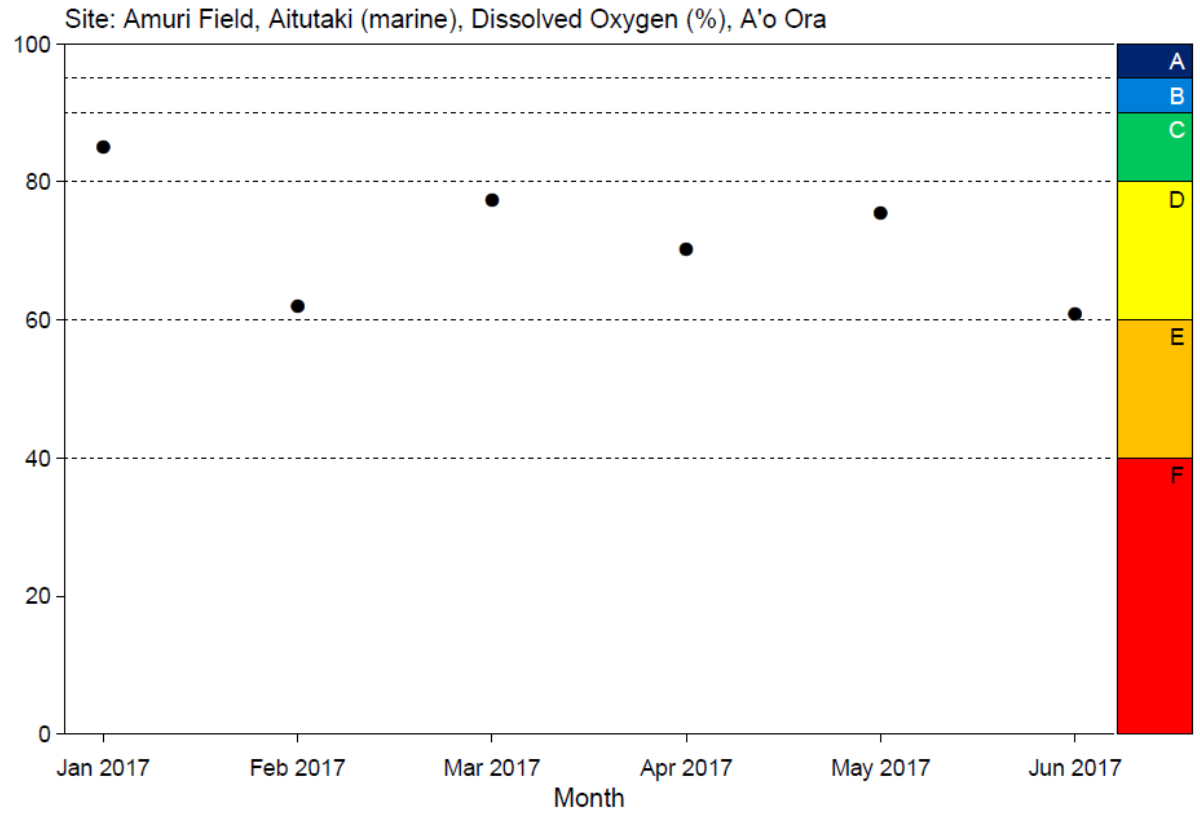
E: Very Poor

A similar 5 tier scoring system is adopted by the Great Barrier Reef Authority (Queensland Government) with their Reef health cards (see Figure 10.3 below)

Grade	Status	Criteria	Colour
E	Very poor	0–20%	Red
D	Poor	21–40%	Orange
C	Moderate	41–60%	Yellow
B	Good	61–80%	Light green
A	Very good	81–100%	Dark green

Figure 10.3: Scoring system adopted by Reefplan for inshore water quality scoring system (Queensland Government)

It is also suggested that MMR should adopt the *"likert-scale"* to help calculate the overall monthly or annual health score for the Lagoon. By this way it would be possible the score different "zones" within Muri Lagoon (namely the terrestrial, zone, the inner lagoon, the outer lagoon and the ocean (reef)) on a monthly / yearly basis to help compare and identify improvements within the overall lagoon system. Figure 10.4 presents some examples carried for annual test sites in Aitutaki for DO and enterococci.



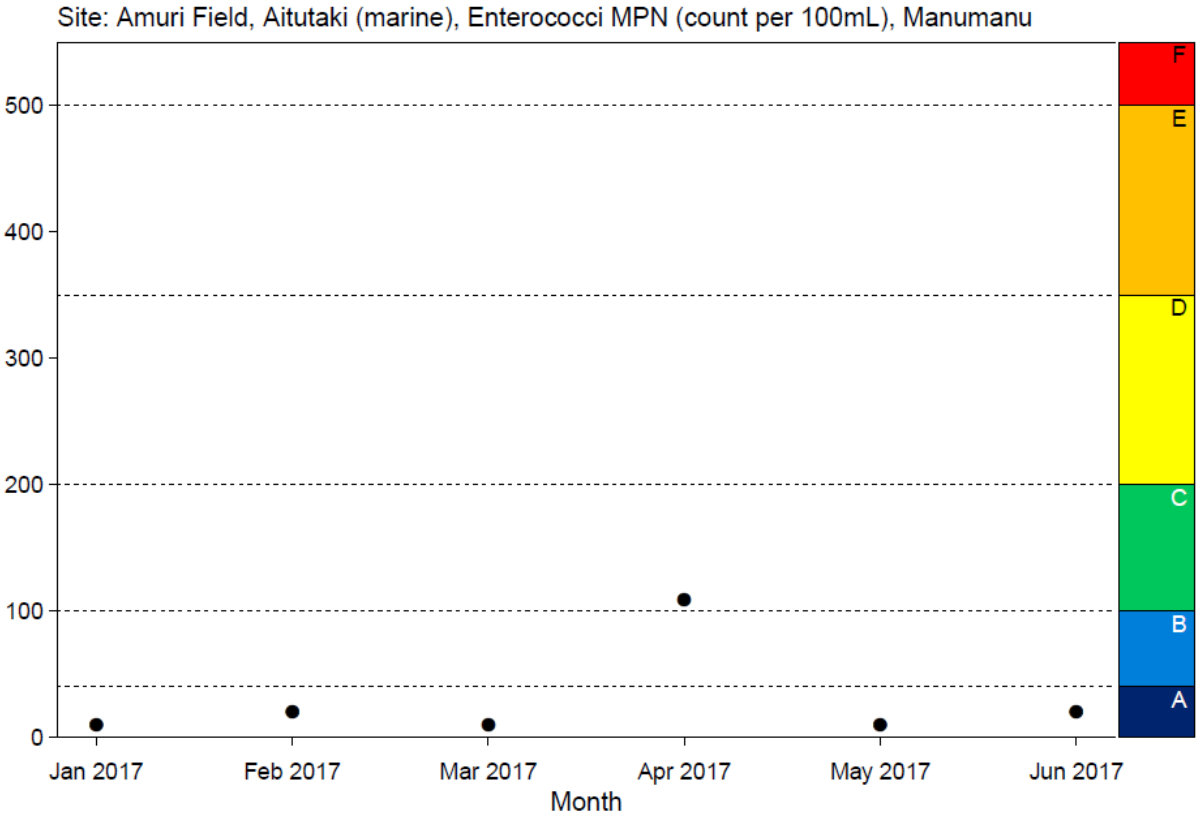


Figure 10.2: Example of visualising progress/deterioration of water quality parameters against WHO standards (for sites at Aitutaki)

10.3. Lagoon Health Report Cards

10.3.1. Overview

Lagoon Health Report Cards are designed by MMR (since 2008) to provide a summary of the health of a specific island, part of an island (Ra'ui or marine reserve) or specific lagoon area (e.g.: Muri Lagoon). A range of Score Cards "styles" are now proposed, however, as stated in Part B section 8 (IMP) there is a need for more detailed engagement and consultation with local communities, separate Departments/Ministries and civil society (NGOs) in the Cook Islands to agree upon the indicators to be selected. AECOM propose the following consistent approach that should be embraced by MMR in the first instance (2018 onwards) which reflects the DPSIR approach towards setting a workable IMP. It is also designed to provide the required information for State of the Coast reporting and SDG indicator assessment work for the NSDP (2016-2020).

10.3.2. Reporting on Lagoon Ecosystem Health

The health of an ecosystem can be assessed by a concept called "ecological integrity". Ecological integrity investigates how native, pristine, diverse and resilient an ecosystem is and if all of its components are present and functioning. It is one measure of how well a lagoon is functioning. Commonly used indicators include water quality, the diversity of marine invertebrate species present and the number of introduced species found and the presence and health of sensitive species (in a healthy condition) are all proposed to be used as indicators of ecological integrity in Cook Island waters (including Muri Lagoon).

Health Cards can (in theory) range in number and focus on specific aspects, though they should be produced and designed to enable a reader (via print or online media) to quickly understand the status of a Ra'ui, or specific lagoon (or oceanic area), and to understand important species that maybe found there plus the pressures that are being upon them.

A scoring system is often adopted. This should describe the status (the condition of an indicator) and trend (change in status through time) of each indicator. Status and trend can be stated for as far back as five years if trusted data is available, during which time any observed change should be captured if regular monitoring is in place. International best practice (Great Barrier Reef – "Reef 2050") recommends that health status is usually listed within 5 categories) as A: Very Good; B: Good; C: Moderate; D: Poor; E: Very Poor; undetermined *(the latter is provided if not enough data has been recorded; the data is too variable or natural levels of an indicator against which to compare current levels, are uncertain)*.

One possibility is to propose a series of report cards "sections" (as part of the overall Muri Lagoon Health Card). These sections (designed specifically for Muri Lagoon though replicable for other areas of Rarotonga and Pa Enau) focus on the following "Themes":

a) Theme 1: Water Quality;

b) Theme 2: Public Health

c) Theme 3: Biodiversity;

The above shall collectively help to convey the "ecological integrity" of Muri Lagoon across the 4 proposed "zones", presenting it in a public-facing form which summarises the various monitoring findings undertaken by MMR (monthly or annually) into an easy read pamphlet. This information can then be easily provided online onto the MMR website. Two possible formats are proposed as set out in Figure 10.3 (a and b).

