Coastal Water Quality Assessment Report: Rapid Assessment of Priority Coastal Areas for Hihifo, Tongatapu, Kingdom of Tonga

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ABBREVIATIONS

ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
cfu	colony forming unit
cfu/100 mL	colony forming unit per 100 millilitres
DO	Dissolved Oxygen
EC	Electrical Conductivity
EDTA	EDTA
GEF	Global Environment Facility
IWCM	Integrated Water and Coastal Management
IW R2R	International Waters Ridge to Reef Project
L	litres
mg/L	milligrams per litre
mL	millilitres
mV	millivolts
MLNR	Ministry of Lands and Natural Resources
MPN	Maximum probable number
mV	millivolts
NRD	Natural Resources Divison
ORP	Oxidation Reduction Potential
ppt	parts per trillion
R2R	Ridge to Reef
RapCA	Rapid Coastal Assessment of Priority Coastal Areas
SSG	Specific Seawater Gravity
TDS	Total Dissolved Solids
WHO	World Health Organization
TOR	Terms of Reference
VEPA	Vava'u Environmental Protection Association
WRM	Water Resources Management
µS/cm	microsiemens per centimetre (unit of electrical conductivity, EC)

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EXECUTIVE SUMMARY

I. Introduction

This Water Quality Assessment for Hihifo district was conducted as part of the Rapid Assessment of Priority Coastal Areas (RapCA), a component of the Global Environment Facility (GEF) multi-year International Waters Ridge to Reef (IW R2R) project implemented regionally through the Pacific Community (SPC) and managed through the project management unit within the Ministry of Lands and Natural Resources (MLNR) of Tonga.

Under the consultancy agreement with the MLNR, the RapCA involved three components:

- an Environmental Survey, which involved conducting surveys of all coastal habitats and recording and identifying unique and threatened biodiversity as well as invasive species, and establishing recommendations that support the protection and management of ecosystems;
- a Social and Economic Household Survey; and
- a Water Quality Assessment.

The Social and Economic household survey will include social discussions and gender considerations in Environmental Survey and the Water Quality assessment work. The social survey will establish the social baseline to be used for the assessment work and include stakeholder engagement plans, consultations with all sectors of the community, with benefits and impacts of the project on men, women and vulnerable groups considered. It will link scientific information and social, economic and gender issues for better understanding of the RapCA.

This report is on the Water Quality Assessment Component of the RapCA, which seeks to bridge the information between the Environmental Survey and the Social and Economic Household Survey. The findings of the Water Quality Assessment address the extent of threats and the impacts of these threats to the environment both, through natural sources of sea-level rise and climate change, and from anthropogenic sources such as unsustainable agricultural and fishing practices as well as unsustainable developments in terms of infrastructure and mismanagement of natural resources.

The purpose of this report is to:

- Provide findings of the status of the coastal water with probable sources of pollution of the Hihifo lagoon to better support the Rapid Assessment of the Biodiversity of the Hihifo lagoon.

This report does not constitute a baseline, nor was it the goal of this component of the RapCA. Therefore, this report cannot confirm nor explain the specific sources of pollution to the coastal water but seeks to highlight areas of interest for future water quality assessments. The interpretation of the data is theoretical and is based on similar water quality assessment examples both within the Kingdom and abroad. This coastal water quality assessment, being the first of its kind to be carried out in this area, has no previous monitoring or testing data available for comparison. The interpretation of hydrogeological data is based on historic monitoring data collected and stored with the Water Resources Management unit in the Natural Resources Division of the MLNR.

Water is an essential part of life for all living things and not just humans. There are complex relationships in nature, which are the foundation of healthy ecosystems. Understanding these relationships requires first establishing baseline data that can be interpreted to be a 'state of normal'

in this and any environment. This report provides an initial snapshot analysis and highlights the need for a prolonged period of monitoring over time to fully understand the 'state' of coastal waters in Hihifo.

The following outlines the analysis of data collected during the Water Quality Assessment conducted between 23 and 26 May 2020 and provides recommendations for future monitoring and project activities that would be beneficial to the biodiversity and ecosystem of the Hihifo Lagoon.

This component of the RapCA in Hihifo, and all activities under this component, were carried out with only the resources that were readily available with the Natural Resources Division of MLNR. Therefore, any other resources in terms of equipment and subsequent methodologies that are not mentioned in this report were not considered. The following constraints are noted for reference:

- Other means of water quality assessment inclusive of all parameters that requires further procurement were not considered.
- Certain methodologies, testing equipment and facilities that are not available in Tonga either in resources, policy or proper waste disposal facilities were not considered.
- Other activities that were not within the scope and budget of the RapCA TOR were not considered.

II. Findings and Conclusion

The parameters tested for in this water quality assessments were:

Physicochemical

The physicochemical parameters measured at each site were:

1. **pH:** varied amongst all testing sites but within tolerable range for aquatic environments. The resulting measurements were deemed reliable when analysed against temperature readings of each site. This is due to the influence of temperature on pH calculated as per Nernst Equation. Thus, the co-relation allows for the pH measurements to stand.
2. **Electrical Conductivity:** resulting measurements were within acceptable range of electrical conductivity found in coastal waters found of similar area and conditions (ANZECC/ARMCAN 2000).
3. **Temperature:** measurements were consistent with the weather conditions of the day, location of site along the coast, and conditions of the site tested i.e., distance from settlement, silt depth etc.
4. **Oxidation-Reduction Potential (ORP):** measurements provided insight into the biochemical reactions of the water body at each site, but most importantly, determined the coastal waters to be in an unhealthy state. Results were consistent with conditions of each site i.e., silt depth, distance from settlement and location of site, either in or near mangrove forest or enclosed reclaimed land areas.
5. **Specific Seawater Gravity (SSG):** measurements were consistent with the Salinity and Electrical Conductivity measurements take at each site. They were also consistent with location and conditions of each site. For example, Site 19 measured 0, which is consistent with the conditions of the site, which is a depression in reclaimed land that collects water from rain and runoff.

6. **Dissolved Oxygen (DO):** resulting measurements were consistent with other parameters and conditions of each site.

7. **Total Dissolved Solids (TDS):** resulting measurements were consistent when analysed against the other parameters measured and the conditions of the sites.

8. **Salinity:** the resulting measurements were consistent with the conditions of each site.

It is important to monitor these variations of the physicochemical parameters to understand the relationship between all the factors of the coastal area, including activities on land, activities in the lagoon, the status of the ecosystem of mudflats and intertidal areas and fringing reefs.

Nutrients

Phosphate and ammonia concentrations exhibited normal background concentrations at some sites and normal elevated concentrations at other sites, which were relative to the surroundings of each testing site. However, all results were within threshold of tolerance advised for such areas.

Nitrate concentrations along the coastline were close to non-existent, which is an anomaly as five out of eight test sites measured 0 mg/L. This requires monitoring of the coastline on a quarterly basis to better understand the relationships within the ecosystem and explain these findings.

Metal contaminants

Six metal contaminants were tested for in this water quality assessment component.

- Zinc
- Copper
- Hexavalent chromium
- Manganese
- Iron
- Nickel

Of all the contaminants tested for along the coastal waters, zinc was found in the lowest concentrations. Zinc was found in two sites with concentrations exceeding the guideline value provided for 99% protection of species, but below the guideline values for recreational use and protection of aquaculture species (ANZECC/ARMCANS 2000).

Manganese was found in low concentrations in six of the eight sites tested. Concentrations were very low and well below any guideline value provided for manganese in coastal waters.

Copper, nickel, iron, and hexavalent chromium were found in all eight testing areas in varying concentrations. All exceeded the guideline values for recreational uses, 99% protection of species and protection of aquaculture species. These concentrations are more than the background concentrations associated with these metals/metalloids in nature. Further investigations into the sources of these additional amounts of metals/metalloids in the coastal water is required.

Microbiological

Faecal coliform counts were found throughout all testing sites along the coastline of the Hihifo lagoon. Specific sources of these faecal coliform cannot be confirmed in this assessment. It is safe to

assume now from initial assessment of the surrounding area of each testing site, relative to the test results, that wandering animals such as pigs and dogs are major contributors to the faecal counts found along the coastal water areas.

III. Recommendations

This coastal water quality assessment provided an initial perspective on the status of the coastline. These initial findings cannot do more than confirm that the coastal area and the lagoon of Hihifo needs further assessments and regular monitoring for a minimum of three years. The findings of the water quality component confirm the heavy impacts of human activities along the coast but cannot determine specific cause or source of disturbance to the coastal water area.

It is recommended that additional sites along the coastline, from Sopu to Ha'atafu, and sites from the small islands within the lagoon be assessed and monitored as well. This is to fully understand the dispersion patterns of pollutants to confirm specific sources of pollutants.

INTRODUCTION

1. Overview

This Coastal Water Quality Assessment report was prepared for the Vava'u Environmental Protection Association (VEPA) and the Integrated Water and Coastal Management Project (IWCM) and is a component of the Rapid Assessment of Priority Coastal Areas (RapCA) in the villages of Fou'i, Ha'avakatolo, Kolovai, 'Ahau, Kanokupolu and Ha'atafu in the Hihifo district.

The Coastal Unit includes a number of assets (over 400 households) and coastal community

populations (approx. 2353) as below, based on information from the 2012 Tonga Census:

- Ha'atafu village (39 households; 236 people)
- Kanokupolu village (53 households; 324 people)
- Ahau village (57 households; 367 people)
- Kolovai village (124 households; 607 people)
- Ha'avakatolo (44 households; 235 people)
- Fo'ui (84 households; 584 people)

(SPC 2013).

The heads of households in the six villages are predominantly male with 19% being women. Sources of household income are mostly waging and salaries (50% of households). Nearly 30% of all income is derived from the household's own agricultural production activities, including women's craft productions. A high percentage of households also receives overseas remittances (PACC 2015).

The RapCA is an initiative under the International Waters Ridge to Reef Project (IW R2R) funded by the Global Environment Facility (GEF) and managed through the Pacific Community (SPC). The IW R2R project is a key component of the IWCM project housed under the Ministry of Lands and Natural Resources (MLNR), Tonga.

The report outlines the results of a water quality assessment carried out at eight sites along the intertidal areas of the lagoon coastline along the Hihifo peninsula, from Fou'i to Ha'atafu. The results of this assessment were compared with available results of relevant studies carried out in Tonga and neighbouring countries of similar environment. Recommendations are made regarding future water quality assessments, management, and related aspects.

2. Assessment Goal

The goal of the Water Quality Assessment Component of the RapCA is to assess the level of nutrient and bacteriological pollution of the coastal waters in the coastal area of the IWCM project sites in Hihifo.

3. Background

The Hihifo lagoon borders the Hihifo peninsula on the north-eastern side. This large lagoon covers an area of approximately 73 km². There are five raised rock and small sand islands within the lagoon. These are: Toketoke – a small rock island to the north-west of the fringing reef; 'Ata'ata – a large island approximately 4 km north-east of Toketoke; Tufaka – a small sand island 1 km south-east of 'Ata'ata; and Poloa'a and Alakipeau – two small rock islands on the enclosing fringing reef 2–3 km south-east of Tufaka Island.

In the middle of the lagoon sits a vast mudflat called Tahi Toafa, loosely translated as Desert Ocean, depicting the nature of the mudflat at low tides. Along the Hihifo coastline are scattered mangrove forest and six villages that exclusively sit along the Hihifo peninsula.

The lagoon has been a source of livelihood for many of the villages in Hihifo and for the smaller settlements on the small islands in the lagoon. It plays a prominent central role in the culture, tradition, and verbal history of the Hihifo side of Tongatapu but remains an understudied part of Tongatapu.

The use of marine resources by men and women can provide a fuller picture of livelihood sources in the area, what are the main sources of subsistence and economic livelihoods, and how development has affected gender roles. Although gender ideologies proclaim a social superiority for women (based on the cultural obligations of men to their sisters), their overall status is also shaped by factors other than their position as female siblings. For example, gender interacts with kinship-based rank to produce very different outcomes for women at opposite ends of the social scale. In addition, the (external and internal) forces of change are eroding some of the more positive aspects of women's former traditional status (Emberson-Bain 1998).

Due to its geography and geology, the Hihifo peninsula has experienced heavy impacts of climate change in the last 30 decades (Kitekei'aho 2014). Over the same period, there have been many developments in the area towards improving coastal protection alongside activities to upgrade the groundwater systems that feed the six villages of the IWCM project. Simultaneously, several resorts have been, or a being built, along the south-western ocean-side coastline, a popular tourist destination with its sandy beaches. There was no testing for water quality along this coastline as the priority area for this RapCa was the lagoon of the Hihifo peninsula and not the ocean-side of the peninsula.

The advancement of technology and influx of western amenities has seen an increase in residential and commercial developments in the six villages. Although the population fluctuates, it is still a densely populated place in comparison with areas of similar size on Tongatapu (Tonga Statistics Department 2016).

Historically comprising of fishing villages, the tides have turned, and a great number of the population now relies heavily on agriculture. Increase in residential and commercial development in the six villages and building of resorts in the area has contributed to the shift in livelihood dependence from fisheries to agriculture. This shift in livelihood sources could impact women and men in different ways, particularly in terms of their different areas of interest and traditional roles.

The diversification of the agricultural sector some 35 years ago, from low-profit traditional commodities towards high profit yielding activities such as squash and vanilla, was the beginning of private entrepreneurship (Sturton 1992). Private entrepreneurship has also led to commercialised methods of agriculture to meet export demands (PHAMA programme 2018). Fishermen and fisherwomen from various places in Tonga have now taken up the vacant niche and have set up

temporary settlements in and around the islands of the lagoon to pursue this livelihood. Although most women in the western-most villages of 'Ahau, Kanokupolu and Ha'atafu still find daily meals from marine resources within the lagoon, most are there to earn an income.

This water quality assessment has focused on the water quality along the coastline of the lagoon. The groundwater was not assessed in this round of testing due to the location of the current water supply borewells, which are not located on the peninsula itself. The groundwater that supplies water to the six IWCM villages is located 1–1.7km south-east of the centre of the settlement of Fou'i (Kitekei'aho 2014).

The freshwater lens in the Hihifo peninsula was initially found to be brackish (Kitekei'aho 2014). However, historic monitoring data shows the lens conductivity to fluctuate between 1500 µS/cm and above the human potable limit of 2500 µS/cm (compare Figure 1 and Figure 2). Historic monitoring data from 2007 (Figure 1) shows the water lens to be fresh (1500 µS/cm – 2500 µS/cm) in areas of Ha'avakatolo and brackish closer to the western tip of the peninsula at Ha'atafu (above 2500 µS/cm).
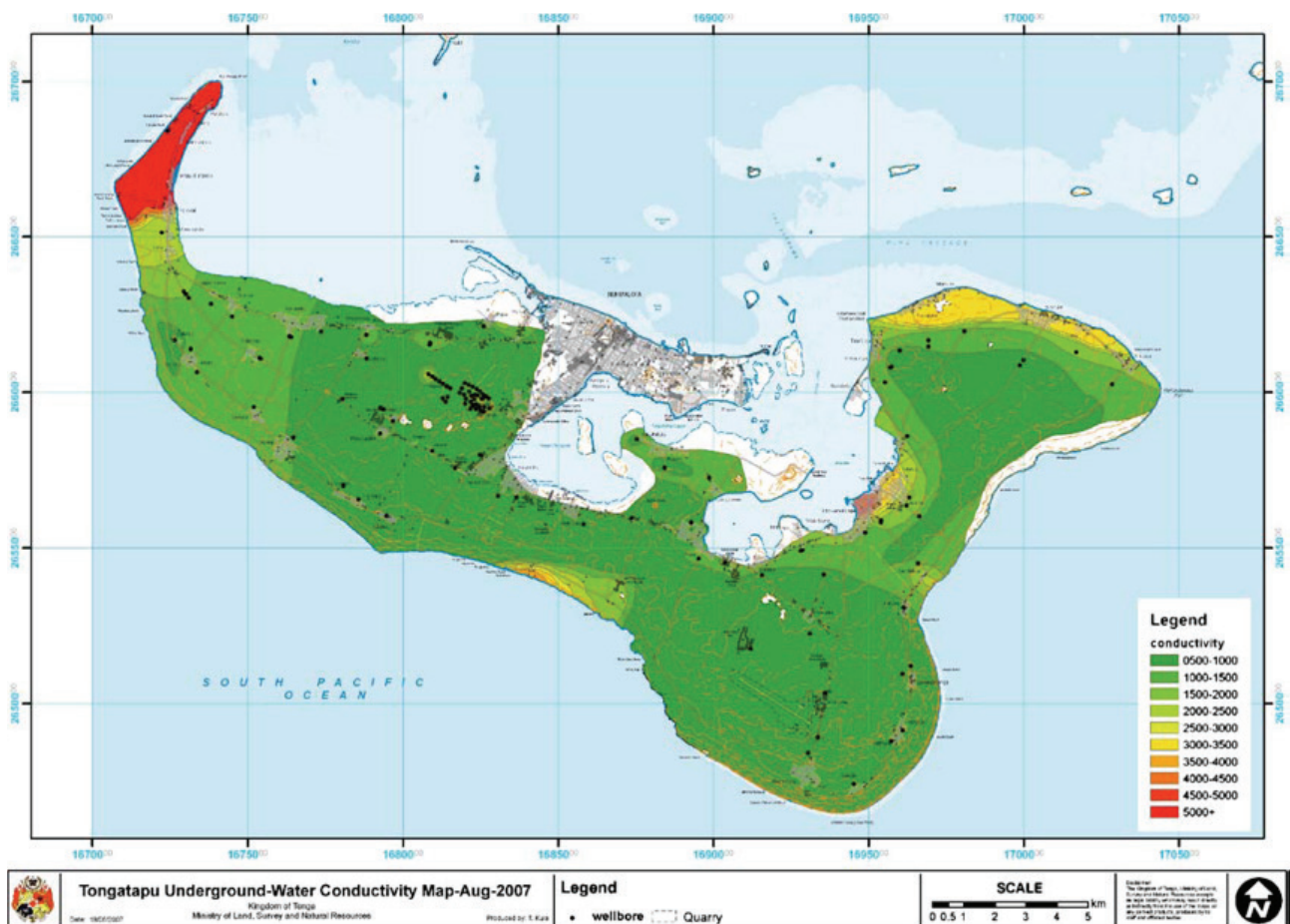
Figure 1. Conductivity map of groundwater in Tongatapu. The Hihifo peninsula is marked distinctively from Kolovai onwards towards Ha'atafu in red, meaning conductivity range is above the potable limit of 2500 microsiemens per cm. Fou'i towards Ha'avakatolo water conductivity are found to be in the range of 1500-2500 microsiemens per cm.

Three borewells are located on the peninsula: two in Ha'avakatolo where historic data shows the conductivity of the water lens is in the range of 1500 µS/cm – 2500 µS/cm and one private borewell in Kanokupolu, where the water lens conductivity is found to be above the human potable limit of 2500 µS/cm (See Figure 1). In recent years, the monitoring data mapping (Figure 2) shows the conductivity of the water lens has lowered. The groundwater conductivity range was found to be between 1500 µS/cm –1800 µS/cm in most areas of the Hihifo peninsula.

Other than reviewing the historic data available at the Water Resources Management unit of the Natural Resources Division, no testing was carried out on the groundwater as the borewells mentioned above were either locked or inaccessible at the time of field mission.
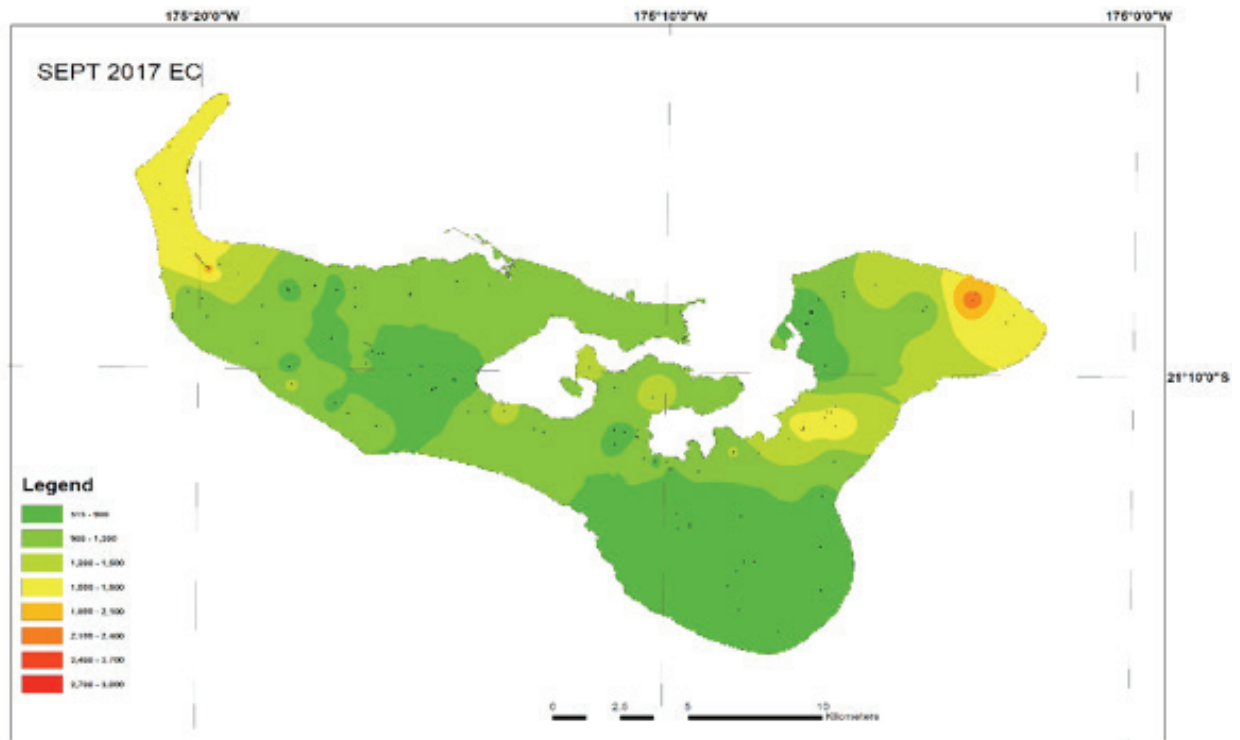
Figure 2. Conductivity mapping of Tongatapu for 2017. Hihifo peninsula is showing groundwater conductivity in the range of 1500 - 1800 microsiemens per cm.

The narrow strip of land in the Hihifo peninsula is low-lying at about 2 m above sea level. The six villages are located closely along the coastline of the lagoon, rather than on the ocean-side of the peninsula. Although the villages utilise all the surrounding coastal area, there is heavy emphasis on the large lagoon area; thus, the relationship between the coastal villages on the peninsula and this complex ecosystem. The water quality along the coastline would provide not only insight on the status of the complex relationships at play within this ecosystem, but also highlight gaps in current management of resources in the area with direct and indirect impacts on the watershed. Recent mapping of the catchment area is shown in Figure 3. This map shows the importance of the relationship between activities in the catchment area for all villages on the western arm of the island of Tongatapu from Puke to Ha'atafu and the Hihifo lagoon.

Figure 3. Hihifo Water Catchment Map depicting the area of the Catchment and highlighting the extent of activities on land that can impact on the Hihifo lagoon.

OUTLINE OF WATER QUALITY COMPONENT

1. Terms of Reference

The Terms of Reference for the Water Quality Assessment component of the RapCA are provided in Annex 1.

2. Summary of Activities

Eight sites were identified along the coast for the RapCA in Hihifo. These sites were identified via Google Maps, GIS maps and drone images that were readily available at the Natural Resources Division and using Google Earth prior to a preliminary site visit with the water quality team on 20 May 2020.

The purpose of this preliminary trip was to assess the accessibility to, and the conditions of the sites prior to the set date of testing on 23 May 2020.

The Water Resources Laboratory was prepared alongside the equipment required for the task on 21 and 22 May 2020. High tide was forecast for 7:30am on 23 May 2020 and fieldwork was conducted at eight sites on Saturday 23 May 2020 during the hours of 7am and 11am.

Table 1. Schedule of Activities for the Water Quality Assessment Component.

Activities	Timeframe
Desktop studies on area to be tested	11 –18 May 2020
Mapping of sites	19–21 May 2020
Preliminary visit to sites	21 May 2020
Equipment checks/lab preparation work	21 –- 22 May 2020
Field mission for sampling and on-site measurements	23 May 2020
Laboratory testing	23 – 25 May 2020
Data collaboration and discussion	26 – 28 May 2020

Samples were taken for faecal coliforms, nutrients (ammonia, nitrate, and phosphate) and metal contaminants to be tested in the laboratory. On-site measurements of other relevant parameters (pH, TDS, Salinity etc.) were measured in addition to the sampling procedure carried out. Details of all eight tested sites, water quality parameters, test methods and other details are provided in the Water Quality Assessment Details.

3. Water Quality Assessment Team and Duties

Table 2. Water Quality Assessment Team & Duties

Name	Position & Organisation	Designated Roles
Sesimani M T Lokotui	Water Quality Consultant - Independent	Water Quality Assessment Lead
Folauhola Latu'ila	Assistant Geologist – MLNR	Heavy Metal Testing, Sites & Sampling
Ameilia Sili	Assistant Geologist – MLNR	Sites Assessment, Faecal Coliform Testing
Penikolo Vailea	Hydrogeologist – MLNR	Nutrient Testing, Heavy Metal Testing
Apai Moala	Senior Geological Assistant – MLNR	Equipment Inventory and Checklist, Lab Work Preparation
Tiana Matoto	Assistant Geologist Grade II – MLNR	Laboratory Assistant, Nutrient Testing, Sites Assessment
Nimo Ngauamo	Logistical Assistant – MLNR	Logistical assistant, Equipment handling

4. Water Quality Assessment Sites
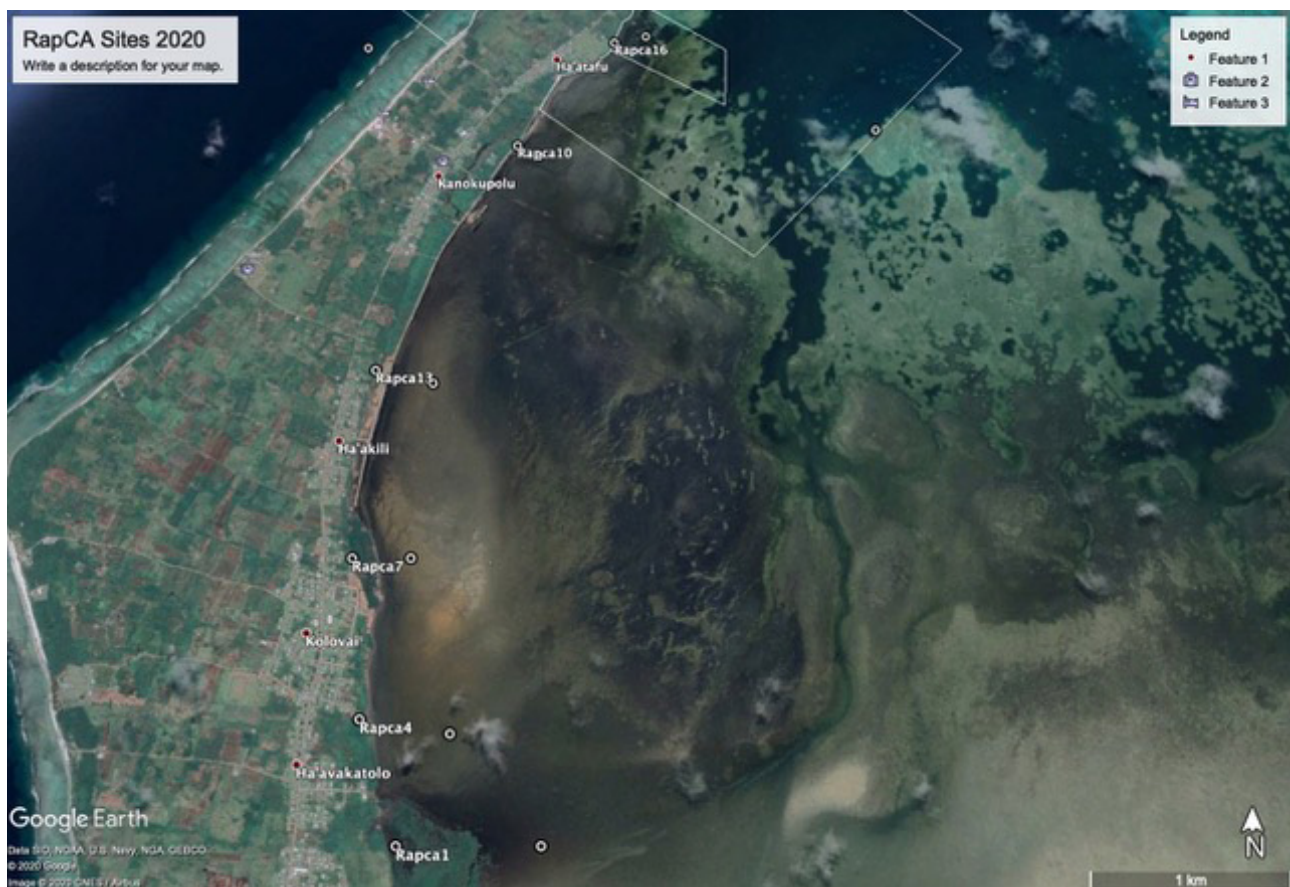
Figure 4. Initial Water Quality Assessment Sites

WATER QUALITY ASSESSMENT DETAILS

1. Water Quality Assessment Sites

Originally a total of six sites was requested for Water Quality Assessment for the purpose of this RapCA for Hihifo.