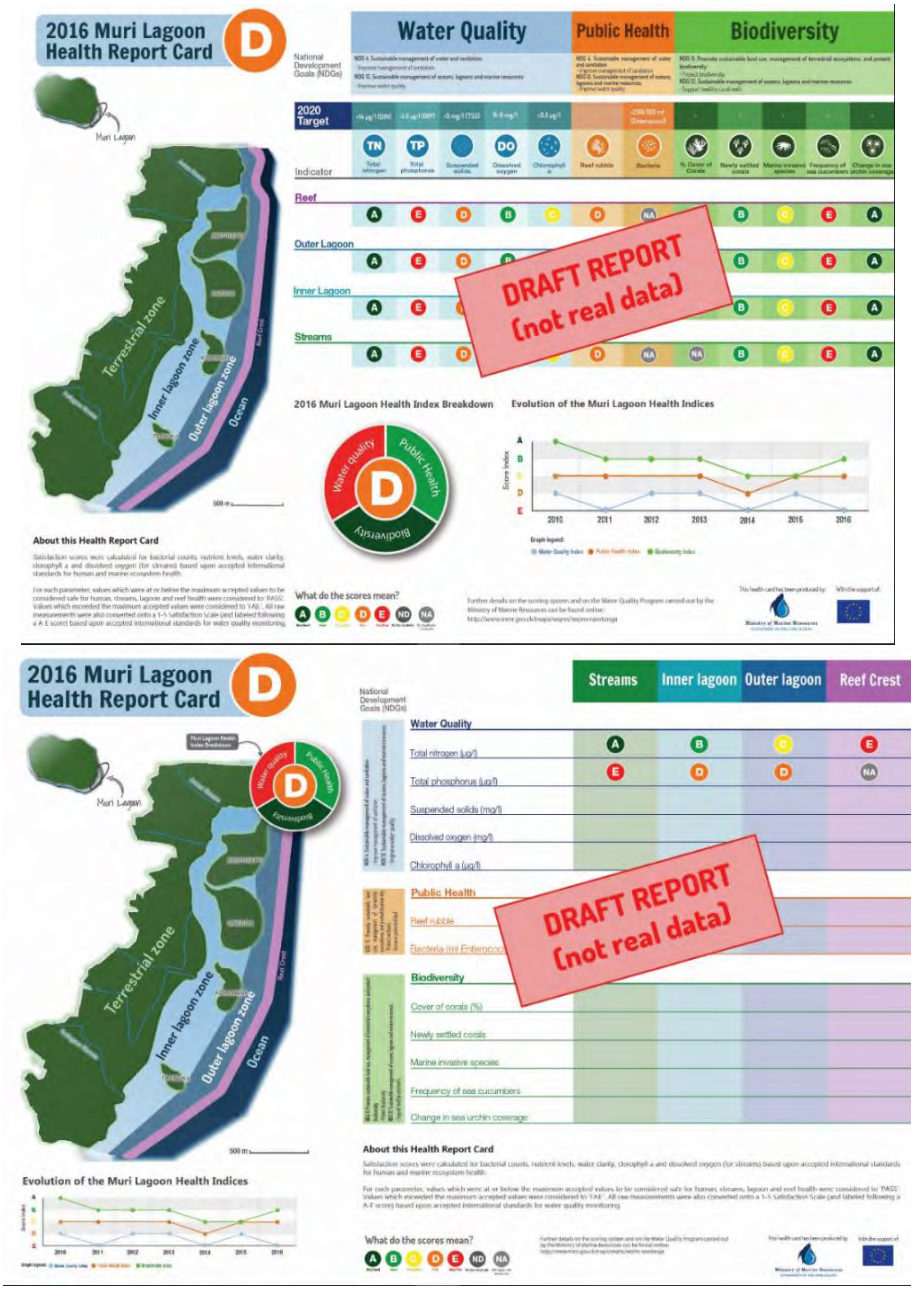


Figure 10.3: Two styles for the proposed updated Health Card for Muri Lagoon

The possible listing is elaborated in Table 10.1.

Report Score Card "sections" as part of the Muri Lagoon Health Card	Table 10.1 AECOM Recommended "Indicators" for Monitoring and subsequent Scoring	
	Draft Indicators to be included in the Health Card	**Draft Indicators to be measured *(but perhaps inappropriate to be included in the Health Card)***
THEME 1 Water Quality	• Total Nitrogen; • Total Phosphorus; • Suspended sediments (future parameter); • Dissolved Oxygen; • Chlorophyll "a";	• Salinity; • pH; • Temperature;
THEME 2 Public Health	• G.toxicus (ciguatera) • Bacteria (enterococci);	• E.coli (future parameter) • Seaweed coverage observations (using AUV/drone to calculate against sand coverage); • Reef rubble extent (to assess for dinoflagellate frequency);
THEME 3 Biodiversity	• Percentage cover of corals (both live and dead), algae and non-living material; • Presence of newly settled corals and juveniles; • Frequency of Crown-of-Thorn Starfish (CoTS) or other marine invasive species; • Frequency of sea cucumbers etc. (*Holuthuria atra* black sea cucumber etc.); • Change in sea urchin coverage (*Echinothrix diadema) Droplet tunicate (Eudistoma elongatum);*	• Species or genus composition and size structure of coral communities; • Numbers, species composition, size (biomass) and structure of fish populations; • Extent and nature of coral bleaching; and or extent and type of coral disease; • Macro-algal (seaweed) coverage (m2) (Caleurpa spp / Boodlea spp);

10.3.3. Theme 1: Water Quality Score

Water quality scores have been designed by MMR since 2009 and they represent a good indicator of lagoonal ecosystem health. Water quality is affected by contamination from many sources including wastewater outfalls, discharge from vessels, sediment and nutrient run-off from land. Eutrophication (water enriched with nutrients, usually from nitrogen and phosphorus run-off) stimulates plant growth and disrupts the balance of the ecosystem. These conditions can cause seaweed growth as already observed within Muri Lagoon (see Appendix A). Regular water quality measurements (including salinity, pH, turbidity, suspended sediment, nitrate and enterococci bacteria) already being collected by MMR and researchers are providing data for this indicator.

10.3.4. Theme 2: Public Health Outbreak Report Cards

The occurrence of ciguatera disease outbreaks in lagoonal areas is sensitive to be reported within public focused report cards. The decision on how this information is presented to the public still requires a sensitive approach. Closer working relationships must however continue to be forged between MMR and MoH on this issue and the proposed recommended a separate reporting system improvements for ciguatera and respiratory illnesses (that may be caused by water quality issues) still require a continued partnership approach to ensure that a simple yet improved surveillance system is set up. Specific information on this is presented in Part A Section 5.

One possible addition to the score card is to help convey the health of both the outer and inner lagoon systems. This is important with regards to better understanding the increase extent of “open sand” or “coral rubble” areas that may have occurred after cyclone or repetitive storm events. These new barren areas are often populated opportunistically by specific dinoflagellate species and consequently ingested by reef fish (e.g.; parrot fish etc.). This new physical “indicator” (reported via the new Heath Score Card) could be used especially for Event Surveillance Response Officers (ESRO’s) which may prove valuable as a monitoring and reporting system approach. It is recommended that Cook Islands Tourism Board are made aware of this approach, though (as stated above) the communication of any numerical findings and early warning system should be kept internal only (i.e.: to Event Surveillance and Response Officers within the MoH). It is not recommended to embark on a ciguatera awareness programme as this would not convey the correct and required messages at this time. In discussion with MMR, the alternative to the physical indicator proposed (coral rubble) is to monitor the prevalence of *G.toxicus* dinoflagellate species. Should this indicator be preferred by MMR, it is vital that MMR have the capability to monitor and test for this on a regular monthly basis (and increased frequency of sampling during high risk times (up to 3 months after a cyclone).

Part A Section 5 has already uncovered AECOMs concerns over the bacterial analysis that has been recorded and the subsequent need for re-testing in order to be certain about the bacterial results being found to date (Enterococci in particular). Card reporting for this indicator should only be included once a separate laboratory validation exercise has been undertaken through an ISO accredited laboratory (possibly in New Zealand).

Finally, recording seaweed growth observations (recorded and "scored") on these cards is possible, though care should be taken towards even using this as an indicator or health, as it is clear from water quality results that despite seaweed outbreaks, there is no impact on the health of the water from a human recreational perspective. Impacts of the seaweed outbreaks on increasing toxicity levels in fish, shellfish and other marine organisms have not been measured by MMR and so subject to that being analysed, it is recommended that no seaweed extent indicator is adopted in the immediate term (no current evidence that this is detrimental to human health).

10.3.5. Theme 3: Biodiversity (Ecosystem Health) Score

It is acknowledged that whilst it is relatively simple to assign water quality rating scores based on MMR monitored data, deciding on a score for lagoon health, based on bio-indicators, is more complex. Nevertheless, it is proposed that to complement the existing Water Quality Health Card, that a separate supporting "Biodiversity (Ecosystem Health) Score Card" is produced.

Selecting ecologically relevant biomarkers/bio-indicators (defined as processes/organisms - see Table 10.1) that provide information on the marine environmental quality through identifiable reactions (biochemical, physiological and morphological) is a useful separate exercise for MMR to embrace. The approach for bio-monitoring programs of the lagoon environment for the Cook Islands is beneficial to MMR, not only for helping to monitor Muri Lagoon in a more integrated manner (see Part B Section 8), but also remains a critical aspect of the MMR "State of the Coast" reporting system (see above) and also for annual Marae Moana Act reporting responsibilities.

Using the best information available, AECOM have sought a consensus view from our experts, but will develop criteria and limits as more field ecological monitoring data is collected. Questions that the score card must seek to answer include *"How diverse is the habitat" and "how is it changing?"* To answer these points, new field data is required on regular habitat monitoring to help provide data for this indicator. Existing lagoonal habitat variance and knowledge on its health is presented in Part A Section 3.

One important bio-indicator to include in future regular monitoring links to invertebrates. As these are key components of all marine ecosystems and their health and survival are seriously threaten by marine pollution, it appears relevant that for Muri Lagoon (and other areas around Rarotonga) that a combination of appropriate invertebrate focused "biomarkers" are selected. Specific details on what "indicator" to be selected

does require more field survey investigation to help identify the best biomarker and bio-indicator that may be used for Muri Lagoon (though research presented in Part A Section 3 identifies clear species to focus on). These can be used to act as appropriate prognostic tools to act as an "early warning system" on heightened marine pollution levels. *Holuthuria atra* (black sea cucumber) is proposed as one important bio-indicator though represents one of a number that could be selected by MMR.

Secondly, a specific health score for reefs is relevant in the Cook Islands and something that has not been formally set up. Coral cover is important to assess and a measure of the abundance of hard and soft corals, and indicates the capacity of coral to persist under the current environmental conditions. Coral cover also represents the availability of brood-stock required for the ongoing supply of future coral generations. Coral change is a measure of the observed change in hard coral cover compared to modelled predictions. A healthy and resilient coral reef is expected to show an increase in coral cover during periods free from disturbances and this indicator directly assesses the rate of coral cover increase over the rolling four years of monitoring. Juvenile density cover is another important measure of the abundance of hard-coral juvenile colonies (up to five centimetres in diameter), standardised to the space available for coral settlement. This helps to indicate the ongoing replacement of corals necessary to recover from disturbances or stress.

Coral community composition is another important measure of changes in the relative abundance of coral species from a baseline. If the composition of communities moves beyond the standard error of their baseline condition toward a community indicative of higher concentrations of nutrients and turbidity, a score of zero is returned. Conversely, a score of one is given if the change is toward a community indicative of improved water quality conditions (Thompson *et al*., 2017).

Thirdly, macroalgal coverage (seaweed) is an important bio-indicator to measure. A low score for macroalgae (i.e. poor or very poor) means macroalgal cover is high, which is indicative of poor water quality. Conversely, a high score for macroalgae (i.e. good or very good) means cover is low. High macroalgal cover, once established, reduces the recovery of corals by denying them space or by producing chemical deterrents that limit the recruitment and growth of coral. It is proposed that in the short term, an aerial assessment of coverage is calculated using UAV (drone) technologies to calculate spatial coverage of seaweed compared to bare sand coverage.