Additional sites of RapCA 19 and RapCA 20 were requested prior to commencement of the fieldwork by the RapCA Lead, Karen Stone. The additional two sites were matters of concern to the Biodiversity Team due to indicators of high pollution seen in the area.

Eight sites were thus confirmed for the on-site testing and sampling for microbiological, nutrient and metal contaminants for 23 May 2020 (Figure 5).
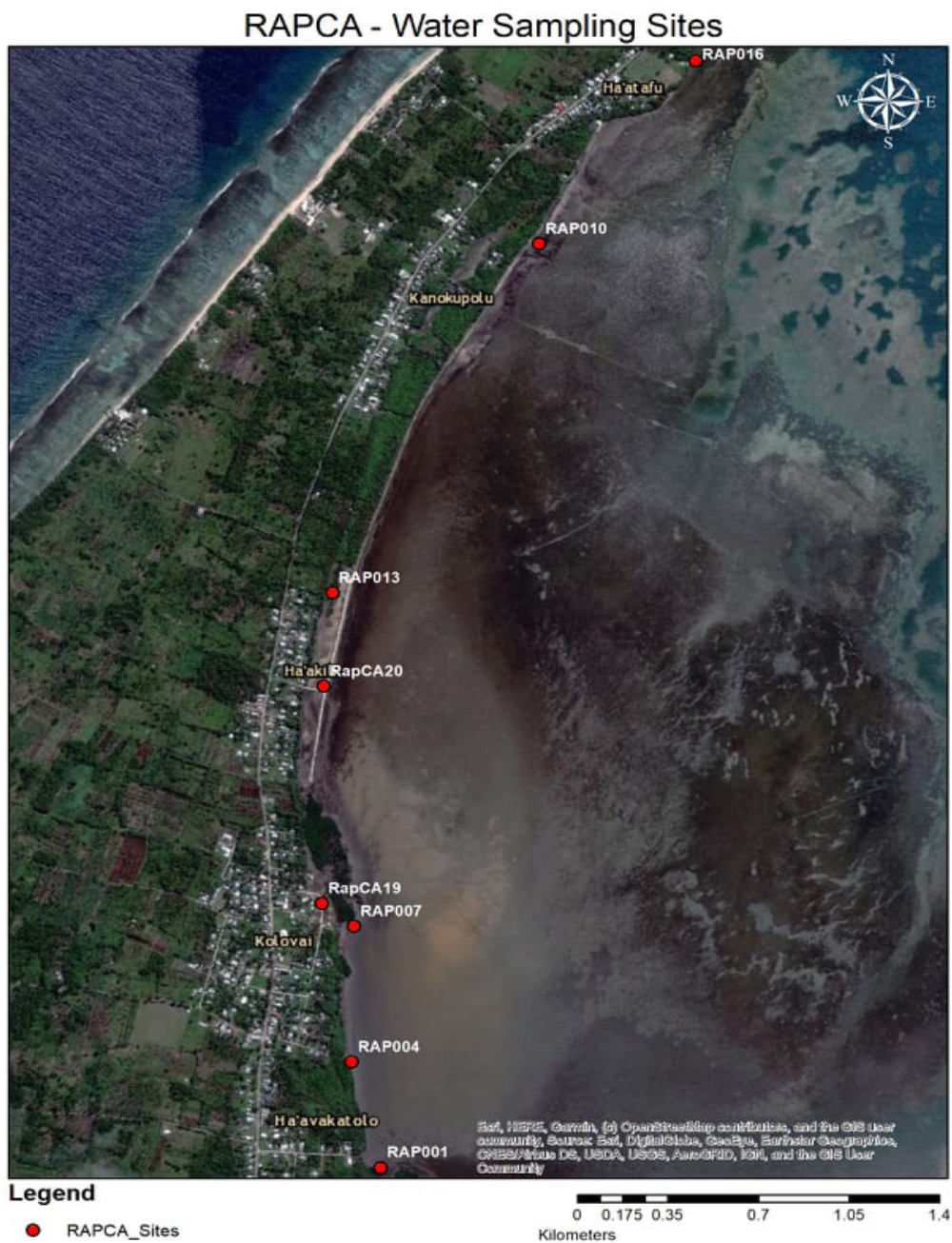
Figure 5. A total of 8 water quality testing sites along the Coastline of the Hihifo Peninsula

2. Parameters

2.1 Physicochemical

The physicochemical parameter is a broad definition of measurements taken on-site for the following:

I.   Temperature (°C)
II.   Acidification (pH)
III.   Oxidation Reduction Potential (ORP)
IV.   Dissolved Oxygen (DO)
V.   Electrical Conductivity (EC)
VI.   Total Dissolved Solids (TDS)
VII.   Salinity
VIII. Specific Seawater Gravity (SSG)

There could be more parameters measured subject to equipment and technology available. For this testing, a multi-meter with the parameters mentioned above was readily available to be used. Given the pioneering nature of the present water quality assessment with no baseline data available for comparison, it was deemed in the best interest to measure the maximum number of parameters at each site. This was carried out to create a better understanding of the state and nature of the coastal waters of the Hihifo peninsula that could be interpreted alongside data from socio-economic and biodiversity surveys. This is to achieve the goal of better understanding the unique relationships of the ecosystem that is the Hihifo peninsula.

2.2 Nutrients

There are a few indicators of various forms of pollution readily available to be tested for in water. The Water Resources unit of the Natural Resources Division of the MLNR perform tests for concentrations of *nitrate, phosphate, and ammonia* as an indicator of possible pollution in water sources. These three nutrients are naturally occurring in water sources. It is only when the natural state of the water sources is disturbed that the background concentrations of these nutrients would occur in high levels (WHO 2008, ANZECC/ARMCANZ 2000). These tests were carried out for the RapCA sites and used as an indicator of polluted water and disturbed ecosystem.

All plants (terrestrial as well as aquatic) require two essential nutrients to grow: nitrogen (N) and phosphorus (P). These nutrients occur in small amounts in healthy water bodies such as the coastal water environment of Hihifo. However, nutrients can cause a major water pollution problem when they are in large quantities. The rapid growth of plants and algae are stimulated by large quantities of nutrients. This leads to waterways becoming clogged. Blooms of toxic blue-green algae are sometimes created by these clogged waterways. This process is called eutrophication. This results in the death of plants and algae. The decomposition of this dead matter uses up large amounts of oxygen (O_2) that is available in the water, meaning that oxygen availability for fish and other aquatic species will be reduced. This can lead to an environment that is so completely oxygen deprived that only a few species of anaerobic bacteria can thrive in it. This is an extreme case scenario that results in death of fish and other aquatic life. Additionally, the aesthetic and recreational value of the water body can be greatly reduced (Millero 1996).

Cultural eutrophication is a process whereby the natural eutrophication is accelerated due to human inputs of nutrients from the atmosphere and from nearby urban and agricultural areas. These inputs

can include nitrates commonly found in sewage and fertilisers, and phosphates commonly found in detergents and fertilisers (Harris 2001).

Nutrient enrichment from urban sources of settlements may be derived from domestic sewage, industrial wastes and storm drainage or run-off from agricultural lands. These are the principal sources of nutrient overload causing cultural eutrophication in water bodies (Harris 2001).

The amount of each source varies according to the types and amounts of human activities occurring in each airshed and watershed (Harris 2001).

2.3 Metal Contaminants

The Earth's crust contains metals and metalloids. These are released to the soils and the hydrologic cycle during physical and chemical weathering of igneous and metamorphic rocks, including volcanic eruptions (Elder 1988).

The geologic characteristic of any watershed mainly controls the background concentrations of metal elements found in water. Some metals, such as aluminium and iron, are naturally abundant and have high background concentrations in some water bodies. Other metals such as silver and mercury are rare and have low background concentrations (Elder 1988). 'Trace metals' or 'trace elements' are rarer metals and have low concentrations. However, at low concentrations, many of these metals are 'micronutrients' and as such are essential for life. Metals such as manganese, iron, copper, and zinc are essential micronutrients that are at times readily available in water bodies. They are essential to life in the right concentrations. In large quantities, they become toxic. Simultaneously, chronic low exposures to heavy metals can have serious and varying health effects, depending on species, in the long run (Elder 1988).

Human activities can add to the existing background concentration of metals in a system, causing an over-abundance that leads to the water source being polluted. There are plenty of anthropogenic sources of metal to the environment. These sources are usually grouped into two types: 1) A point source is when the contaminants are localised and usually the source can be easily identified as a single source; and 2) Nonpoint sources are where pollutants come from dispersed sources and are very difficult to identify. The natural weathering of ore bodies and the minute metal particles coming from coal-burning power plants via smokestacks in air, water and soils around factories are only a few examples of localised metal pollution. In larger, developed countries main sources of metal contaminants are from the mining industries using acid mine drainage system to extract heavy metals from ores (Masindi and Muedi 2018).

2.4 Microbiological

The environment, including soils, groundwater, and lagoon water, are home to microorganisms invisible to the naked eye. These include pathogenic microorganisms such as various types of bacteria, viruses, and protozoa. While microorganisms are essential to the ecosystems on which we depend, there exist pathogenic microorganisms that are a major concern for human health and are responsible for a range of gastro-intestinal and other illnesses (Falkland 2013).

Salmonellae, Shigella, Campylobacter, Vibrio cholerae, Staphylococcus aureus and *Escherichia coli* (*E. coli*) are some of these disease-carrying bacteria that can be found in aquatic environments. *Rotavirus*, *enterovirus*, *norovirus* and *hepatovirus A* are a few viruses that can be transmitted by water. Examples of waterborne pathogen protozoa include *Giardia* and *Cryptosporidium* and the amoebae *Naegleria fowleri* and *Entamoeba hystolytica* (Falkland 2013).

It is often difficult and expensive to directly test for pathogenic organisms in water. Therefore, indicator organisms are commonly used to determine the risk that pathogenic organisms may be present (Mosley et al. 2005). The rationale is that the large numbers of indicator organisms found in a water sample indicates a high risk that pathogenic organisms might also be present.

Coliform bacteria including faecal coliforms, and *Escherichia coli* are common indicator organisms used in water quality testing. *E. coli* is the main constituent of a group of bacteria called faecal coliforms (also called thermotolerant coliforms). Faecal coliforms as a group are a subset of Total Coliforms (see Figure 6) (Falkland 2013).

Mosley et al. (2005) and Falkland (2013) noted that **Total coliforms** are *not an ideal indicator* in the tropics. This is because Total Coliforms can *naturally* persist and reproduce in soil and water in the tropics due to the warm conditions. Thus, the use of total coliforms as an indicator of water quality in Tonga is not advised nor practiced. Verification of water quality for use typically includes testing for *E. coli* as an **indicator** of faecal pollution. An acceptable alternative in many circumstances where *E. coli* testing is not available, is testing for **thermotolerant (faecal) coliform bacteria** (WHO 2011). The alternative was used in this study. Faecal coliforms were used as the indicator bacteria in this coastal water testing for possible pathogenic organisms which are

Figure 6. Diagram showing E. coli as the main constituent of the faecal coliform subset.

harmful to human health by either ingestion or through contact with abrasions on skin or in eyes and ears (WHO 2003). Pollution from warm blooded animals and sanitation systems (pit toilets and septic tanks) could be indicated by the presence of faecal coliforms, especially in large numbers (Falkland 2013).

3. Sampling and Testing Equipment and Location

Table 3. Equipment and Testing details across testing sites

Parameter		Site No.	Equipment
Physiochemical	Temperature	All sites	On Sites tests using Palintest multi-meter
	ORP	All sites	On Sites tests using Palintest multi-meter
	pH	All sites	On Sites tests using Palintest multi-meter
	DO	All sites	On Sites tests using Palintest multi-meter
	EC	All sites	On Sites tests using Palintest multi-meter
	TDS	All sites	On Sites tests using Palintest multi-meter
	Salinity	All sites	On Sites tests using Palintest multi-meter
	Specific Seawater Gravity	All sites	On Sites tests using Palintest multi-meter

	Parameter	Site No.	Equipment
Nutrient	Phosphate	All sites	WRM Laboratory tests using Palintest Photometer 7500
	Ammonia	All sites	WRM Laboratory tests using Palintest Photometer 7500
	Nitrate	All sites	WRM Laboratory tests using Palintest Photometer 7500
Microbiological	Faecal Coliform	All sites	WRM Laboratory tests using Palintest membrane filtration kit
Metal Contaminants	Zinc	All sites	WRM Laboratory tests using Palintest Photometer 7500
	Nickel	All sites	WRM Laboratory tests using Palintest Photometer 7500
	Copper	All sites	WRM Laboratory tests using Palintest Photometer 7500
	Manganese	All sites	WRM Laboratory tests using Palintest Photometer 7500
	Iron	All sites	USP Laboratory test using Palintest Photometer 7500
	Hexavalent Chrominum	All sites	USP Laboratory test using Palintest Photometer 7500

4. Checks and Calibration of Equipment

Equipment checks and calibrations were carried out prior to water testing, both in the field and in the laboratory.