Finally, Section 8.3.4 has identified that NSDP (2016-2020) includes a clear indicator relating to marine invasive species in the Cook Islands and needs to be monitored. Marine pests are species that are not native to the Cook Islands, and can have a negative effect on the marine environment. These species are usually accidentally introduced from overseas by human activities, such as shipping. It is recommended that, into 2018, that a monitoring programme is established to identified marine pests that have established in the Cook Islands. The key question that a future Marine Invasive Species Score Card should seek to answer includes *"What is the impact of marine pests on the lagoon ecosystem and how is it changing?*" It is recommended that close

consultation is undertaken with NGO “Te Ipukarea Society Inc” who undertake research and monitoring into invasive species in the Cook Islands.

10.3.6. Future Health Card Additions: Land/Sea Use Change

The use of surrounding land (Muri Catchment) and also change in sea use can impact on the lagoon environment through pollution and sedimentation via rivers and streams or contamination via ship pollution or dredging activity. This information has been presented clearly in Part A Section 4. The design of a “Land/Sea Use Change Parameter Scoring section” should capture information that helps to answer questions such as *“How much is human activity on surrounding land affecting the health of the ecosystem and how is it changing”*? Information required for this includes up to date Land use maps and other data (remote sensed or aerial survey studies) as available, will prove useful.

10.4. Warrant of Fitness Cards

A Warrant of Fitness (WoF) is a term used in New Zealand. The piece of legislation that regulates the need to have a WoF is the "Public Health (Sewage and Wastewater Treatment and Disposal) Regulations 2014". The section that regulates this is "Part 4 - Operation and maintenance of sewage system". WATSAN's WoF Scheme requires commercial property owners and operators to confirm that their sanitation systems comply with the new regulations.

An accurate WoF, however, cannot be completed due to the missing monitoring data from the MTCKTV project (awaiting finalisation during 2018). New information is required in order to complete a WoF that maybe accepted by all parties which cannot be achieved within the timescales of this consultancy. Regardless of the above, based on observations it would be useful, if all relevant projects and organizations should use the recommended updated and revised “Health score cards”. It is recommended that these new “cards” are applied for an agreed period of time from 2018 onwards, through to the end date of the NSDP in 2020 as a minimum. This is of paramount importance to ensure consistency of message and so that appropriate strategies can be budgeted for in order to address water quality related issues with any degree of confidence.

11. PUBLIC EDUCATION INFORMATION AND MATERIAL

11.1. Communication and Awareness Observations

11.1.1. News and perception on Muri Lagoon's health status

Based on the study and AECOM's own research (including that of Castel 2016), the information on Muri Lagoon's health status is generally originated in two main ways:

Media Outlets: the AECOM team has been monitoring the publication of news related to Muri Lagoon and seaweed outbreaks since the start of the project until its completion (from March 2017 until December 2017, a total of 10 months). Within this period of time, a total of 47 news articles (three of the duplicated) have been published on Muri Lagoon both in the Cook Islands and abroad. These commonly focus on topics such as seaweed outbreaks; water quality; sewage systems; the Ministry of Marine Resources; and the environmental pressure of tourism in Cook Islands in 8 media outlets (mostly published by Cook Islands News and Radio New Zealand). Some of the news published on Muri Lagoon's seaweed outbreaks had the following headlines:

Figure 11.1. ***Example of inappropriate news headline usage.***

> *"Can Muri Lagoon be saved?" (Cook Islands News, 9 November 2015);*
>
> *"'The golden egg is cracked' - Rarotonga tourism industry threatened by lagoon sewage-seep" (TVNZ, 30 December 2015);*
>
> *"Call to save Cook Islands' Muri Lagoon from algal bloom" (RNZ, 29 March 2017);*
>
> *"Call for drastic action to save sick Cook Islands lagoon" (RNZ, 30 March 2017);*
>
> *"Efforts under way to save Cook Islands jewel" (RNZ, 1 April 2017).*

It is clear and apparent that the use of dramatic and alarmistic wording and tone by some news outlets, using terms (for example) such as “save Muri Lagoon”, “drastic action” or “sick Cook Islands lagoon” and “national disaster” can have a harmful effect on public’s opinion. This is something that should be regularly monitored and addressed by the local authorities in Rarotonga and the Cook Islands Government, so corresponding actions could be initiated which may include the delivery of press releases informing about the official health status of Muri Lagoon (the timely provision of water Quality data and the actions taken for its preservation and improvement plus the organisation of press conferences (specially inviting RNZ, which appears to be the media outlet using the most dramatic tone); the request of press interviews to public authorities, the release (or reminder of existence) of official documents or reports with facts and figures on Muri Lagoon environmental status, etc.

An average of 5 news articles have been published on a monthly basis (between March to December 2017) on aspects directly or indirectly related to Muri Lagoon’s ecosystem status and public health-related issues. Since people generally equate levels of media coverage of a given issue with its importance, high levels of Muri Lagoon’s issues coverage (and the way these are presented) have consequences in the local society and abroad, affecting public’s opinion and perception. Although not all news published can have a negative or alarmistic tone (there is also a good coverage on the work that is being done to reverse the issues in Muri Lagoon), the number of news articles focusing on ‘issues’ far outnumbers those proposing any ‘solutions’ or ‘work being done’ to counter rest these issues. These inevitably deteriorate public perception, thus affecting the image and reputation of Muri Lagoon as a tourist destination. Additionally, events like ciguatera poisoning cases, seaweed outbreaks, ecological deterioration of Muri Lagoon are not always reported from the ground, and don’t have sufficient length and depth to provide a complete and comprehensive understanding of both the issue and its background, including the work that is being done around it by all involved stakeholders.

Actual experience: around 20% of the tourists visiting the Cook Islands are repeating visitors, some of which have actually experienced in first person how the ecological conditions of Muri Lagoon (or other regions in the Cook Islands) have deteriorated over time. Some of the comments left by visitors on the Cook Islands International Visitor Survey and travel sites like Trip Advisors can be seen in Section 11.1.2.

Negative comments likes the ones presented in Section 11.1.2 can affect public’s perception on the lagoon’s health status and can easily be connected with public health concerns, leading to the apparition of partly-true, or even false information, and ‘biased beliefs’ (like the association of presence of sea cucumbers with a negative experience, when they actually help clean the detritus present in the lagoon, improving water quality). An example of these ‘biased believes’ from tourists was identified in the aforementioned study carried out by Castel (2016). The source of this belief may come from the way the news is presented by certain media outlets (“sick Cook Islands lagoon”) and Muri Lagoon’s actual water quality status. As a consequence of not providing exhaustive fact-based information and/or possibly lack of consultation of (or lack of information from) official sources, some tourists believe that Muri Lagoon’s water is contaminated in such a way that it becomes toxic and poisoning to humans, something that is not even close to be true. This is a clear example of

how undesired associations are working on some of the tourist minds (presence of algae = bad water quality/pollution = water can be harmful or poisoning to human health), which is partly based on the truth, but it may be distorted by either the way some media outlets present the information or by the lack of rigorous fact-based data and information by the visitor.

The above observations often result in a deteriorated perception of Muri Lagoon's health status. A direct consequence of this is the cancellation of visit bookings, a decline of tourist reservations and a more deteriorated perception of the Muri Lagoon, Rarotonga and the Cook Islands in general. If, besides the regular communication actions undertaken to communicate the actual status of Muri Lagoon's health, no additional efforts are put to counter rest the increasing number (and tone) of news published on the deterioration of Muri Lagoon, the public perception will deteriorate even further if the conditions of the lagoon improve.

11.1.2. Travel Site and International Survey Observations

11.1.2.1. TripAdvisor

The AECOM team has been monitoring comments on popular travel sites, such as TripAdvisor, since January 2017 until November 2017. During this period of time tourists have taken to these travel sites and social media to announce their displeasure at the state of Muri Lagoon, whose deterioration status varies over time. Some of the tourists are openly complaining on these online sites, something that can have some influence in the tourism industry if the trend continues to increase (Figure 11.2).

Comment title	Date	Travel site	Url
"Beautiful Destruction"	18-11-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r541847884-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#REVIEWS
"Far from being the paradisiac lagoon I was reading about"	11-11-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r540272873-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#REVIEWS
"Beautiful - but woeful snorkeling"	08-10-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r531227148-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#REVIEWS
"Fantastic lagoon however don't suck in any sea water"	29-09-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r528382633-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#REVIEWS
"Lots of activities, lovely scenery, shame about water quality"	01-09-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r520368815-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#REVIEWS
"Muri"	08-08-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r510243060-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#REVIEWS
"Beautiful too view but snorkelling not great"	31-05-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r489372252-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#REVIEWS
"Very sad"	16-05-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r484761441-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#REVIEWS

"Very"	17-04-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r476340671-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#CHECK_RATES_CONT
“Lagoon has improved!”	15-04-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r475937813-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#REVIEWS
“Lovely and quiet”	19-02-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r461310880-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#REVIEWS
Pacific Resort Rarotonga Questions & Answers	02-02-17	TripAdvisor	https://www.TripAdvisor.com/FAQ_Answers-g1166723-d309570-t3059877-Hi_we_are_going_to_stay_at_pacific_Resort_and.html
“Pretty, but don't ingest the water”	02-02-17	TripAdvisor	https://www.TripAdvisor.com/ShowUserReviews-g309713-d309954-r435452762-Muri_Lagoon-Rarotonga_Southern_Cook_Islands.html#CHECK_RATES_CONT
"Muri Lagoon Questions & Answers"	18-01-17	TripAdvisor	https://www.TripAdvisor.com/FAQ_Answers-g309713-d309954-t3015421-Am_staying_at_muri_beachcomber_in_april_is_muri.html

Figure 11.2. Selection of comments on TripAdvisor that are mentioning or complaining seaweed outbreaks in Muri Lagoon

Some key quotes collated from international visitor surveys (in addition to Trip Advisor) are listed below:

1. *“Would be swimming and you'd have bits of algae floating around you. Didn't have that happen 10 years ago.” (Cook Islands International Visitor Survey)*

2. *“We have been visiting the Cooks for 30 years and were upset this recent visit by the general increase in rubbish and deterioration of facilities. Also we have real concerns about the water quality of the lagoon, especially at Muri Beach.” (Cook Islands International Visitor Survey)*

3. *“This was our 6th time and we were devastated to see the algae in the Muri Lagoon and the mess on the beach….We came to Rarotonga for the lagoon so would have not spent 27 hours travelling to get there if we had known what had happened to it. We hope that it can get cleaned up and back to the paradise we once knew. We will not return until the problem is fixed.” (Cook Islands International Visitor Survey)*

4. *“Beautiful lagoon on the surface, but lots of pollution coming from touristic activities and hotels, algae has settled in most parts of the lagoon, but even worse, all the sea slugs which have invaded the bottom of the shallow water over the last couple of years, which makes it ugly to walk into now, and a horror movie when you snorkel. It is worth investing in reef shoes for the stones and rocks as well, not the white sand type of lagoon unfortunately... Better look at the fabulous Titikaveka beaches just a 5mins drive from Muri.” (Trip Advisor, 11 November, 2017)*

5. *“I have mixed feelings about this lagoon. On one hand it's stunning with the sheltered location, picturesque waters and amazing sights. On the other its coral is destroyed, it's overused and over catered to the resorts and lagoon tours. Muri beach is where everything happens so the environmental impact is always going to be rough but that's something you can make your own mind up on. I enjoyed the fact that I could walk over to the other island,*

help myself to a drink of cordial that was put on for the actual paying guests, use the toilet and walk back over the other side and have a nap under a coconut tree. Perception is everything." (Trip Advisor, 18 November, 2017).