The main equipment used for this water quality testing was calibrated as shown in Table 4. The photometer was calibrated at least once a quarter prior to on-going monitoring and testing carried out by the Water Resources Management unit of the MLNR Natural Resources Division.

Table 4. Calibration details for equipment used in this water quality assessment

Equipment	Date of Calibration	Method of Calibration
Palintest Macro 900 Water Quality System	22 May, 2020	MacroCal Solution
Palintest 7500 Photometer	6 May, 2020	Palintest Colour Standards A, B, C, D

5. Details of Sites and Data Collected

A summary of the water quality assessment sites and data collected on-site are provided in tables 5 and 6.

Table 5. Details of Sites sampled and tested on 23 May 2020

Site	Time	GPS Coordinates	
RAP016	07:13AM	-21.0689	-175.325
RAP010	07:58AM	-21.0754	-175.33
RAP020	08:30AM	-21.0911	-175.338
RAP013	08:52AM	-21.0878	-175.337
RAP019	09:08AM	-21.0988	-175.338
RAP007	09:23AM	-21.0996	-175.337
RAP001	10:20AM	-21.1081	-175.336
RAP004	10:32AM	-21.1044	-175.337

The testing and sampling took place on Saturday 23 May 2020. The team started from the western-most site and worked through sites along the way back towards Nuku'alofa (Table 5).

An assessment was made of the surroundings of each site and observations are provided in Table 6. The data collected from the on-site measurements are provided in the Results and Analysis section. The raw data are provided in Annex 3.

Table 6. Initial Assessment of Surroundings of each Testing Site

Site	GPS Coordinates		Observations
RapCA 001	-21.108141	-175.335715	On-site measurements and samples were taken at the edge of a mangrove forest. Sedimentation was approximately 30 cm to 45 cm deep. Plume from disturbance of silt at testing area was observed. Depth of water at testing site approximately 20 cm deep. Hydrogen sulphide release from sedimentation indicating decomposition in areas of deep sedimentation.
RapCA 004	-21.104404	-175.336723	Open mudflat. Sedimentation in a few areas only. Depth of water at testing site approximately 18 cm. Plume from disturbance of silt around testing site was observed. Hydrogen sulphide released from sedimentation indicating decomposition.
RapCA 007	-21.099592	-175.336651	Sedimentation surrounding testing site approximately 40 cm to 45 cm deep. 10 m from edge of residential fence is an area of accumulated sea grass and debris. Decomposition in surrounding area high as hydrogen sulphide released into the air whilst walking to testing site. Water depth at testing area approximately 20 cm deep. Plume from silt disturbance is observed. New shoots of mangroves seen in the area.

Site	GPS Coordinates		Observations
RapCA 010	-21.075416	-175.330216	There is a man-made trench 3 m from the foreshore. The sedimentation in area is approximately 30 cm to 40 cm deep. Plume from silt disturbance observed. Depth of water at testing site approximately 60 cm.
RapCA 013	-21.08779	-175.3374	Testing site in a mangrove forest. Plume from silt disturbance observed. Sedimentation in and around testing area.
RapCA 016	-21.068941	-175.324777	Testing site 20 m from coastline. Depth of water at testing site 65 cm. Limited sedimentation with limited plume observed. Popular fishing cove depicted by the shell middens around testing area.
RapCA 019	-21.098785	-175.33776	Testing site in a small pond within a residential curve 15 m from coastline. The pond is cut off from the coastline by a public road and small wall. The pond sits within a town allotment with evidence of in-filling of the allotment currently being carried out. The pond part of the land yet to be reclaimed. Therefore, a collection of water of sorts. Less than 10 m from site of testing stands a residential lavatory with septic system currently in use.
RapCA 020	-21.091094	-175.337699	Testing site located 20 m inland from edge of the seawall protection. In a small water-logged area of what seems to be a mangrove rehabilitation effort, pollution was observed (plastic, animal waste, cyanobacteria etc.). Sedimentation in and around area approximately 10 cm – 25 cm deep. Plume from disturbed silt observed. Depth of water at testing site 15 cm deep.

6. Recording, Checking and Archiving Procedures

Details of sample dates and times and on-site measurements were recorded in water-proof books. This data and the results from the nutrient, faecal coliform and metal contaminant testing were transferred to a spreadsheet. Copies of this Excel spreadsheet were kept with the Water Resources Management (WRM) unit in the Natural Resources Division and shared with the PMU and RapCA Lead Investigator, Karen Stone, from VEPA.

7. Results and Analysis

The results of the Water Quality Assessment are outlined in this section.

7.1 Physicochemical

7.1.1 Methodology

Eight physicochemical parameters were measured in this Water Quality Assessment. These parameters were measured on-site using a Palintest water quality multi-meter.

7.1.2 pH

Except for RapCA Site 019, the pH measurements for all sites were within the tolerance range for recreational purposes (Figure 7).

The pH measurements for all sites were within the range for protection of aquaculture species as provided by the ANZECC/ARMCANZ (2000) guideline values (Figure 8).

Figure 9 shows RapCA Site 019 is on the site of an enclosed water body much like a small pond, within a residential allotment with in-filling activities. This site is cut off from the coastline and is most likely a collection point for rainwater and runoff.
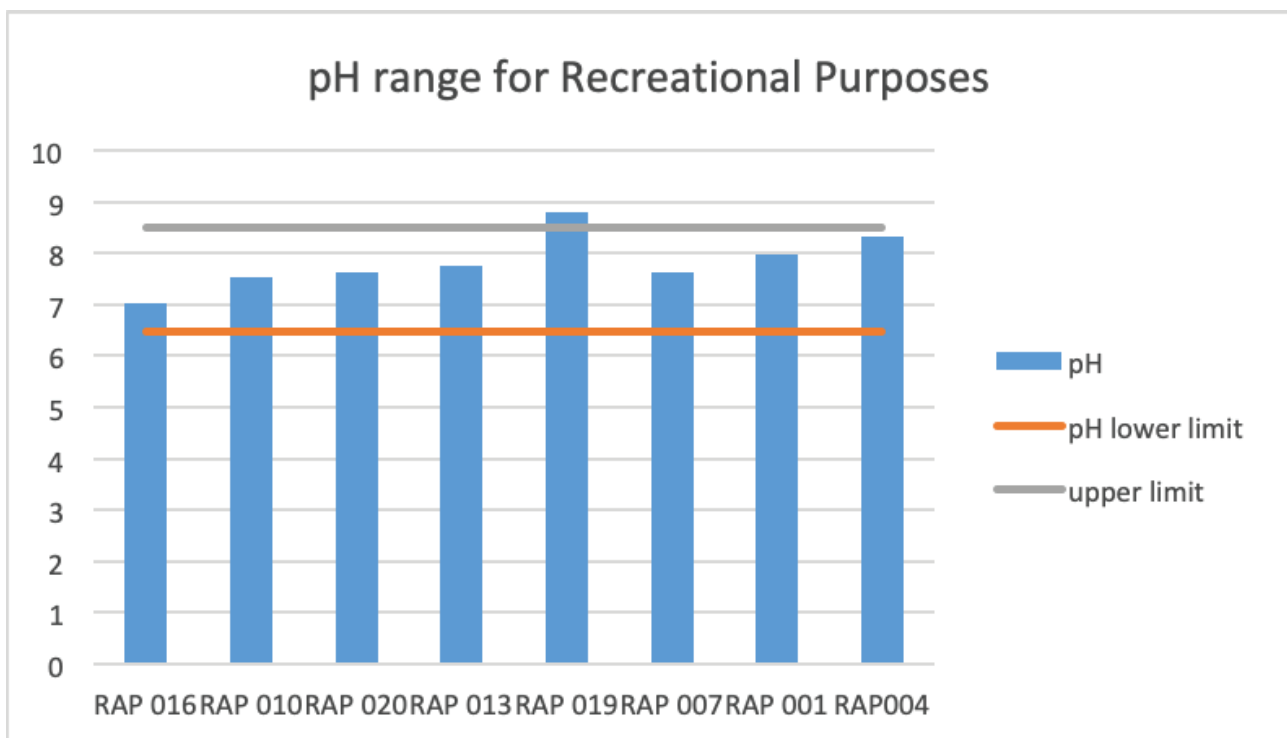
Figure 7. pH results of the 8 test sites showing lower and upper limits for recreational purposes.
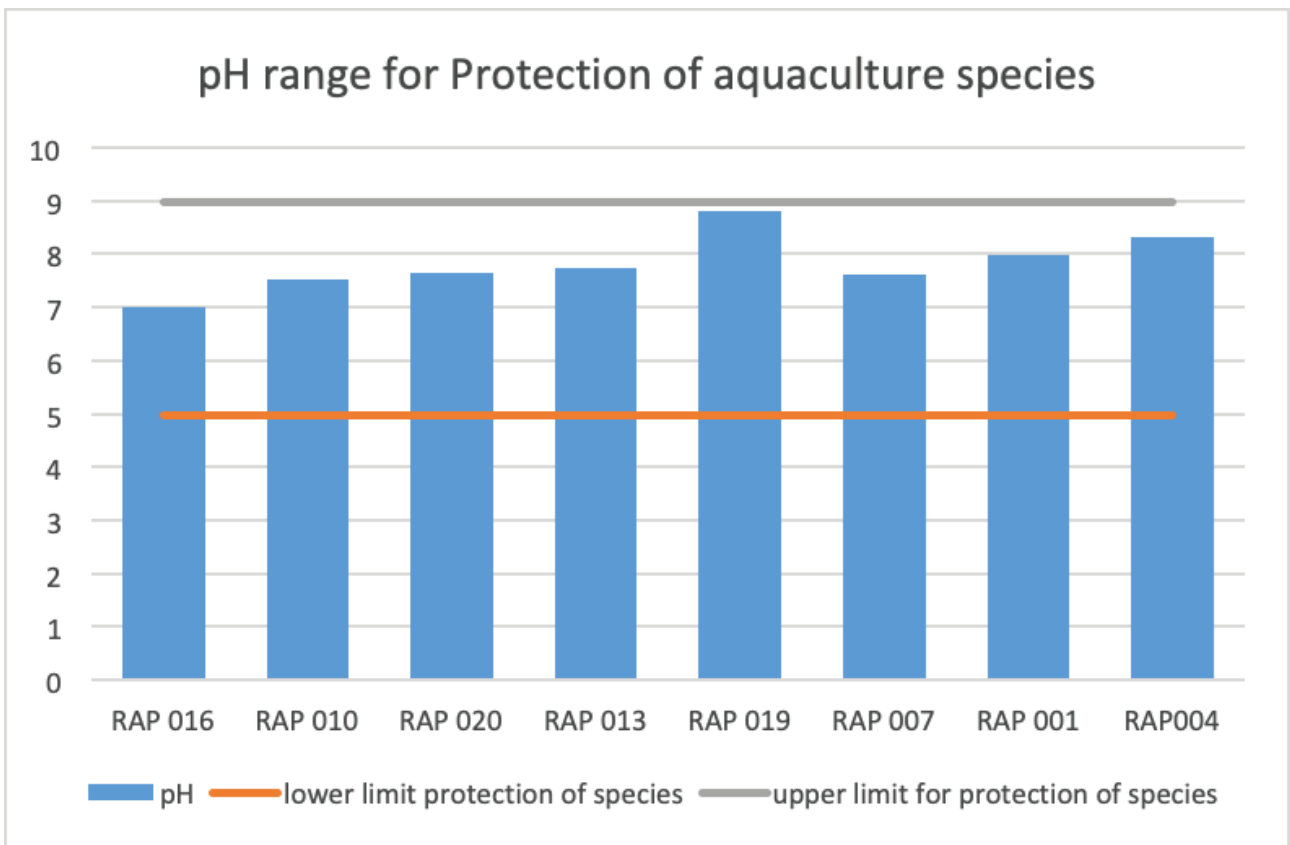
Figure 8. pH results of 8 test sites showing lower and upper limits for protection of species.
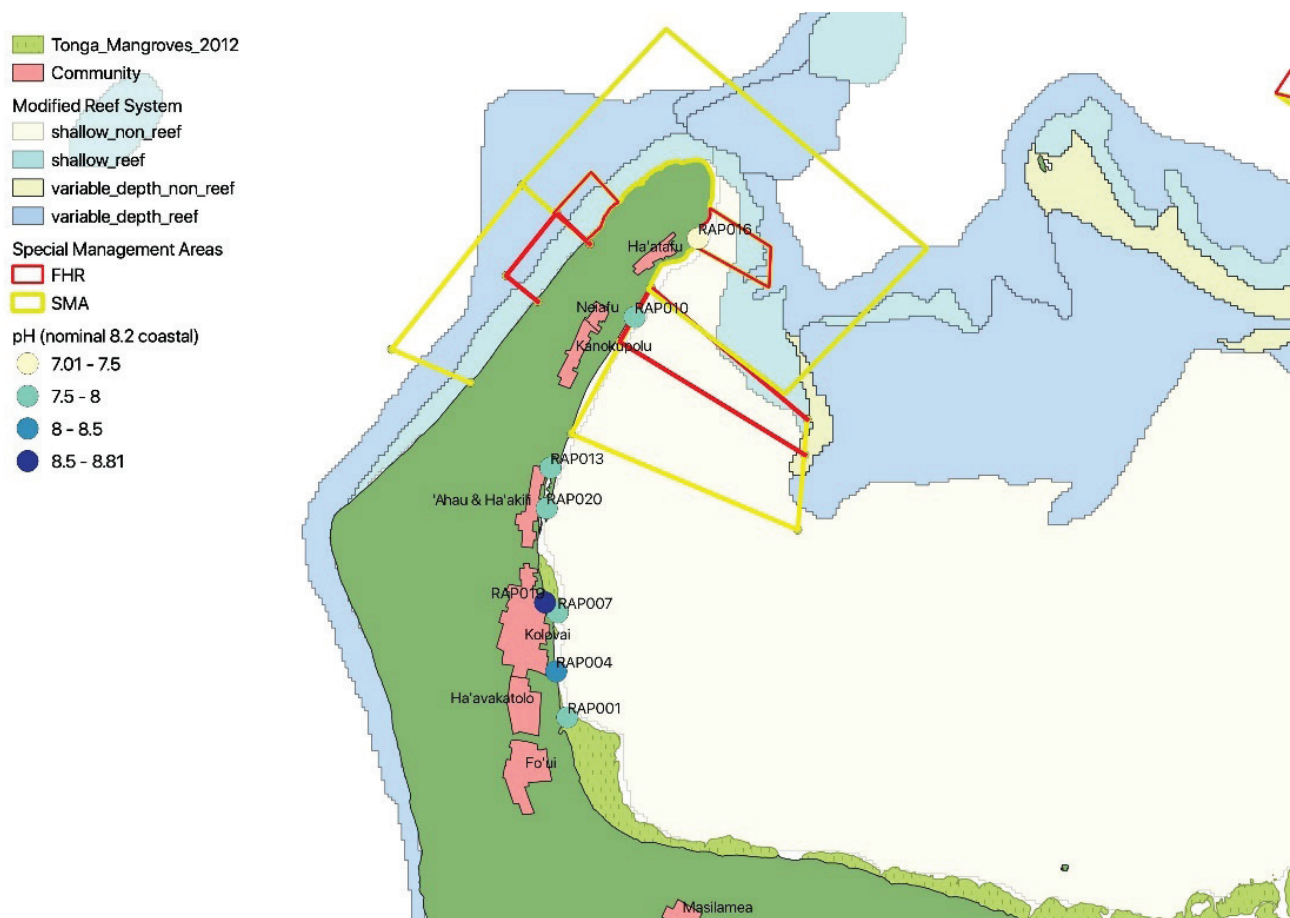
Figure 9. Map of the Hihifo peninsula showing the pH results of the 8 test sites

7.1.3 Temperature

The temperature of the water measured at each site was within normal range for the time of testing. The variability of temperature was dependent on the time of day that the measurements were taken and the surroundings of test site. Factors such as water depth and type of water body being tested explains the trend seen in Figure 10.

Temperature vs. time of measurements

	RAP 016	RAP 010	RAP 020	RAP 013	RAP 019	RAP 007	RAP 001	RAP0 04
Temperature(°C)	22.9	23.38	21.3	23.35	22.83	22.88	25.08	23.8
Time	7:13:00	7:58:00	8:30:00	8:52:00	9:08:00	9:23:00	10:20:00	10:32:00
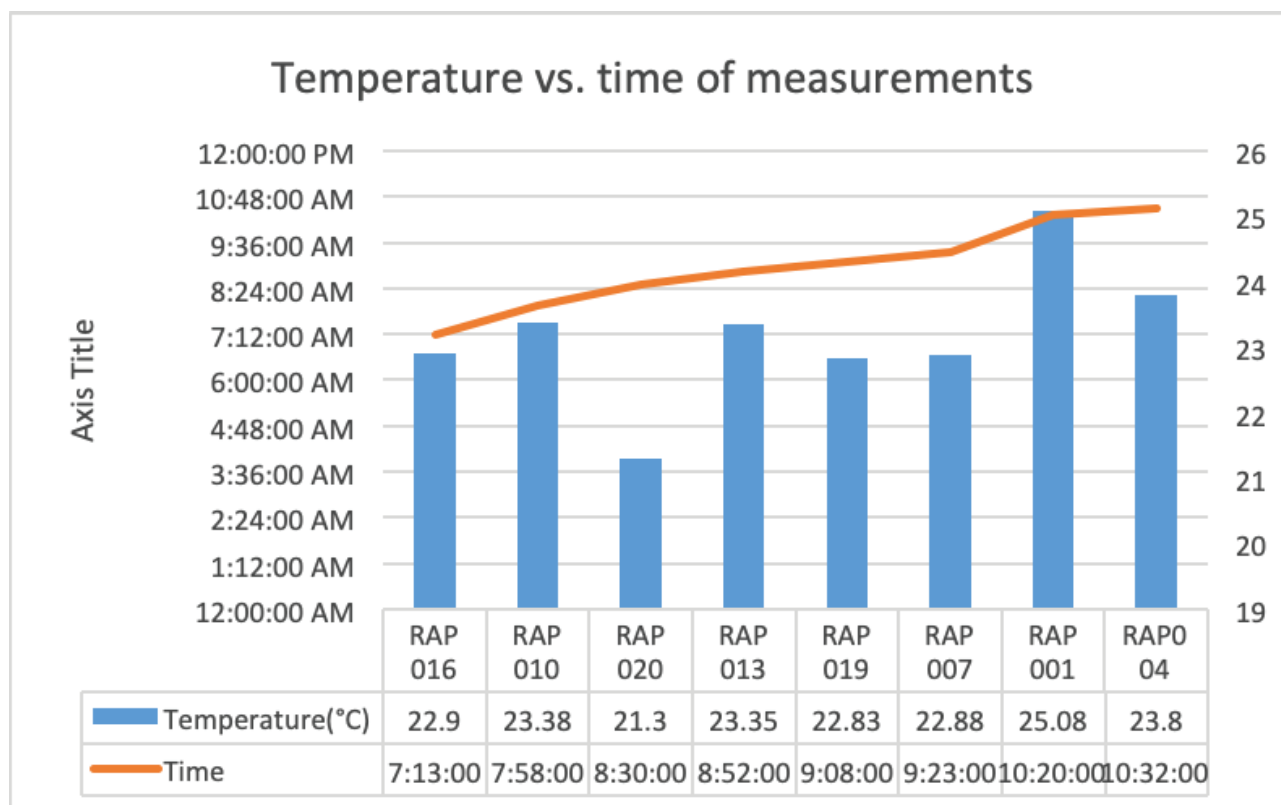
Figure 10. Temperature measurements results from 8 test sites.
The temperature is graphed against time of measurement.

7.1.4 Oxidation Reduction Potential

The Oxidation Reduction Potential (ORP) indicates that the water tested at each site is not in the healthy range, which is between 300 mV and 500 mV (Figure 11). However, the ORP does indicate various other possible biochemical reactions such as those in Figure 12.

The ORP values, when considered against the information provided in Figure 12, explains the trend seen in the Figure 11.

RapCA Site 007 from the initial assessments was an area with obvious hydrogen sulphide release from sedimentation and this is confirmed by the ORP values.

The measurements from RapCA Site 001 and 004 indicate that more than one biochemical reaction could be taking place in the water.

The measurements from the remaining RapCA sites indicate reactions of nitrification occurring in the water.
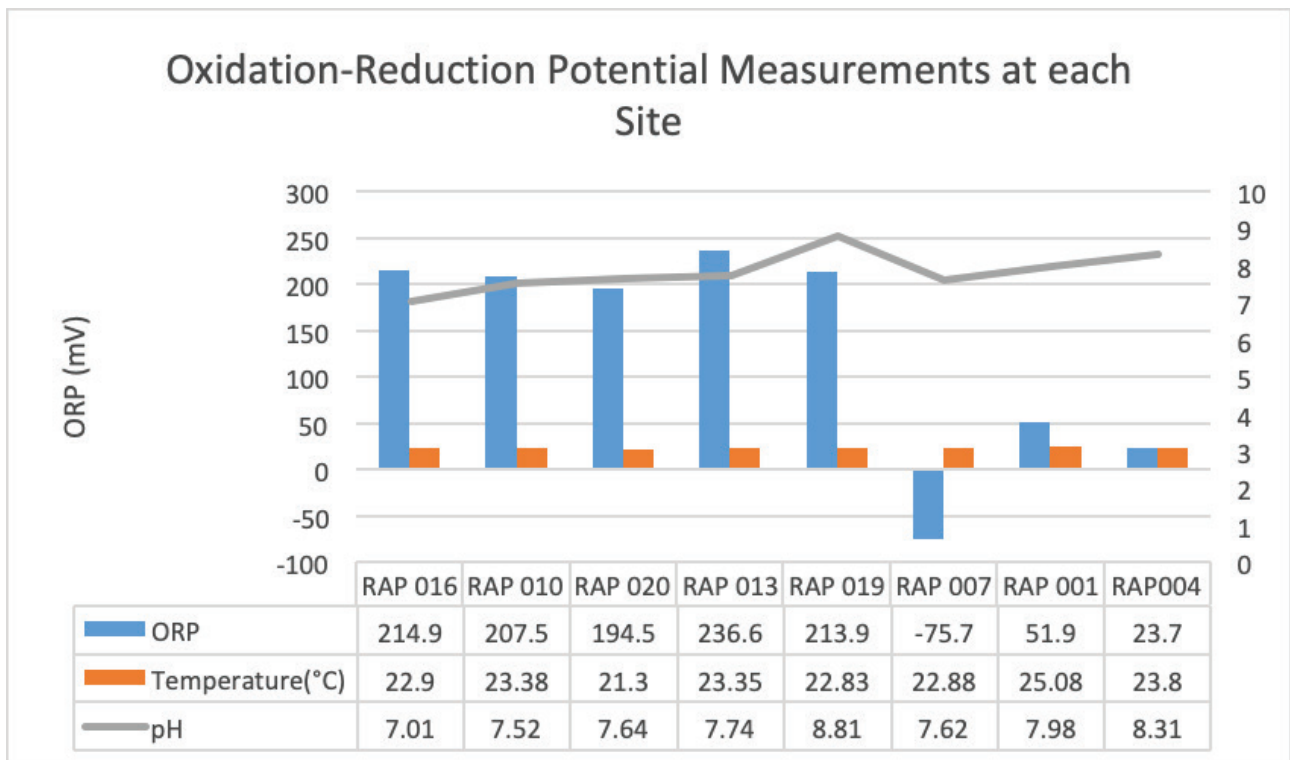
Figure 11. ORP measurements at 8 sites. ORP is graphed together with the pH and temperature measurements in each site to show the relation between these calculated values.

	RAP 016	RAP 010	RAP 020	RAP 013	RAP 019	RAP 007	RAP 001	RAP004
ORP	214.9	207.5	194.5	236.6	213.9	-75.7	51.9	23.7
Temperature(°C)	22.9	23.38	21.3	23.35	22.83	22.88	25.08	23.8
pH	7.01	7.52	7.64	7.74	8.81	7.62	7.98	8.31

Biochemical Reactions and Corresponding ORP Values

Biochemical Reaction	ORP, mV
Nitrification	+100 to +350
cBOD degradation with free molecular oxygen	+50 to +250
Biological phosphorus removal	+25 to +250
Denitrification	+50 to -50
Sulfide (H_2S) formation	-50 to -250
Biological phosphorus release	-100 to -250
Acid formation (fermentation)	-100 to -225
Methane production	-175 to -400

Figure 12. Biochemical Reactions and Corresponding ORP Values. Useful guide to the ORP values measured at each site. YSI Environnemental Application Note. https://www.ysi.com/File%20Library/Documents/Application%20Notes/A567-ORP-Management-in-Wastewater-as-an-Indicator-of-Process-Efficiency.pdf

7.1.5 Dissolved Oxygen

Figure 13 shows the dissolved oxygen measurements at eight sites against the lower and upper limits of dissolved oxygen in per cent saturation. Trigger values are used to assess risk of adverse effects due to nutrients, biodegradable organic matter, and pH in various ecosystem types. The results show that RapCA sites 020, 019 and 001 are below the lower limit for trigger values provided by the ANZECC/ARMCANZ (2000).

Dissolved Oxygen (DO)

	RAP 016	RAP 010	RAP 020	RAP 013	RAP 019	RAP 007	RAP 001	RAP004
DO (%)	87	81.5	47	86.3	28.6	78.5	71	102.6
DO lower limit % saturation	80	80	80	80	80	80	80	80
DO upper limit % saturation	110	110	110	110	110	110	110	110
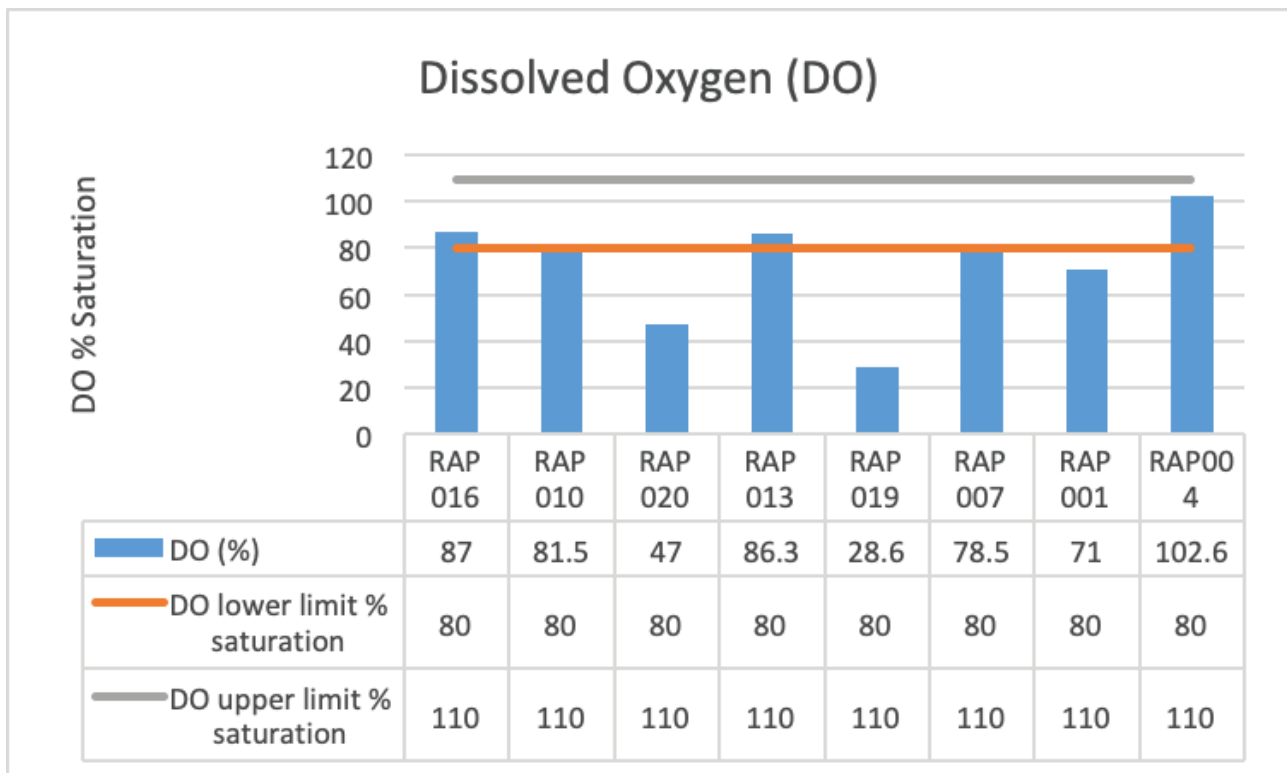
Figure 13. Dissolved Oxygen in % saturation measurements at 8 sites. The upper and lower limit for trigger values for physical and chemical stressors for estuaries-like ecosystems like that of the Hihifo Coastline.