6. *"It's so beautiful to walk on the beach, but if you go out into the water to snorkel you see a lot of sea cucumbers. Unless you go right out..." (Trip Advisor, 8 October, 2017)*

Research carried out by AECOM team indicate that there is no proactive action or response from the Cook Islands Tourism Corporation (CITC) to these recurring comments that are taking place on online travel sites, which can eventually affect potential newcomers to Rarotonga. Some type of informative intervention is suggested by the CITC in order to explain and provide accurate information about all the actions that are being taken to improve Muri Lagoon's conditions and the outcomes obtained over time. At present, only a few community members and private sector companies are reacting to these comments and questions.

11.1.2.2. Cook Islands International Visitor Survey

In 2006, the Cook Islands Government engaged the New Zealand Tourism Research Institute (NZTRI) to conduct the first online International Visitor Survey (IVS) for the Cook Islands. Its success has resulted in IVS being undertaken for the Cook Islands Government since this time to the present day. The NZTRI team now have an ongoing barometer running in the Cook Islands which allows them to understand visitor changes from year to year, and from quarter to quarter. The data generated from the IVS can, for example, enable a great understanding of the impact of new government legislation on the Cook Islands tourism industry or the impact of new visitor experiences.

Specific research on the perception of algal blooms was carried out by the NZTRI team (Eilidh Thorburn, Nicholas Krause, and Simon Milne) in February 2016, whose results were provided in a presentation named "The impacts of algal blooms on visitor experience", which was available for consultation by the AECOM team. The study was based on data taken from the Cook Islands International Visitor Survey database from July 2015 to June 2016 (with a total number of 4,087 responses). A total of 470 respondents left comments in the open-ended questions. Of these, 151 people (32.1%) specifically commented on algal blooms in Muri Lagoon. The

Figure 11.3. ***Share of visitors responding to the "Least appealing aspect of visit (environment /rubbish)" on the online International Visitor Survey carried out by NZTRI***

following graph shows that a spike in comments related to the presence of rubbish and deteriorated environmental conditions (a perception based on the presence of algae) took place in the third quarter of 2015.

The study found that, although satisfaction with the overall visit remained high, there was a significant difference ($p < 0.05$) between Algae Sensitive Visitor (4.48 out of 5), and the Regular Visitor (4.6 out of 5). Both groups would equally recommend the Cook Islands to others but the Algae Sensitive Visitor provided more suggestions for improvement. Another finding of the study was that despite negative emotions and lower satisfaction, the strong bond with place was over-riding decisions not to return. Instead, those visitors who were more concerned about the algal bloom in Muri Lagoon called on the local stakeholders to take urgent action. A series of recommendations were put through by the authors of the study:

- Continue to monitor visitor comments in the IVS relating to algal bloom on visitor experience.
- Incorporate insights from the Cook Islands Business Confidence Index about loss of income due to algal blooms.
- Monitor news about algal blooms.
- Continue to monitor the impact of negative emotions on satisfaction place attachment/intention to return.

The AECOM team agrees upon these recommendations and stresses the need to regularly monitor visitor's comments (undertaken by CITC) and follow-up on the publication of news related to seaweed outbreaks or water quality/public health issues in Muri Lagoon (it is not clear whether this action is carried out or not), and take action when these appear.

11.2. Multiple Project Communication

Several ongoing projects are taking place simultaneously (see Appendix B), all focusing on providing support and action to help alleviate the algal / seaweed problems at Muri Lagoon. These are explained in more detail within Appendix B though are summarised here as being *Te Mato Vai (TMV), Mei Te Vai Ki Te Vai (MTVKTV), Ridge to Reef (R2R)* and *the Interdisciplinary Assessment of the Muri Lagoon (IAML)*. The following findings are made following the May and November 2017 site missions for the IAML project.

There is a strong support amongst all stakeholders to "fast track" interventions that seek to address Muri Lagoon's environmental degradation and ongoing seaweed outbreaks. So far, most of the potential solutions presented to the public (short-term: regulating use of chemicals, sediments removal, regulating on-site wastewater treatment, reducing sediments/nutrients entering the lagoon; long-term: construction of a reticulated system) are received in a positive manner (Figure 11.4).

Figure 11.4. ***Screen capture of an article published in November 2015 which questions the effectiveness of the measures proposed by international consultants.***

One important observation made amongst local citizens that there is a high number of international consultants present and "duplicating effort" on similar activities related to Muri Lagoon. However, not many successful outcomes are being readily seen by the local population. The lack of short-term results and clear implementable advice that relates to the prevention of seaweed outbreaks and on water quality improvement may cause frustration to the public. A simple collective pamphlet or news article conveying what is happening, and through which funder, would have been a sensible approach at the start of the MFEM project (January 2017).

Related to the previous point, there is real unfounded concern that relates to the 'low return of investment'. There is a feeling among local citizens that a lot of resources are being invested in engaging foreign consultants as opposed to the engagement of local expertise or at least "shadow support". The approach being adopted by GHD (in particular) does use local staff as existing WATSAN staffs (from ICI) are fully engaged within the MTVKTV project however this does not include marine ecologists/scientists (including no Cook Islanders now based overseas).

From a local perspective, there is not much clarity on 'who is doing what' in Muri Lagoon. There is a risk of perceiving duplicated efforts by locals, which may derive in questioning how investment decisions are made by both the government of Cook Islands and International Donors. There is also a risk by the local community of not having a clear 'big picture' on what is being done in Muri Lagoon to ensure its preservation. This situation can create uncertainty and confusion to the public if non-coordinated and inconsistent information is delivered to the audience, which may result in the future consultation fatigue and eventual project opposition. For this reason, it is of high relevance to establish a good communication system among projects and establish a joint mechanism to ensure public messaging is complementary and consistent across stakeholders. Possible solutions (in the future) to address this issue are presented below.

Develop a joint information material. This approach would integrate (within one single brochure, leaflet, poster, etc.) all actions that are taking place in Muri Lagoon to ensure its preservation. This may help the audience to understand that several actions are running for this very same purpose, that there is cross-communication and coordination among projects in order to seek complementarity and avoid duplications and would provide one 'single voice' from the government of Cook Islands. This may be an action oriented towards providing greater clarity on 'who is doing what' and especially 'why' putting emphasis on short-term action while addressing long-term challenges.

Coordinate information updates. Various pieces of information are being delivered to the public through different communication channels (Press releases, Social Media Channels, e-newsletters, websites, community workshops, etc.). It is seen as a desired action that the several communication officers engaged in Muri Lagoon's related projects and agencies set up some kind of coordination system to ensure a consistent message is being delivered to the audience. The 'Communications Commission on Muri Lagoon' may be a good body to enhance this coordination.

Coordinate and organise public events. For the last few years various public consultation and information workshops have taken place in Rarotonga about Muri Lagoon. From the Sanitation Upgrade Programme (2011-2014), to the 'Ecological and Aesthetic Restoration of Muri Lagoon – Environmental Impact Assessment' by the Muri Lagoon Action Group (November 2016), to the most recent project: MTVKTV (started January 2017). With each of these projects a public consultation/information process was initiated, however none of them coincided in time. Currently there is an ongoing public engagement process undertaken in the framework of MTVKTV project (with three sessions organised so far between January and June 2017). In order to prevent the initiation of too many community workshops both MTVKTV and IAML projects are coordinating efforts to restrict the number of dates where to communicate progress and outcomes to the public. The same philosophy is proposed to be followed in the future.

Coordinate the production of awareness materials. A variety of awareness materials have been produced by several organisations in the last few years, being especially active non-profit organisations like Te Ipukarea Society and Muri Lagoon Action Group. Before any new awareness materials are to be produced in the framework of the ongoing projects it is seen as a recommended practice to carry out an initial research on what type of materials are already available and being currently used. This exercise has been undertaken by the IAML project team and after consultation with several stakeholders, Muri Lagoon-related projects, schools and various ministries a new set of awareness materials is to be produced as a result.

11.3. Primary and Secondary Education

11.3.1. Specific Education Programmes

A strong educative programme is a necessary and represents an important component of delivering the NSDP (2016-2020). The Ministry of Education will play an important role in coastal education and it is important that this Ministry is brought into the discussions on Muri Lagoon, along with Higher Educational institutions (Colleges) and research facilities (e.g.: USP).

MMR (with NES) have already begun dialogue with the Ministry of Education and Higher Education institutions as to how coastal and lagoon management could be incorporated within the Cook Islands education system curriculum.

In November 2017, MMR made presentations and conducted in-the-field activities with a group of 60 students (aged 13-14) from Huanai College (Whangarei, NZ) and Titikaveka College on the mornings of Tuesday 28 and Wednesday 29 November at Titikaveka College. The activities counted on the support of the AECOM team who produced several factsheets and made recommendations on possible ways to perform and conduct the activities. The main focus for the students was to look at impacts on the lagoon (including harmful material from waterways, and impacts of tourism) to marine life and water quality. Huanai College students have been visiting Titikaveka for several years and used this occasion to gather and compare datasets. MMR worked with 30 students (and 4 teachers) each morning in tandem with NES staff who covered land-based issues). Since this is a yearly activity carried out by MMR it is suggested that a brief manual/protocol is developed with a proposed agenda for the involved team to follow. Besides presenting who MMR is and what it does, the activity represents a good opportunity to work with the students (see later on in the report some suggestion of gamification activities – see Appendix H) on Muri Lagoon's preservation; working on the causes of its environmental deterioration, its effects and potential solutions to be adopted by the different agents involved (government, private sector, local community, etc.).

It is recommended that in the future, MMR seek to utilise the services of national experts in appropriate fields to help add local value with traditional knowledge, Maori language and science. This would act as a capacity building exercise as well for existing staff that would benefit immensely from such a contributor. It is important to ensure MMR engage with national experts to help advertise the work of MMR plus also to inspire young pupils. Links to NGO's such as Kōrero O Te `Ōrau who can support MMR work and bridge science and traditional knowledge.

11.3.2. Lagoon Day

Lagoon Day began in 2008 as a two-day environmental event to raise awareness about the fragility of the Cook Islands marine ecosystems and propose solutions on how to best manage them. During its inception, it was called "Takitumu Lagoon Day" and was undertaken by MMR which included the Cook Islands Marine Institutional Strengthening project (CIMRIS) embedded within it. The Lagoon Day's date was, however, never fixed and this is thought to have contributed to its eventual demise. Initially, it coincided with worldwide Environment Week in June, but as outer islands schools and the Ministry of Health got involved and started to assist with funding, dates were moved so that more students could be present in Rarotonga. This meant moving the date to seize other events like Careers Day (around July) or during the Math Quiz (November).

The idea of a Lagoon Day event was proposed by June Hosking, (funded by the CIMRIS project), based on similar interactive educational expositions that she was involved in in New Zealand when the stakeholders were considering how to best inform/involve the general public (see Figure 11.5).

Figure 11.5. Pictures of the Takitumu Lagoon Day in 2009

Due to its success, Lagoon Day continued to be organised in the following years until 2010, when funding was no longer available. Between 2011 and 2015, the event was organised locally on a voluntary basis by individuals, local organisations and businesses, though expense budgets were covered by MMR.

The Lagoon Day content included a wide variety of activities over the years, including demonstrations of septic tank systems, the meanings of terms such as climate change, marine biodiversity, marine parks, foreshore protection, composting and waterless toilets, pig waste management, problems caused by chemicals (from agricultural sprays to washing powders and cleansers used in the home), etc.

A post event report completed in 2013 declared that over 2 days around 1500 people attended Lagoon Day (944 students with 51 teachers/supervisors, approximately 50 Lagoon Day crew, and an estimate of around 400 - 500 locals and visitors). A survey carried out in 2013 found out that 22% of the attendees surveyed were 18 years and below, being the rest spread throughout the decades from 19 years and over. 46% were first time attendees. Of those surveyed, 21% heard of Lagoon Day via schools, 20% via newspaper, and another 20% via friends. The others were split between radio, TV, posters, work, emails, CITC, and tourist accommodation. 33% of the participants were from Te Au o Tonga, 25% from Takitumu, 16% were visitors to the island, 15% outer islands, and 10% from Puaikura. In 2014 around 1043 students and adults attended Lagoon Day from all schools on Rarotonga as well as 3 outer islands schools with senior classes (i.e. Mangaia, Aitutaki and Atiu).

After consultation with several stakeholders, it is clear that there is an interest in bringing back the organisation of the Lagoon Day, but it is still unclear who may support it and if there may be any funding associated to ensure its durability. ICI-WATSAN showed an interested in moving the Lagoon Day forward in coordination with MTVKTV project by late 2017, but this ended up not taking place due to lack of resources allocation. The key lesson from this is that any future Lagoon Day must come from the key departments funds within the Cook Islands (MMR, NES, ICI, etc.) and not be a separately donor funded initiative. The former instils commitment and engagement for all agencies. A Ministry or Agency should take the lead on the organisation of this event and commit an annual budget for its implementation otherwise it is unlikely that the event will take place again any time soon.

11.4. Communication Recommendations

11.4.1. Adopting an Effective Communications Strategy

A three-fold external communications strategy would be recommended as follows:

- **Media:** regular monitoring on the publication of seaweed outbreaks (not using the term "algae"), water quality and public health issues is recommended. An emergency communications protocol should be activated when relevant and potentially impactful news appears (see Appendix F for draft protocol text). To ensure consistency and to demonstrate that the government is committed to the preservation of Muri Lagoon (and to show that its work is not dependant only on what is being published in the news), regular news conferences, media releases, report releases and interviews on the health status of Muri Lagoon should be carried out even when there are no apparent issues on the lagoon.

- **Tourists:** public comments on social media or travel websites should be monitored and addressed by local authorities or authorised tourism representatives to provide factual information on Muri Lagoon's health status. Regular information in the most consulted communication channels by tourists should be undertaken, for example on the work that is being done by the local government to preserve Muri Lagoon's health. If the public opinion worsens it would be suggested to consider the installation of some on-site physical information (through banners or panels on the beach) on the specific work that is being undertaken to help preserve Muri Lagoon's health status (like the Water Quality Monitoring Programme). Some educational and awareness-raising pieces of information could be developed (using R2R funds) to help "educate" the visitors on what they see in Muri Lagoon. For example, to show that the presence of sea cucumbers or sea urchins is not a negative issue, on the contrary, their presence is an indicator of the lagoon's good health.

- **Local Community:** regular and timely information should be provided to the local community, through the standard communication channels and perhaps additional systems (like specific workshops), on the health of Muri Lagoon. Furthermore, engagement activities (rather that only one-way information practices or consultation sessions or workshops) should also be undertaken by the local government, ensuring the participation of the most relevant stakeholders in the preservation of Muri Lagoon's health status. This would help undertake collective action and effort in the joint exercise to conserve the environmental status of the lagoon

11.4.2. Project leaflet

At the beginning of the project (in March 2017), the AECOM team produced a two-fold leaflet (Figure 11.6) whose main purpose was to introduce the project objective, it's main expected tasks, phases and implementation calendar to the public. The leaflet was produced for MMR to help communicate their work using donor support from the EU, but it was not made available to the public given the number of ongoing projects that were taking place in the island. This was considered to possibly raise confusion amongst the public. This type of materials may now be useful for MMR to disseminate the completed projects they are participating in, and therefore, it is recommended to explore the idea of producing them in the future with updates of key findings from this specific study.

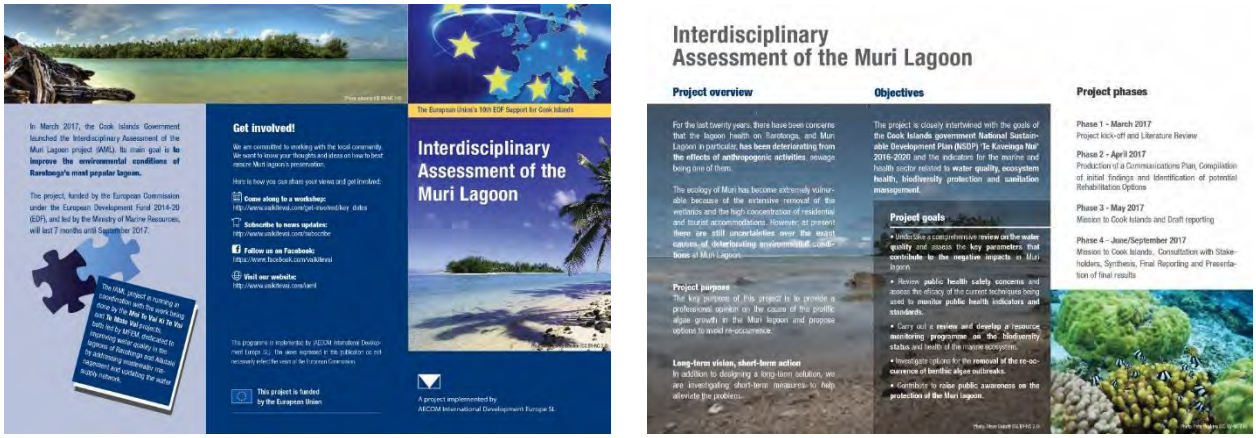


Figure 11.6: Project Description Leaflet

11.4.3. Muri Lagoon Poster

An A3 poster has been produced and elaborated upon (Figure 11.7). This is aimed at raising awareness on what are the causes and effects of Muri Lagoon's environmental degradation. This material has the potential to be used in school activities, similar to the one that took place on 29 November 2017 organised by MMR (see Section 11.3.1).

Figure 11.7: Poster on Muri Lagoon

11.4.4. Social Media posts

A series of Facebook posts (which are valid to be shared on other Social Networks such as Twitter or Instagram) were designed and produced in the framework of the project. The posts were aimed at raising awareness on Muri Lagoon's health status deterioration, to give pieces of advice to the public on what can they do to help preserve Muri Lagoon's health, and to inform about the actions that are being taken by the government (with special emphasis to MMR) in regards to the preservation of the Lagoon. The main goal is to link this type of images, when posted on Social Media, with a website containing advices on how to protect Muri Lagoon's health or with information on what is being done to preserve its environmental status (or similar depending on the issue that needs raising). This type of content is easy to produce and can have a positive awareness-raising impact to the community of followers. A total of five draft examples have been produced by AECOM for MMR update and potential future use including a list with some more post suggestions (Figure 11.8). For these to be produced it is necessary to receive the assistance of a person with basic knowledge of Adobe Photoshop

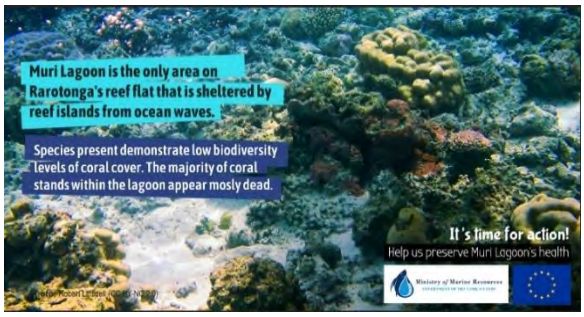


Figure 11.8: Social Media Posts

11.4.5. Environmental Fact Sheets

A total of four factsheets have been produced during the project (Figure 11.9). The Factsheets have been mainly designed for the local community, the regulating agencies, the public stakeholders and the "visitors" community. Their purpose is three-fold:

- To raise awareness about the health status of the Muri Lagoon;
- To present the most recent findings on the pressures and effects of the Muri Lagoon;
- To introduce the work that is being done to preserve Muri Lagoon's health.

The specific content of these factsheets is indicated below:

Factsheet 1: this factsheet presents some of the findings and information produced in the reports that have been elaborated during the AECOM project's lifespan. The sheet presents Muri Lagoon's current health status by gathering inputs and information from three main themes: biodiversity, physical conditions and water quality.

Factsheet 2: this factsheet presents what are the main drivers and effects of Muri Lagoon's environmental degradation and provides a few pieces of advice to the general public on what people can do to contribute to the Muri Lagoon's preservation pursuing greater awareness and the public's engagement and involvement in its conservation.

Factsheet 3: this factsheet addresses Muri Lagoon's most concerning issues (water quality, public health and seaweed outbreaks) and presents the latest information and tests results available on those respective topics in an attempt to fight against miss-leading perceptions that have been identified from visitors.

Factsheet 4: this factsheet presents MMR's work and provides specific inputs on their tasks in relation to the protection and preservation of the lagoons in the Cook Islands.

Figure 11.9: Series of 4 separate Fact Sheets

The Fact Sheets are proposed to be included within a MMR "information packs" on topics such as Lagoon Health, Turtle Research (in partnership with Ariki Holidays Ltd who are producing similar fact sheets), long-liners, etc. These materials would be readily accessible documents with up to date information on current issues but also to communicate the day to day working of the MMR. These materials could be distributed both internally and externally to keep stakeholders informed plus also to ensure that all MMR staff are aware of what type of activities are being carried out.

11.4.6. Relaunch of Lagoon Day

Due to its huge success and proving to be the single and most successful environmental awareness event in the Cook Islands, it is highly recommended that Lagoon Day is relaunched. Funding will need to be sorted from public donors, private sponsors (hotel groups) or the CIG to ensure that the event takes place. It is recommended that the event should not be an international donor funded initiative, and it should be an inter-departmental initiative where relevant Ministries and Agencies (like MMR, NES, ICI, etc.) take responsibility for key aspects of the day, resourcing accordingly.

Another alternative is to delegate the organisation and development of the event to civil society and local businesses involving local participation of organisations (such as the Te Ipukarea Society, the Muri Lagoon

Action Group, Volunteer Raro, local businesses and the schools, etc.) when some funding is secured and granted. Ti Ipukarea represent a good example of a potential organizing NGO as they have experience in organizing and undertaking several activities related to environmental education and awareness for the local community, including schools (now they are entering the final 6 months of a 2-year project funded by GEF to teach how to compost food waste in all schools in Rarotonga). Two years ago, for example, they organized successfully a Marine Science Camp.