Except for RapCA sites 020 and 019, the DO (mg/L) measurements at all sites are above the guideline value provided for the protection of aquaculture species (Figure 14).

Dissolved Oxygen (mg/L)

	RAP 016	RAP 010	RAP 020	RAP 013	RAP 019	RAP 007	RAP 001	RAP004
DO (mg/L)	6.44	5.96	3.66	6.58	2.53	6.04	5.37	7.51
Physico-chemical stressor guidelines for the protection of aquaculture species (mg/L)	5	5	5	5	5	5	5	5
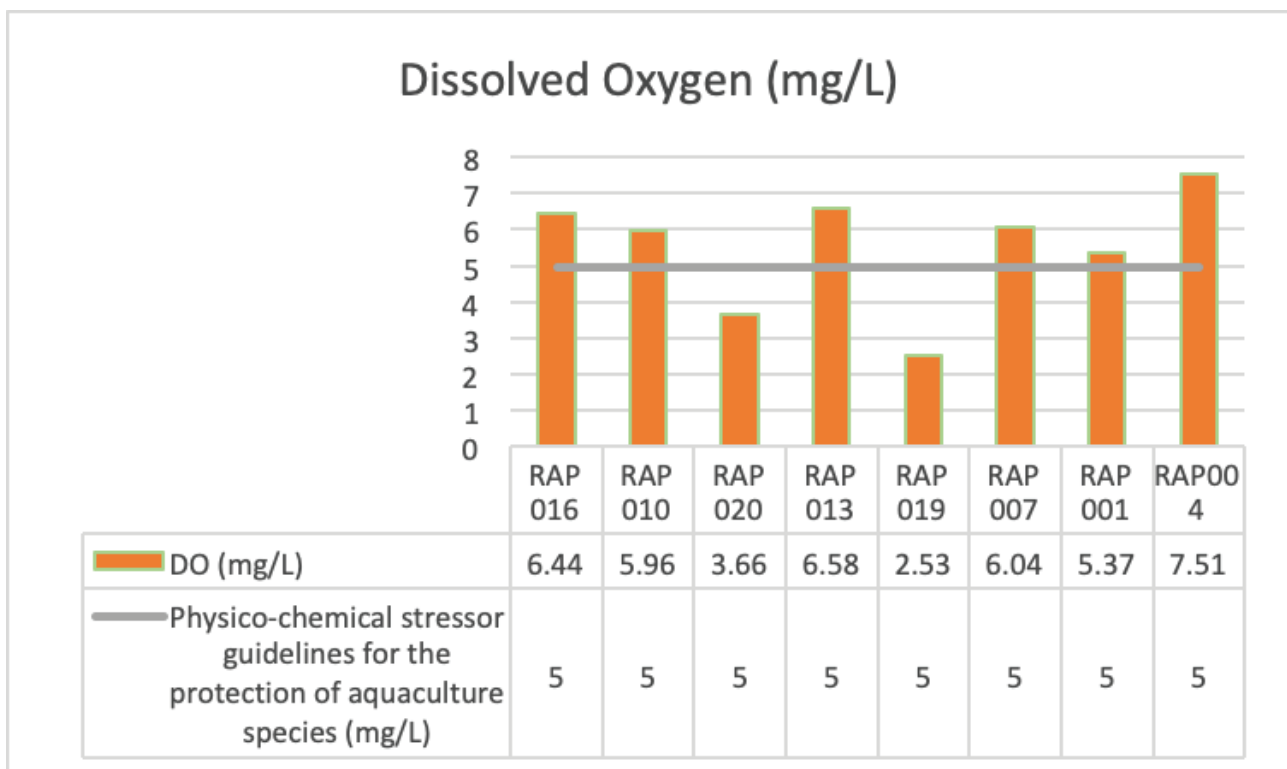
Figure 14. Dissolved Oxygen measurements in milligrams per litre at 8 sites
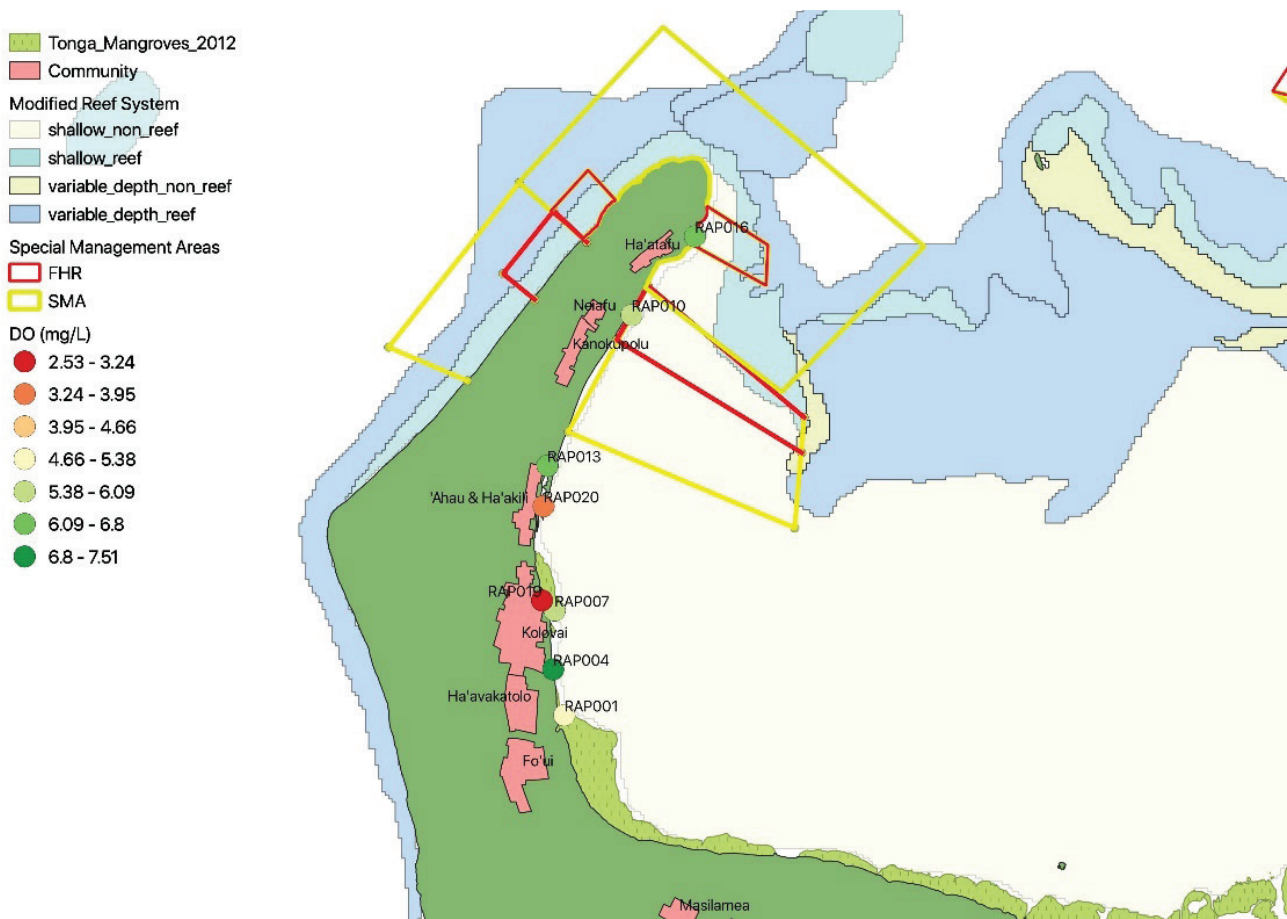
Figure 15. Dissolved Oxygen in milligrams per litre measurements mapped out on the Hihifo peninsula.

Figure 15 shows the sites with the resulting DO (mg/L) measurements taken. This map confirms the graphed results highlighting RapCA 019 and 020 as areas of interest.

7.1.5 Total Dissolved Solids

The Total Dissolved Solids (TDS) measurements across the eight sites are shown above in Figure 16. The TDS at RapCA 019 is very high, confirming RapCA Site 019 as a pond water collection for rainwater and runoff from the residential land upon it sits.
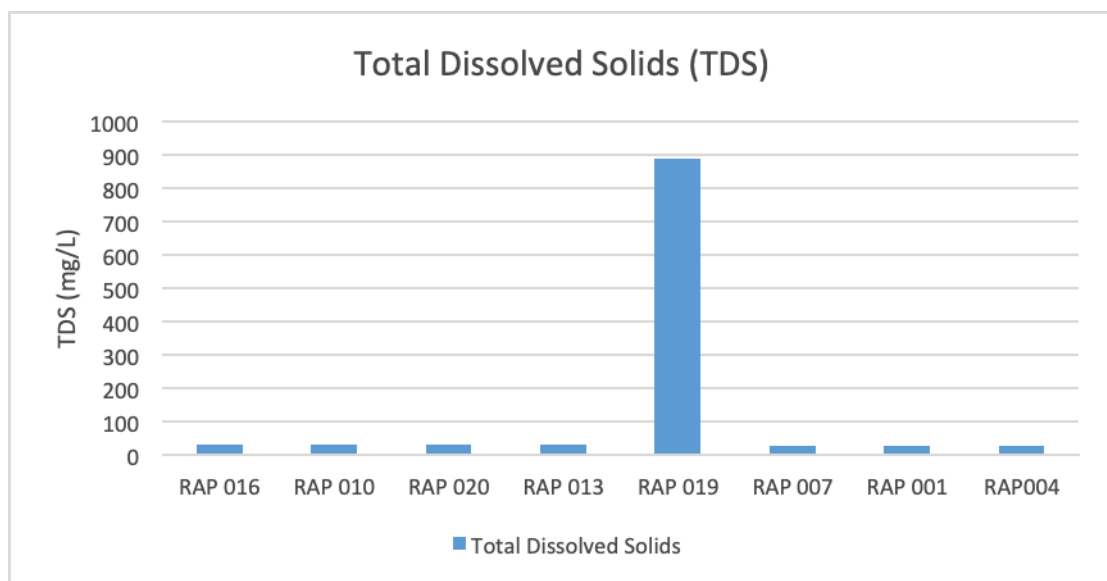
Figure 16. Total Dissolved Solid measurements across 8 sites.
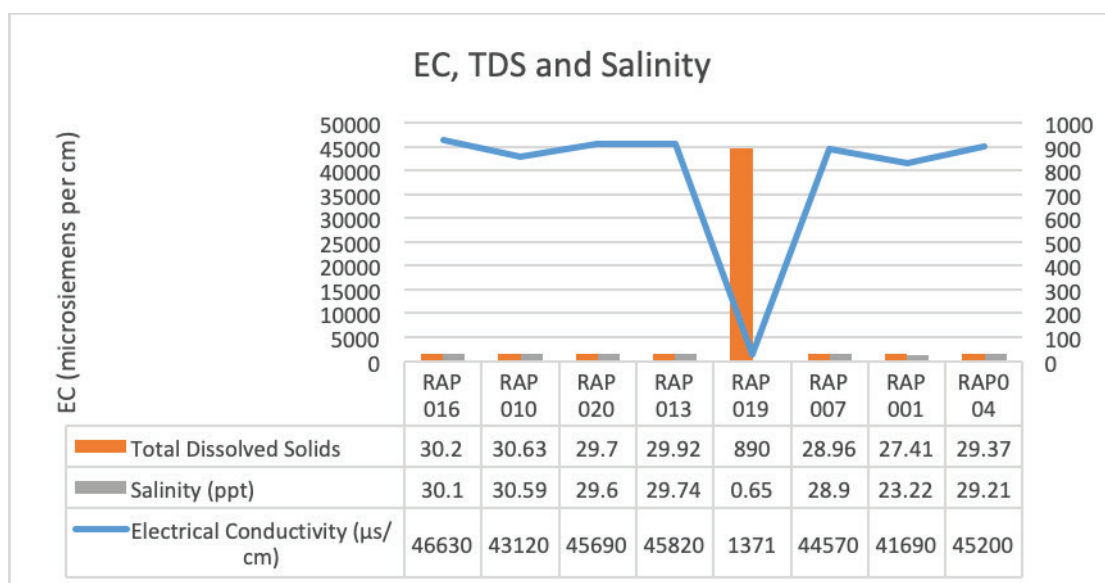
Figure 17. Total Dissolved Solids graphed together with Electrical Conductivity (EC) and Salinity

Figure 17 further confirms RapCA 019 as a collection of rainwater and runoff as the Electrical Conductivity (EC) and Salinity measurements are indicative of freshwater and not saltwater as commonly found along the coastline. It can be explained that due to the nature of the pond water being enclosed and collecting runoff and rainwater, it is expected the dissolved solids over time will be high.

7.1.6 Electrical Conductivity, Salinity and Seawater Specific Gravity.
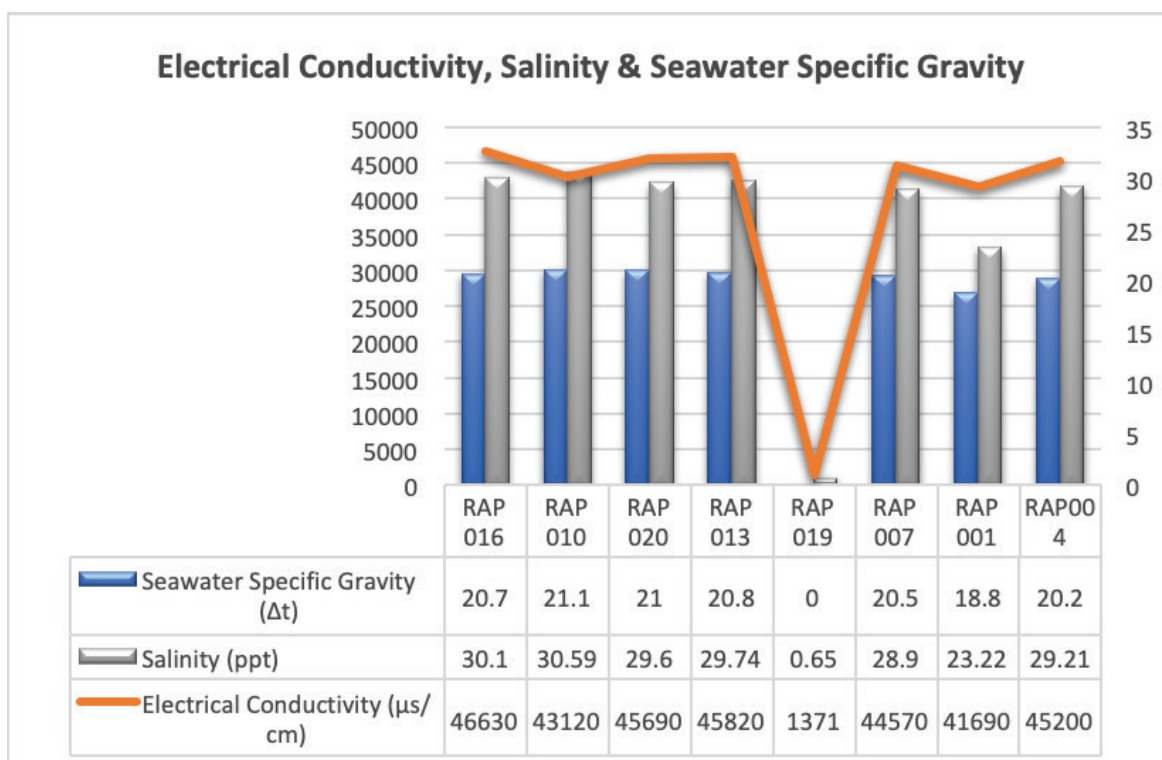
Figure 18. Graphed results of Electrical Conductivity, Salinity and Seawater Specific Gravity.

Electrical Conductivity (EC), Salinity and Specific Seawater Gravity (SSG) are all relative indicators of saltwater. As seen from Figure 18, all the measurements for each RapCA site are in line with coastal water testing confirming conditions indicative of coastal water. The exception is RapCA site 019. The results further confirm RapCA 019 as pond water collection of rainwater and runoff.

7.2 Nutrients

7.2.1 Nitrate

For the purposes of coastal water testing the ANZECC/ARMCANZ (2000) report provides a guideline (trigger) value for aquatic species at the 95% protection level in freshwater (moderate reliability) and marine water (low reliability) of 700 µg/L (or 0.7 mg/L) as nitrate (NO_3).

Most applicable to the coastline of Hihifo, is the guideline value of **30 µg/L** (NO_x-N). Assuming that the nitrite component is much smaller than the nitrate component (as is the case in most situations), it is reasonable to assume that the guideline value is 30 µg/L as NO_3-N. This nitrate concentration is equivalent to about 130 µg/L or 0.13 mg/L as NO_3. Based on this, the adopted guidelines for nitrate (as NO_3) concentration in the Hihifo coastal waters of the lagoon is 0.13 mg/L for minimising algal blooms and 0.7 mg/L for protection of aquatic species at the 95% protection level (Falkland 2013).

Methodology

The nitrate concentration was measured in the Water Resources Laboratory from water samples taken at each site.

The concentration of nitrate at each site was measured using a Palintest photometer. The Palintest methodology used was a Tablet Reagent System. This includes a reduction of nitrate to nitrite using a unique zinc based Nitratest powder and tablet which allows for rapid flocculation after a minute contact period. This reaction is carried out in a specific test tube provided solely for this part of the testing. In the presence of N-(1-nahthl)-ethylene diamine, the resulting nitrite is further reacted with sulphanilic acid to produce a reddish dye. These reagents are provided in tablet form which is dissolved and allowed to stand for full colour development prior to measurement using the photometer. The concentration of nitrate in the sample is proportional to the intensity of the colour produced (Palintest Ltd 2016).

Comparison with Guideline Values

Figure 19. Nitrate results for the 8 sites graphed against the guideline values for minimising algal blooms and protection of aquatic species at 95% level. "N" in darker shade of pink represents the Total Nitrogen found in the form of Nitrate (NO_3) per sample tested from each site.

Figure 19 shows that the nitrate levels at all RapCA testing sites were below the guideline values provided by ANZECC/ARMCANS (2000). It is noteworthy t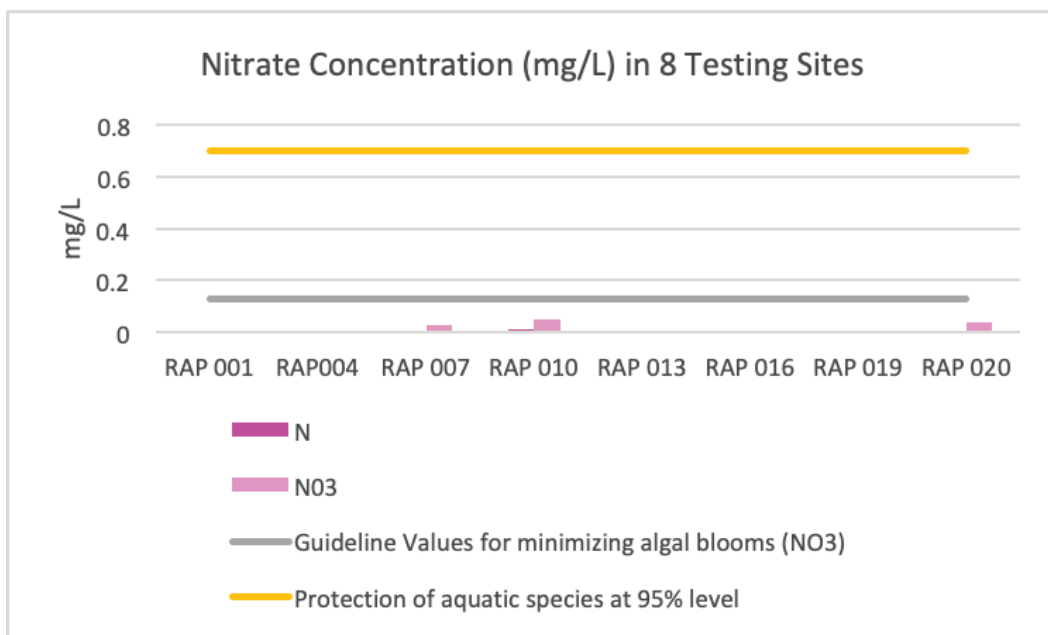hat while the nitrate levels were extremely low at RapCA 007, 010 and 020, *no* nitrate levels were detected for the remaining RapCA Sites. This aspect of the water quality assessment findings needs further investigation.

7.2.2 Ammonia

High levels of ammonia also indicate pollution of water sources. The term "ammonia" refers to two chemical forms of ammonia i.e., un-ionised (or non-ionised or free) ammonia (NH3) and ionised ammonium (NH4+). Total ammonia is the sum of the two forms.

The proportion of each form depends on the properties of the water, particularly pH and temperature. For example, at pH 8.5 and 20°C, NH3 comprises about 11% of total ammonia, while at pH 8 at 20°C, it comprises about 4% (Falkland 2013). The guideline values adopted for this report are taken from the ANZECC/ARMCANZ guideline values for aquatic ecosystems that had previously been adopted for water quality testing in the Fanga'uta Lagoon in 2013 (Falkland 2013).

The guideline (trigger) value adopted here for aquatic ecosystems is **0.91 mg/L.**

The guideline value for recreational use taken from the ANZECC/ARMCANZ (2000) for activities such as swimming and bathing, is **10 µg/L (0.01 mg/L)** as **N**, which is equivalent to **12 µg/L (0.012 mg/L)** and **13 µg/L (0.013 mg/L)** as ammonia **(NH3)** and ammonium **(NH4+),** respectively.

Methodology

The ammonia concentration of the water samples from each site was measured in the Water Resource Laboratory.

The concentration of ammonia is determined using a Palintest Photometer. The Palintest methodology used is a Tablet Reagent System for Ammonia. This is based on an indophenol method. The ammonia is reacted with alkaline salicylate in the presence of chlorine to form a green-blue indophenol complex. To ensure complete and rapid colour development, a catalyst is introduced into the reaction.

The reagents are provided in tablet form, which are added to the water sample. Tablets are dissolved and allowed to stand for full colour development then measured using a photometer. The colour produced is proportional to the ammonia concentration in the sample (Palintest Ltd 2016).

Comparison with Guideline Values

Figure 20 shows the ammonia concentration across the eight testing sites graphed against the guideline values discussed above. The trigger values for the protection of aquatic ecosystems were breached in RapCA site 020. The concentrations at RapCA Sites 001, 010, 016 and 019 were very close to the trigger value. RapCA Sites 004, 007 and 013 were well below the trigger value for aquatic ecosystems. However, all testing sites were determined to be above the guideline values for recreational use.
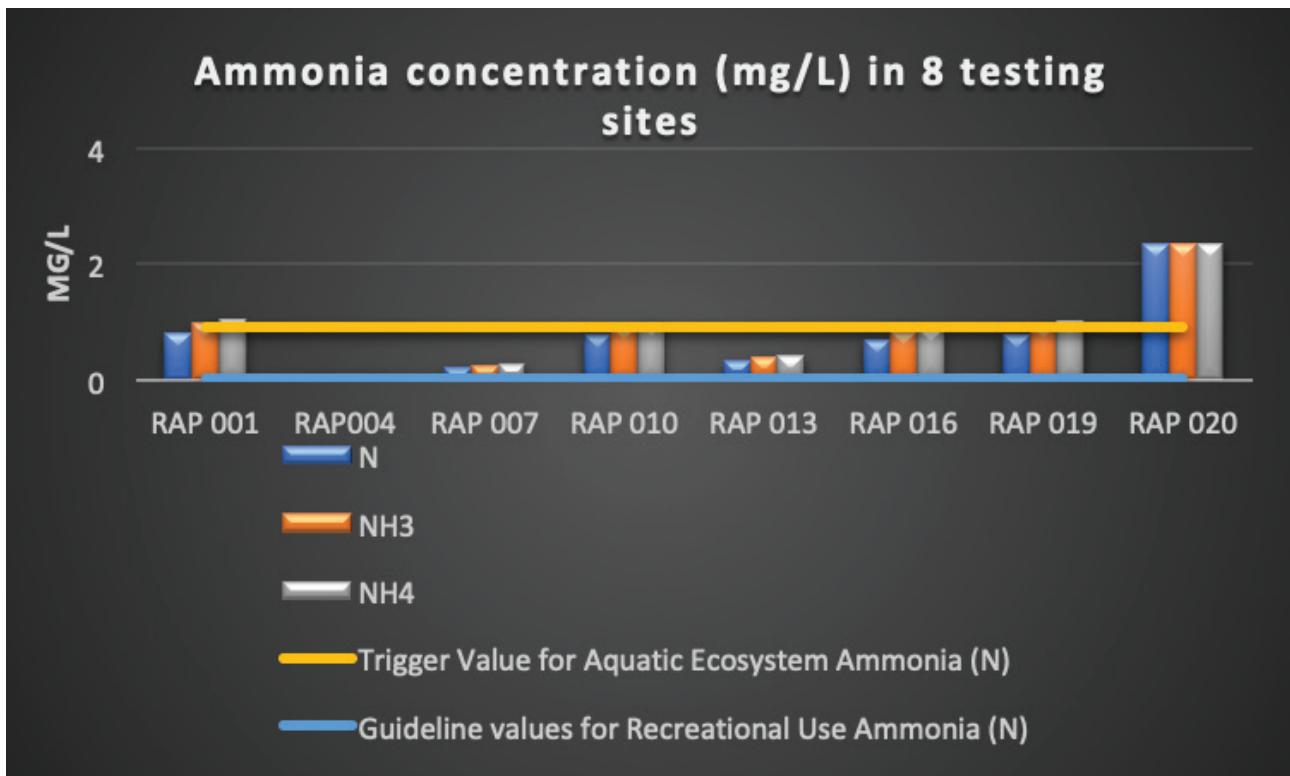
Figure 20: Ammonia concentration across 8 RapCA testing sites graphed against the Guideline values for Aquatic Eco-system and for Recreational Use of Water. "N" in bright blue, represent the Total Nitrogen found in the form of NH_3/NH_4 per sample tested from each site.