11.4.7. Communications campaign during seaweed/ciguatera outbreaks

Research carried out by AECOM team indicate that there is no pre-emptive communication, proactive messaging to the public when seaweed outbreaks occur (typically from December to February, when the risk is highest – see Part A Section 2) even though there are recurring negative comments that are taking place on online travel sites and social media about the lagoon status, which can eventually affect potential newcomers to Rarotonga. Some type of informative intervention is suggested by the Cook Islands Tourism Corporation, with the collaboration of the MMMR and MoH, in order to explain the true facts about the lagoon's health status (for example using one of the factsheets that has been produced in the framework of this current assignment) and about all the actions that are being taken to improve Muri Lagoon's conditions and the outcomes obtained over time. Other actions that are proposed to be undertaken are the following:

- **Establish an "emergency or extreme event communications protocol":** seaweed /ciguatera outbreaks can happen without previous notice or forecast. However, this project (Part A Sections 2 and 5) suggest that there are "seasons" when the risk of seaweed or ciguatera outbreaks may be most likely (December to February or after cyclone events etc.). Independently of what situation is taking place, it is highly recommended to design, develop and implement an "emergency communications protocol" (see Appendix F4 as a draft) for those cases in which Muri Lagoon's environmental and/or public health status is suddenly and majorly affected. The protocol should list and operationalise the following: *a) what are the major risks for the health of Muri Lagoon, b) what is the type of action/response that should be adopted (delivery of a media release, publication of a specific report or factsheet on the official website/Social Media, interviews on the public TV/radio, etc.), c) what communication channels should be used, d) what kind and what number/frequency of messages shall be disseminated, e) what resources should be available, and f) what monitoring system should be put in place to monitor the impact of the communications/action.*

- **Develop a "Ready-to-use communications toolkit":** a ready-to-use set of materials (as produced by AECOM) but with up-to-date and fact-based official information on the health of Muri Lagoon and MMR's work (following the completion of the MTVKTV and R2R projects) should be available at any time for when major incidents occur, which may impact on the public opinion. This communications toolkit should include the latest information or reports on the health of Muri Lagoon (water quality tests, public health surveys, biodiversity surveys, etc.) along with specific materials that explain clearly

what is the regular work being done by the government to address the topic impacted (water quality, public health issue, environmental impact, etc.) and what are the specific actions being taken to tackle and address the specific incident that is taking place. The "launch" of specific social media posts (see Section 11.4.4) should be readily available in case of specific events taking place (including if there is a need to announce the increased risk of ciguatera – see Figure 11.8).

- **Monitor and respond the comments left on social media/travel websites:** local newspapers and tourists are noting their displeasure at the state of Muri Lagoon, with many becoming vocal online about the unsightly seaweed growth (as indicated in Chapter 11.1.1). Popular travel websites like *Trip Advisor* have received a number of comments (and also questions) from holidaymakers unhappy with the growth of the seaweed. The majority of these comments are not addressed or responded, having an impactful effect for future potential visitors. It is suggested that a regular monitoring and reply policy is adopted by the Cook Islands Tourism Corporation, with the assistance of any other relevant Ministry to best approach the tone and content of the messaging.

11.4.8. Beach and Lagoon Safety Advice

Further to the recent drownings of two American tourists at Muri Lagoon (November 2017), it is advocated that MMR could help to provide support to the Cook Islands Tourism on beach and water safety across Rarotonga and Aitutaki. To ensure that Cook Islands remains competitive (and indeed has the competitive advantage) it is paramount the beaches and lagoons are perceived and are indeed safe and clean. Providing a lifeguard service, whilst not a statutory requirement, is needed to safeguard the large influx of visitors unaccustomed to the dangers of the sea and the need for coastal services such as beach cleaning, coastal environmental management and protection schemes.

Existing signage on the risks is poor on this matter and techniques are required to instill better messaging on the use of kayaks and knowledge on currents. The existing posters (see Figure 11.10) are of value and are advertised in tourism magazines (such as "Escape Magazine") which are available to read at most accommodation and retail outlets. Nevertheless, what is recommended is a formal process of training with regards to the initiation of beach safety for Muri Lagoon and around Rarotonga. Up until recently there have been no International Standards for beaches or lagoons and very little guidance on beach / lagoon safety management for operators. A new beach a new management scheme (building on the main sustainability "pillars" set internationally by Blue Flag) is likely to be needed that is flexible enough to adapt to visitor demands in the same way as any other business or service. Having such a management system in place will seek to ensure that the beach and lagoon remains safe and enjoyable for all users (local and tourist) now and in the future. Cook Islands Tourism with support from MMR and the private sector should be encouraged to adopt the new ISO 13009 Beach Standard which may be of significant marketing value to the Cook Islands and Muri Lagoon.

Figure 11.10 Water Safety Posters produced by Cook Islands Tourism in partnership with MMR

The ISO 13009, "Tourism and related services — Requirements and recommendations for beach operation", has just been published by the International Standards Organization (ISO). This is the first standard that provides beach operators with the information and guidance needed to manage beaches effectively, anywhere in the world. The ISO13009 brings a range of important elements together that could offer guidance on lagoon operations to help sustain a resorts economic future. As well as general beach or lagoon management, the ISO 13009 includes initial guidance on beach safety, beach cleaning and waste removal, beach access, infrastructure, beachfront planning, stakeholder communication, beach promotion and commercial services (vendors etc.). Therefore, assisting the tourism sector to comply with ISO 13009 is likely to help significantly towards generating both media and public interest within resorts and beach fronted hotels. This in turn may help secure public funding for future improvements to the surrounding beach area.

11.4.9. Participatory 3Dimensional Modelling

Ongoing work (funded by SPREP with support to NES) is already taking pace on P3DM on a number of islands in the Cook Islands including Rarotonga and Mangaia. The purpose of a P3DM is to provide the local communities with a birds-eye view of important areas within an island, area or village, which includes dwellings, ra'ui sites (coastal protected areas), native and endemic trees, marai, churches and other features that the community sees as a valuable resource to be highlighted onto a 3D model (see Figure 11.11).

Figure 11.11 P3DM model prepared for Mangaia Island (by NES staff)

The ongoing Regional R2R project is seeking to release funds to produce a P3DM for Muri Lagoon. This is likely to commence during early 2018. MMR should be important partners in the design of such a model, especially with regards to lagoon related issues that have been learned to date from this and parallel projects (MTVKTV etc.).

11.4.10. Gamification

Gamification is the application of game-design elements and principles within a non-game context to improve user engagement and organizational productivity. Research shows[2] that a majority of studies on gamification find it has positive effects on individuals, despite that individual and contextual differences exist.

Gamification has also been applied for the raising awareness purpose, and more specifically within the field of environmental and sustainability awareness. It can help overcome some of the obstacles that hinder popular support for sustainability awareness and action. This includes environmental-detachment and the perception of sustainability as complex and boring. In this aspect, one of the most important things that a game can do is instil interest. Additional examples of Gamification are demonstrated in Appendix H.

11.4.11. Initiate a "LagoonSnap" visitor monitoring system

Coast Snap (adapted to be entitled "#LagoonSnap" or "#MuriSnap" for Muri) is an innovative community-based beach monitoring system developed by the Office of Environment and Heritage, Water Research

[2] Hamari, Juho; Koivisto, Jonna; Sarsa, Harri (2014). "Does Gamification Work? – A Literature Review of Empirical Studies on Gamification". *Proceedings of the 47th Hawaii International Conference on System Sciences, Hawaii, USA, January 6–9*: 3025. doi:10.1109/HICSS.2014.377. ISBN 978-1-4799-2504-9.

Laboratory (UNSW Sydney) and Northern Beaches Council in New South Wales, Australia. With this system, visitors' can capture and share a photo with their mobile device using "CoastSnap" precision photo points. These could be simply set up at agreed vantage points along the Muri Lagoon. Shared photos taken from fixed locations can then be used to (for example) measure change in the shoreline position and beach width at the same time that citizens capture iconic (or seaweed growth) pictures of the beaches. By controlling the position and angle of the camera, it is possible to measure beach features in users' photos, providing an accurate record of the beach state and shoreline position at the time of capture. Over time the idea of "LagoonSnap" data will provide a visual record of algal coverage (or clear conditions) and indications of recovery cycles, and any long-term trends in lagoon characteristic change where present (Figure 11.12).

Figure 11.12. CoastSnap photo-point fixture. Source: New South Wales Government.

Users should be encouraged to share their photos on Social Media using the hashtag #LagoonSnap. A similar idea could be implemented in Muri Lagoon using the name and hashtag #MuriSnap, encouraging users to take photos from fixed points in Muri Lagoon to help the government monitor change in the shoreline position and beach width. Some potential locations could be the Koromiri island (two stands placed, one facing North-West and the other one facing South-West), a location that is frequently visited by tourists, and the Pacific Resort and the Koka Sails area *(NB: this business has the link towards producing welded products and so could be interested in producing the mounted stands for this*).

A small banner, combined with a larger information stand could be introduced to explain tourists and citizens how the LagoonSnap works and they would be invited to share their pictures on a Facebook page, specifically created for this purpose, at the time they would be taking beautiful snapshots from iconic locations in Muri Lagoon. If the idea moves forward it may be of interest to create the welded "stands" to also accommodate more formal monitoring location positions for MMR staff to place their monitoring tablet devices when monitoring, so that photos could be taken during the monitoring exercises (see Part A Section 6). Therefore, the idea would be more than just the general public to use this, but it could also be designed so that MMR/NES staff can use tablet technology to capture images whilst taking water quality, undertaking field surveys, etc.

11.4.12. Information and Awareness Panels

Muri Lagoon offers a good opportunity to raise awareness on marine ecology and biodiversity to the general public. By conceptualizing and designing informative and interpretive panels on the values of the lagoon's natural heritage, visitors can easily identify and appreciate the presence of vegetal and animal species and their role in the ecosystem.

These panels could be part of a wider project aimed at identifying and setting up of 'Lagoon biodiversity hotspots and routes' within Muri Lagoon. The awareness panels could be the starting point of 'snorkelling tracks' that would convey users what species they would be able to see under water when practicing snorkelling. The panels and interpretative tables would target the general public, both local population and tourists, and its location would be based on pre-identified biodiversity hotspots in the Muri Lagoon. This could be extended (over time) to embrace future snorkel trails to new "coral gardens" (see Part B Section 7 and Appendix D).

One potential possibility to explore is to take advantage of the existing Ra'ui signs in Muri to raise awareness on this traditional conservation initiative, along with putting emphasis on marine biodiversity. In 1997 the Ra'ui concept was revived again by Aronga Mana and the following year, signs were erected in front of 12 conservation zones around the island, including Muri Lagoon. The signs could be re-designed, or a new panel could be placed alongside to include further information to raise awareness on Muri Lagoon's ecosystem wealth. Another option would be to insert a QR code onto the Ra'ui sign that, when using a QR reader mobile application, directs the user to a specific website featuring information on marine life and biodiversity (possibly an updated MMR website page which would need to be repeatedly updated on specific public awareness related marine biodiversity/fishing/conservation information).

12. COMMUNICATION PLAN

This Section addresses the following project objectives (already defined in Part A Section 1.2)
Design a communication plan for public awareness and informing regulating agencies

12.1. Overview

In May 2017, the AECOM team produced the Communications Plan for the 'Interdisciplinary assessment of the Muri Lagoon' (IAML) project. The document was produced to set the standards for how and when communication should take place during the project implementation. The document also identified the communication objectives for the project, key messages for important questions, how participants should communicate, and the timing of communications. The document addresses mainly external communications. The document was included in the Zero Draft Report produced on 1 May 2017 by AECOM and delivered to MMR for revision. Rather than developing a new Communications Plan for MMR, and in the light of the existing work being done by MMR in preparing a new Communications Strategy, the AECOM team have engaged with MMR communications officer to review the new strategy and support MMR in its development.

In June 2017, MMR produced their 'Draft Communications Strategy (2017-2021)', a document aimed to set the framework for communicating key information to key stakeholders who support MMRs work. Its primary goal is to provide clear, informative and engaging bilateral communications which effectively link together key messages and contribute to the achievement of the goals of MMR. The document addresses both internal and external communications and seeks to create an important link with MMR's Strategic Plan 2017-2021 (whose Outcome 4 is relevant for the communications purpose, namely to create, "Informed stakeholders through education, communication, consultation and commitment").

The contents of this section are designed to provide feedback and suggestions to the MMR's Draft Communications Strategy with the aim to improve the current version and help MMR finalise this document.

12.2. The Communications Strategy

One of the main goals of a Communications Strategy (also referred to as the "Comms Strategy") is to become a tool to ensure **transparency to the target audience (in this case the stakeholders and the general public)**. This means that it should offer rigorous, clear and timely information on the progress of the implementation of policies, projects and activities, on the information provided and on the outcomes disseminated. A Communications Strategy should also provide **consistency** on the design and delivery of communicational outputs, allow **smooth communication** between the stakeholders, **avoid potential communication misunderstandings**, and aim to foster **community engagement** in order to reach greater public awareness.

12.2.1. Improving the Format

12.2.1.1. Main goal

The MMR Communication Strategy's main goal is to engage with its stakeholders, which means that it mainly addresses external communications (those that are generated by the Ministry and whose destination and target audience are agents external to MMR). However, the document includes some content related to Internal Communications.

The duration of the Communication Strategy coincides with that of the MMR Strategic Plan 2017-2021. The Comms Strategy refers to the Strategic Goal 3 (informed stakeholders) of MMR's Strategic Plan, which aims to ensure transparency through effective communication and timely distribution of information. With the aim to ensure consistent linkage between all strategic documents elaborated by the Ministry, it is also advised to connect the Comms Strategy with Outcome 4 of the MMR Strategic Action Plan, which focuses on having "Informed stakeholders through education, communication, consultation and commitment". Connection with MMR's business plan should also be established.

12.2.1.2. Structure and Contents

When producing a Communications Strategy, it is recommended that at least the following actions/items are considered and included in the document:

1. **Objectives and Purpose of the communication**

   What are the main goal and the specific objectives of the communication? Why are we undertaking these activities? How are we planning to undertake them? And what do we expect to get out of them?

2. **Target Audience(s)**

   To whom do we want to communicate? Which target audience might benefit the most from our information?

3. **Key Message(s)**

   What do we want to communicate? What is the content, tone and language of our message(s)?

4. **Communication Channels**

   What channels do we have available to reach our targeted audience by delivering our message?

5. **Activities and Materials**

   What are the activities, events, and/or materials—to be used in our selected channels—that will most effectively carry our message to the intended audiences?

6. **Resources, Roles and Partnerships**

   What are the resources available for our communication campaign? List of allies or partners who will support or work with our audiences or share in our goals.

7. **Action Plan**

   How can we bring all previous steps together and take action? List of activities to carry out along with resources and staff available. This part should be closely linked with the expected outcomes (Outcome 4) of the MMR Strategic Pan (2017-2021) and MMR Business Plan.

8. **Evaluation and Monitoring Plan**

   Follow up on the implementations of the communication activities and results and evaluation of results. Determine strengths and weaknesses. Linkage with other plans, policies and strategies should be established when evaluating and evaluating the progress and outcomes of the Communications Plan.

The following table assesses which one of the items listed is included in the existing MMR Communications Strategy (Draft version):

Item/Action	Included?	Comments
1. Objectives and purpose	Partially	The document sets a list of objectives and strategies; however, it remains unclear what is the difference between the two of them. The purpose of the communication is not described in the document. In this section there should be some mention of outcome 4 of MMR's Strategic Action Plan/Business Plan.
2. Target Audience(s)	Partially	The document equals target audience(s) with stakeholders which is not necessarily equivalent. A target audience is a person or entity that is receiving the communications generated by MMR, while a stakeholder (which can also be a target audience) can be a partner that is cooperating with MMR in the generation of such communication or action to be communicated. It is advised to identify and briefly define what are the communication lines between MMR and the stakeholders. This means identifying what person(s) will be in charge of reporting/informing about specific communications, what is his/her position in MMR, what is his/her responsibility in the communications line (generating, delivering, approving, etc.), what type of information/communication will be developing and with what frequency. Based on the above, the document identifies and classifies the stakeholders according to stakeholder groups. Given the number of projects running in the country, which are usually carry out by private sector companies and consultants, it is recommended to add to the list another stakeholder group: "project implementers/consultants". It is also advised to carry out a stakeholder mapping exercise (that can be followed by a stakeholder analysis using the Stakeholder Matrix) which identifies specific stakeholders relevant to MMR. This exercise may include at least the following stakeholders: The Ministry of Infrastructure, The Ministry of Health, The Ministry of Agriculture, Office of the Prime Minister, National Environmental Service, Island Environment Authority, Ministry of Finance and Economic Management, Infrastructure Cook Islands, Cook Islands Police Service, Cook Islands Tourism Corporation, Cook Islands Tourism Industry Council, Cook Islands Meteorological Service, Chamber of Commerce, Te Ipukarea Society, Muri Lagoon Action Group, Muri Environment Care, Delegation of the European Union for the Pacific, SPC Geoscience Division, etc. Communication lines with stakeholders would also be of assistance, but this is something that could be placed in a specific section 'Protocols' which is advised to be included as an Annex of the document.
3. Key Message(s)	No	The document includes a 'Key Messages' section but the list of messages is still to be developed. This should be linked to Outcome 4 of MMR's Strategic Plan.

4.Communication Channels	Yes	A list of communication channels has been collected. It is suggested to include in the list 'Face-to-face communication and engagement events' (meetings, workshops, presentations, school activities, etc.). Are other offline communication channels (like public banners or boards) being used in Cook Islands? If so, they should also be included in the list.
5.Activities and Materials	Yes	The list of communication channels referred above does also include activities and materials. It is suggested to consider the development of an e-newsletter to be delivered periodically (monthly, bi-monthly, once in a quarter, etc.). The write-up of press releases should be included in this section too and some printed materials would also be desirable (brochures, pamphlets, posters, etc.). Specific topics of relevance should be included in this section: how to address sensitive topics like (seaweed outbreaks, ciguatera poisoning, etc.).
6.Resources, Roles and Partnerships	No	These items are not included in the document. They are important because they identify the current resources used to carry out the communication tasks and they allow an assessment on whether these are appropriately allocated or not. Additionally, this section identifies the key staff members involved in communications and their roles, defining an operations flowchart and setting the protocol of action (which is very briefly described in the document). A list of stakeholders is identified in the Strategy but they are presented more like target audiences rather than partners, which may be valid in some occasions. Partnerships with existing projects (like MTVKT or R2R) should be included in this section too.
7.Action Plan	No	This item is not included in the document. This should be seen as a work plan expected to list and schedule all the tasks to be implemented during the Strategy's timeframe (2017-2021) over time and assign who is the relevant agent or division within the MMR in charge of its execution. This plan should also demonstrate the clear links to the MMR Business Plan (implementation strategy) for 2018 (how Marae Moana Goal 10 is to be achieved per year, etc.
8.Evaluation and Monitoring Plan	Partially	This item is partially included in the document (section named 'measurement of successes). Because the Communications Strategy is a living document, a set of indicators and expected Strategy revisions should be foreseen in the document. Evaluation and mid-course corrections should also be expected, as long as remedial actions.

12.2.1.3. Document Sections

The document is synthetic and concise but with some additions it would be exhaustive enough to be operational. The format may be improvable but is clear enough for the Strategy to work as an internal document. However, this would require revision if the document was to be made available to the public.

It is highly recommended that the sections contained in the document are numbered and that the hierarchy levels are clearly set and presented (at least three levels should be defined, with specific title styling based on the hierarchy: Title 1, Title 2 and Title 3). The current version of the file does not allow a quick assessment by the reader of what content belongs to a specific section or another.

Specific recommendations based on the current document sections:

- **'Branding' section:** this section introduces MMR's logo. However, the logo is not included in the section. It would be recommended to include the logo in its different versions. It would also be recommended to include under this section other elements of MMR's brand identity such as fonts and colours to be used, report styling and format, as well as other element of MMR's visual identity.

- **'Risk Analysis' section:** this section is currently located in the introductory part of the document but it can also be placed in the last proposed section 'Evaluation and Monitoring Plan'.

- **'Communication channels' section:** is MMR's work to be seen only in Cook Islands or also abroad. If it pursues not only national but international visibility then other media should also be taken into account. These may include:

    - Radio New Zealand
    - RNZ: Dateline Pacific
    - Pacific Islands Report
    - TVNZ
    - Fiji TV
    - Pacific Pulse
    - Pacific.scoop
    - Asia Pacific Report

- **'Measurement of success' section:** this section corresponds with the proposed 'Evaluation and Monitoring Plan' section. This brief section would require some more development, including the identification of key monitoring metrics. Below there is a suggestion of metrics to be used:

    - Media coverage

        - *How much coverage did we receive?*
        - *What was the tone of that coverage (positive/negative)?*
        - *Which media outlets was the coverage in? Where in those outlets? What's the audience of those placements?*
        - *Did we achieve the desired visuals?*
        - *Did they pick up our key messages?*

- *Were our spokespeople quoted?*
- *Were the mentions of our initiative the focus of the coverage, or a side note?*

- MMR website

  - *How many visitors saw our project content? (on our project partner's site)*
  - *How long did they spend on the site?*
  - *What pages did they visit?*
  - *Did they hit specific landing pages?*
  - *What was their bounce rate?*
  - *What was their conversion rate (identify a goal for visitors – purchase/registration/download, etc.)?*

- Social Media

  - *How many visitors saw our project content? (total reach, unique visitors, etc. on our project Social Media Channels)*
  - *How many interactions the visitors had with our content? (likes, reactions, comments, shares).*
  - *What was the tone of the comments received (positive/negative)?*
  - *How much negative feedback did our content receive?*

- Stakeholders

  - *How many stakeholders attended our meeting?*
  - *What was their feedback? How did our stakeholders react?*

- Public inquiries

  - *How many/emails/calls did we receive on the project?*
  - *What was the tone of the incoming correspondence?*
  - *What did the correspondents say/ask?*

- *Events*

  - *How many people attended our event?*
  - *What and how many materials were handed out during the event?*
  - *How many people were reached during the event? (individuals and organisations contacted)*
  - *What kind of feedback did the project receive (positive/negative)?*

The Marae Moana Act: The Draft Comms Strategy also needs updating with regards to the Marae Moana Act which was passed in 2017. It only refers to a "bill". Linked to that Act there is a clear recommendation for clear reporting, and that aspect is missing from the Comms Plan (State of the Coast).

- **'Protocol' section:** a short 'Protocol' section is included in the document. Still, a 'Protocols' section, developed in greater detail (it can be developed later on when the Communications Strategy is approved and operational), is advised to be included as an Annex of the document. This section would aim at operationalising all communication procedures, from how to produce and disseminate a media release to how to organise a stakeholders meeting or deal with an emergency crisis.

AECOM has not included in this document the Project Communications Plan that was developed in May 2017. This document was presented in the Draft Report (AECOM September 2017) and readers should refer to that document to get more insights on how the aforementioned indications made above were incorporated within the document.

PART D: IMPLEMENTATION WORK PLAN AND INDICATIVE BUDGET

13. PROPOSED WORK PLAN

This Section addresses the following project objectives (already defined in Part A Section 1.2)
Provide work plans that meet specific objectives with timelines and cost breakdowns

Table 13.1 has extracted relevant “outputs” and associated actions from the latest MMR Business Plan (2017). AECOM have “mapped” specific actions/recommendations (already presented in Section 7-12) as appropriate again MMR specific tasks.

Table 13.2 is produced to reflect “non MMR” directly responsible actions. These are still costed and presented within a Work Plan for possible inclusion into the MMR 2018 Business Plan (if relevant to the MMR Strategic Action Plan) or to relevant other Ministries, Departments or organisations.

Table 13.1: MMR Business Plan (2017) compliant actions and AECOM Recommendations

MMR Strategic Output Title	Link to NSDP Goal (2016-2020)	MMR Strategic Goal *(from MMR Strategic Plan 2017-2021)*	MMR Work Programme deliverable *(stated within the MMR Business Plan 2017)*	MMR Proposed Action (for 2018)	Link to AECOM Specific Muri Lagoon Report Recommendations
Output 2: Pearl Industry Support	Goal 12: Sustainable management of oceans, lagoons and marine resources	1.3) Monitor lagoon water quality	Establish warning systems to alert authorities when public health safety standards are exceeded	Muri Lagoon Health Card implementation	See Part C Section 10.3
		1.5) Protect marine biodiversity *(replicated also in Output 3)*	Ensure marine ecosystems and fisheries are being adequately observed and monitored	Trials in Muri Lagoon to rehabilitate marine ecosystems and biodiversity	See Part B Section 7.2
		1.7) Build resilience and adaptive measures to climate change impacts on the marine sector *(replicated also in Output 3)*	To establish targeted monitoring and research programmes to understand climate change impacts	Recording, training and reporting of "unusual outbreaks" that may be climate related (within 2 weeks of occurrence)	See Part B Section 7.4
Output 3: Inshore Fisheries and Aquaculture	Goal 12: Sustainable management of oceans, lagoons and marine resources	1.2) Maintain heathy coral cover	Monitor live coral cover.	Record species level, coral cover and heath around Rarotonga (including Muri Lagoon)	See Part A Section 3.4 and/or See Part C Section 10.3
			Monitor populations of keynote species	Record key finfish, invertebrate species level, around Rarotonga (including Muri Lagoon)	See Part A Section 3.4 and/or See Part C Section 10.3
	Marae Moana Goal 11 - Informed stakeholders through education, consultation, communication and commitment	4.2) An educated, informed and committed community	Implement GIS technology	QGIS systems in place	See Part B Section 9.2
Output 5:	Marae Moana Goal 11 - Informed	4.2) An educated, informed	Effective and efficient ICT	Reduce overall systems	See Part B Section 11

Corporate Services	stakeholders through education, consultation, communication and commitment	and committed community	system	downtime.	
			Website and social media platforms maintained		See Part C Section 9.2

Table 13.2: Integrated Actions based on AECOM full recommendations

	Primary responsibility	Scheduled Completion Date	Indicative Budget (EUR)
Section 2: Water Quality			**38,000**
2.1. Purchase of chemicals for the laboratory to enable the re-testing of nutrients levels *(Phosphates, Ammonia, Nitrates and Chlorophyll-a)* since August 2014.	MMR	Q1 2018	8,000
2.2 Re-evaluation of AECOM analysis using new MTVKTV monitored data for groundwater and from this, update the "standard" benchmark figure for DRP and DIN.	MMR	Q3 2018	15,000
2.3 Based on completion of 2.2, update existing MMR (2011) Water Quality Monitoring Manual to ensure new data collection techniques are to collect samples from the terrestrial, inner lagoon and outer lagoon "zones" as a minimum	MMR	Q2 or Q3 2018	12,000
2.4 Agree on Emergency Event monitoring procedures (between MMR/NES) and insert into an updated MMR (2011) Water Quality Monitoring Manual.	MMR/NES	Q1 2018	3,000
Section 3: Marine Biodiversity			**44,000**
3.1 Purchase drone and supporting ortho-mosaic software packages	MMR	Q1 2018	7,000
3.2 Carry out marine habitat and seaweed extent mapping survey map production (using drone technology)	MMR/NES	Q2 2018	11,000
3.3 Boodlea spp ambient niche condition assessment survey (Dr Susan Williams)	MMR	Q1 2018	7,000
3.4 New reef survey of Muri Lagoon to determine coral bleaching, juvenile recruitment and species diversity	MMR/RAPCA (R2R)	Q2 2018	19,000
Section 4: Coastal Hydrodynamics			**15,000**

4.1 Await the outputs of the UoNSW Coastal Hydrodynamics modelling contract to produce a "Muri Lagoon Conceptual Model" which can be used for updating the Integrated Monitoring Programme (IMP) (including placement of sediment traps etc.).	MMR/MFEM	Q3 2018	15,000
Section 5: Public Health			**20,000**
5.1 Formalize an "engagement" strategy between MoH or MMR on ciguatera recording and initiate Risk Assessment procedures as part of the MMR monitoring process	MMR/MoH	Q1 2018	2,500
5.2 Re-analyze the enterococci samples carried out in 2016/2017 (through an ISO accredited laboratory) and update Health Cards	MMR	Q1 21018	9,500
5.3 Introduce and formalize e.coli testing (purchase of test kit equipment/laboratory chemicals etc.)	MMR	Q1 2018	8,000
Section 6: Field and Laboratory Sampling			**41,000 (max)**
6.1 Initiate production of a Laboratory Strategic Plan and implementation business plan	MMR	Q2 2018	5,000
6.2 Purchase of tablet based technology (x4) to help improve the quality and timeliness of field based survey work	MMR	Q2 2018	5,000
6.3 Purchase of additional data loggers	MMR/MTVKTV	Q2 2018	8,000 for WQ Sonde and 15,000 for current meter
6.4 Update the MMR (2011) Water Quality Monitoring Manual to better embrace all laboratory testing protocols, field data collection protocols (coral/invertebrate/seaweed/sediments/WQ etc.)	MMR	Q2 2018	8,000
Section 7: Intervention Measures			**TBD**
7.1 Dredging Channels and Stream Deltas and beach re-nourishment	ICI/NES	Q4 2018	Tbd
7.2 Improved watershed management (creation of storage ponds, improved water conveyance and trash traps etc)	ICI	Q4 2018	Tbd

7.3 Roadside storm water reticulation systems to determine the levels of pollutants draining off roads during peak rainfall events (in partnership with ICI) and establish protocols, standards or "collecting systems"	ICI	Q4 2018	Tbd
7.4 Coral rubble clearance in outer lagoon area	ICI/NES/MMR	Q4 2018	Tbd
7.5 Removal of traditional fish traps	Local groups	Q4 2018	Tbd
7.6 Pilot osmotic "shock" trial	MMR	Q1 2019	Tbd
7.7 Pilot Coral Garden (Muri Lagoon)	MMR	Q4 2018	Tbd
7.8 Riparian planting and wetland nursery creation	MoA/NES	Q2 2018	Tbd
7.9 Sediment trap installation to record suspended sediment levels at different times of the year.	ICI	Q3 2018	Tbd
7.10 Preparation of a Muri Lagoon Management Plan (under R2R project)	MMR/R2R team	Q2 2018	Tbd
7.11 Preparation of an Environmental Guidance Manual	NES/MMR	Q2 2018	Tbd
7.12 Training and Capacity Building (GIS/new field data collection techniques/laboratory)	All parties	Q1 2018	Tbd
Section 8: Integrated Monitoring Programme			**55,000**
8.1 Transform the proposed Integrated Monitoring Framework (IMF) into a formal IMP (consultation/finalization of MTVKTV/agreeing management arrangements etc.)	MMR/CCD/NES/ICI	Q3 2018	40,000
8.2 Production of an updated MMR Monitoring Protocol Manual (see Appendix F)	MMR	Q2 2018	15,000
Section 9: Database Management and GIS			**59,000 (min)**
9.1 Design and implementation of a new geo-database and Web based data dissemination for MMR (to replace RFID) – Purchase ARCGIS Enterprise	MMR	Q2 2018	28,000
9.2 Purchase Tablets and Tablet data Collection Software (ARC Collector)	MMR	Q3 2018	20,000

9.3 Purchase Statistical Software (SPPS or STATA or PRIMER 7)	MMR	Q2 2018	2,000
9.4 Improve current IT infrastructure including internet Capacity	MMR	Q2 2018	MTVKTV one off donation
9.5 Receive training on ARCGIS Enterprise and Statistical Analysis / Software	MMR/MFEM	Q3 2018	9,000
Section 10: MMR Reporting			**25,000**
10.1 Production of a State of the Coast Report (annual)	MMR/NES	Q1 2019	15,000
10.2 Produce a Warrant of Fitness Card (one al MTVKTV data is collected)	MMR/MFEM	Q2 2019	10,000
Section 11: Public Education			**32,000**
11.1 Re-launch the organization of the Lagoon Day (annual)	MMR/NES/ICI	Q4 2018	Tbd if required
11.2 Install 4 "lagoon snap" tablet/mobile device placement units	MMR	Q2 2018	4,000
11.3 Update existing or Produce additional Fact Sheets (post MTVKTV)	MMR	Q2 2018	3,000
11.4 Organise the implementation of gamification activities (annual- linked to 11.1 above)	MoE/MMR/NES	Q2 2018	15,000
11.5 Establish a PPP between MMR and private sector operators to undertake edutainment activities	MMR/NES/Chamber of Commerce/CITC	Q4 2018/Q1 20019	Tbd
11.6 Produce regular content to be shared on Social Media (like image posts) to raise awareness on Muri Lagoon's health, promote action and show actions taken for its preservation	MMR	Q3/Q4 2018	3,000
11.7 Join International Awareness Campaigns	MMR	Q2 2018	Tbd
11.8 Install Information and Awareness Panels	MMR	Q4 2018/Q1 2019	7,000
Section 12: Communication Plan			**28,000**

12.1 Finalise MMR's External Communications Strategy	MMR	Q1 2018	3,000
12.2 Produce MMR's Internal Communications Plan	MMR	Q2 2018	3,000
12.3 Disseminate, mainstream and integrate all project Communication Plans and establish a joint commission on Muri Lagoon	MoE/MMR/NES/ICI	Q2 2018	3,000
12.4 Establish a regular monitoring programme of news, travel website comments and social media feedback on Muri Lagoon's health and seaweed blooms (monthly/quarterly)	MMR/CITC	Q2 2018	4,000
12.5 Publish and make available to the public regular information on Muri Lagoon's health status and water quality indicators (monthly)	MMR	Q1 2018	5,000
12.6 Establish an Emergency Communications Protocol to be implemented in case of major Seaweed Outbreaks or Public Health issues	MMR	Q1 2018	2,000
12.7 Develop a Ready-to-use Communications Toolkit on Muri Lagoon's health (for Schools).	MMR	Q1 2018	8,000

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