7.2.3 Phosphate

High levels of phosphate may result from the breakdown of organic pesticides, which contain phosphates. ANZECC/ARMCANZ (2000) provides guideline (trigger) values for total phosphorous for slightly disturbed ecosystems in tropical Australia. For the coastline of Hihifo the most applicable phosphate guideline value is **20 µg/L as P** (PO4-P). This value is equivalent to about 60 µg/L or **0.06 mg/L as PO4**. Based on this, a reasonable guideline for phosphate concentration for this assessment is *0.06 mg/L as PO4*.

For phosphate there is no ANZECC/ARMCANZ (2000) guideline for recreational use of water (bathing, swimming, etc.).

Methodology

The phosphate concentration was measured in the Water Resources Laboratory from samples of water taken from each site.

The testing was carried out using a Palintest Photometer. The Palintest methodology used was a Tablet Reagent System. This testing was the Palintest Phosphate Low Range testing method. Under acidic conditions, the phosphate in the water sample is reacted with ammonium molybdate to form phosphor-molybdic acid. Ascorbic acid is then used to reduce the resulting compound to form a molybdenum blue complex, which is intensely coloured. To ensure complete and rapid colour development, a catalyst is introduced. To prevent any interference from silica present in the sample, an inhibitor is used (Palintest Ltd 2016).

The above reaction is carried out using tablet forms of the reagents. Tablets are dissolved and allowed to stand for full colour development then measured using a photometer. The resulting colour intensity is proportional to the phosphate concentration present in the water sample (Palintest Ltd 2016).

Comparison with Guideline Values

The results graphed in Figure 21 show that the concentration of phosphate at all sites, except RapCA Site 010, was above the guideline values. At RapCA Site 010, the phosphate concentration in water was well below the guideline value.
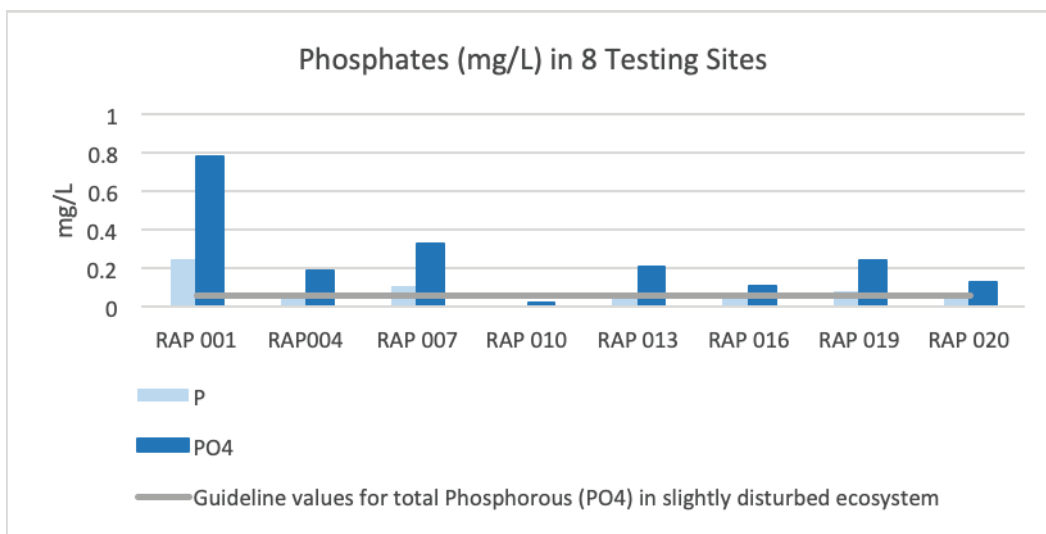
Figure 21. Phosphate concentration in 8 sites graphed against the Guideline value for total phosphorous in slightly disturbed ecosystem.

The map in Figure 22 shows that the testing sites with higher concentration of phosphates were located further inward along the coastline in areas between Fou'i and Kolovai. It can be said that these are areas that experience accumulation due to the sheltered nature and therefore these are not areas of high energy or part of the active coastal zone.
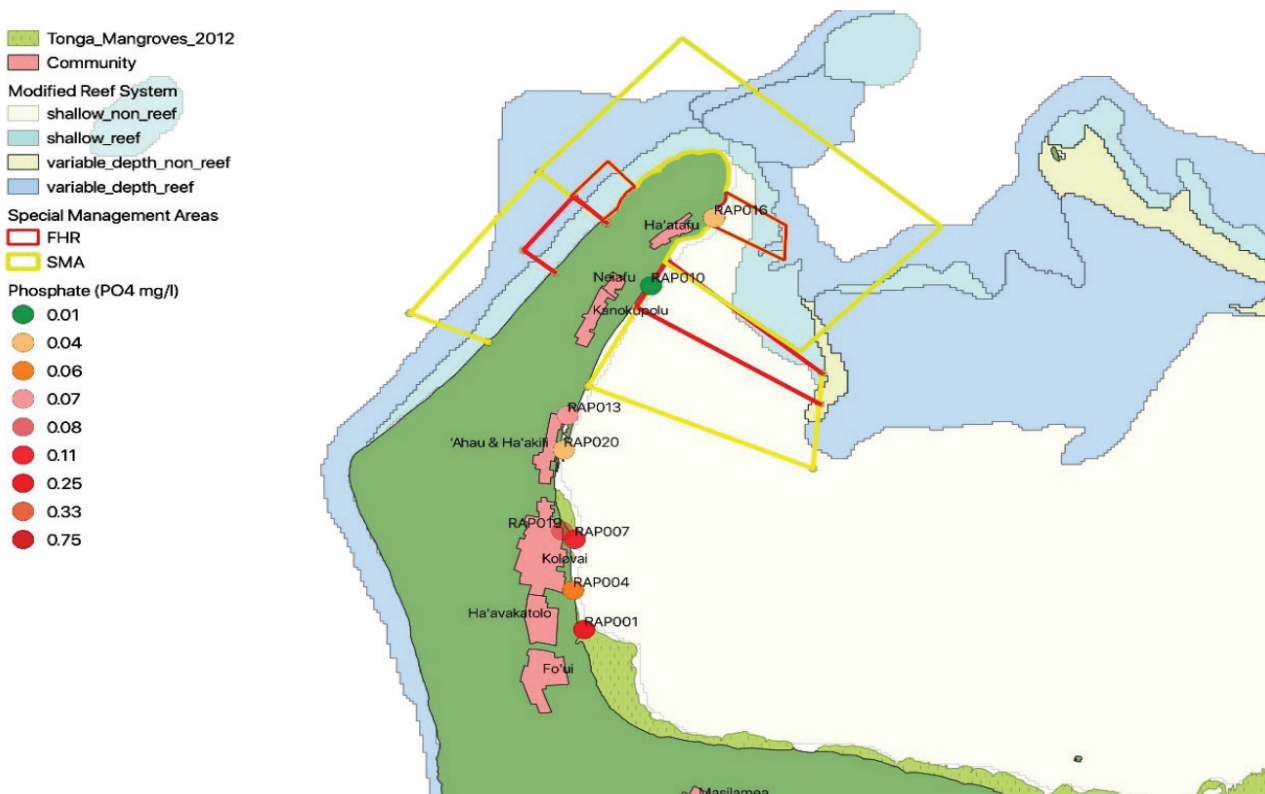
Figure 22. Phosphate (PO4) concentration across 8 sites along the Hihifo Coastline

7.3 Metal Contaminants

Metals are known to be naturally occurring compounds, but anthropogenic activities introduce them in large quantities in different environmental compartments. This reduces the ability of the environment to function properly, and human, animal and plant health become threatened. Naturally occurring common metals include lead, nickel, zinc, mercury, chromium, and arsenic.

7.3.1 Copper

Methodology

The copper concentration was measured in the Water Resources Laboratory from samples of water taken at each site.

The concentration of copper was measured using a Palintest Photometer. The Palintest methodology used here was a Tablet Reagent System. This involves the reduction of copper salts to the cuprous form, which is then reacted with 2,2 Biquinoline-4, 4-dicarboxylic salt to form a complex that is coloured purple. This results in free copper ions in the sample that can then be measured. A de-complexing agent is introduced in the second half of the testing to remove any chelated copper compounds that could still be present in the sample. The reagents are provided in tablet form, which are dissolved, allowed to stand for full colour development then measured using the photometer (Palintest Ltd 2016).

Comparison with guideline values

Concentration of Copper (mg/L) at 8 Testing Sites

	RAP 001	RAP004	RAP 007	RAP 010	RAP 013	RAP 016	RAP 019	RAP 020
Copper	0.12	0.14	0.1	0.1	0.1	0.12	0.22	0.08
Recreational Uses Guideline Value	1	1	1	1	1	1	1	1
Trigger Value for 99% protection of species	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Guideline Value for protection of aquaculture species	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
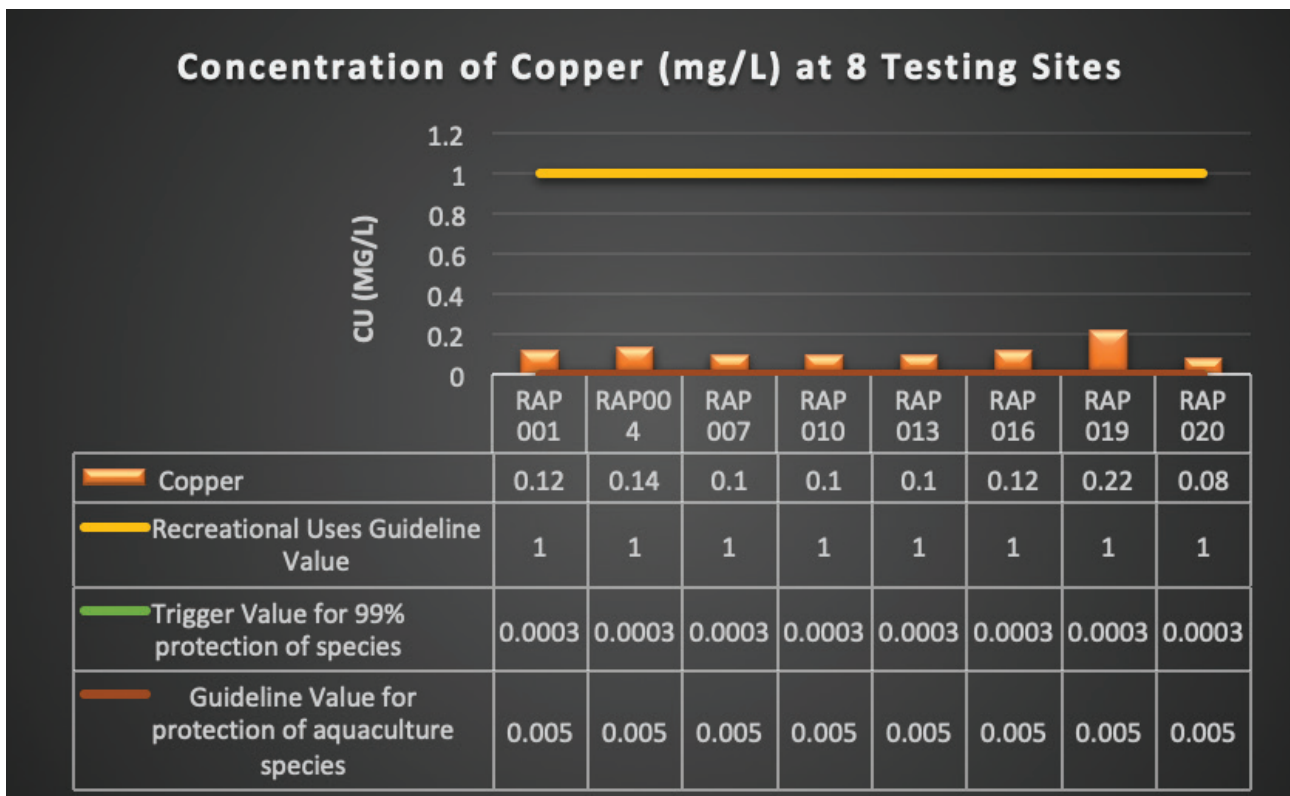
Figure 23. Concentration of Copper across 8 testing sites graphed against the recreational guideline value, the trigger value for 99% protection of species and the guideline value for protection of aquaculture species (ANZECC/ARMCANZ 2000).

Figure 23 shows that while the RapCA sites tested below the guideline value for recreational use, the concentration of copper at each site was well above the trigger value for 99% protection of species and the protection of aquaculture species.

7.3.2 Zinc

Methodology

The zinc concentration was measured in the Water Resources Laboratory from samples of water taken at each site.

The zinc concentration for each site was determined using a Palintest Photometer. The Palintest methodology used here was a Tablet Reagent System. This method reacts the zinc with 5-(o-carboxyphenyl)-1-(2-hydroxy-5-sulphophenyl)-3-phenylformazan (Zincon) in an alkaline solution to produce an intense blue colour. The Palintest testing kit provides the reagents in a tablet form containing both the Zincon and an alkaline buffer. There exists a large spectrum of resulting colours from a range of orange through to purple to blue, depending on the zinc concentration found in the sample. The tablets are dissolved in the sample, allowed to stand for full colour development and then measured in the photometer (Palintest Ltd 2016).

Further steps to this methodology included the removal of chlorine residuals to prevent bleaching of the test colours using a dichlorination tablet. Ethylenediaminetetraacetic acid (EDTA) is also used to remove any copper complexes that may be found in the sample as zinc reacts in a similar manner to copper. The intensity of the colour produced in the testing is indicative of the zinc concentration found in the sample (Palintest Ltd 2016).

Comparison with Guideline Values

Zinc Concentration (mg/L) at 8 Testing Sites

	RAP 001	RAP004	RAP 007	RAP 010	RAP 013	RAP 016	RAP 019	RAP 020
Zinc	0	0	0	0.02	0	0.01	0	0
Recreational Uses Guideline Value	5	5	5	5	5	5	5	5
Trigger Value for 99% protection of species	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
Guideline Value for Protection of Aquacultue species	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005

Figure 24. Zinc concentration from 8 testing sites graphed against guideline values for 99% protection of species, protection of aquaculture species and recreational guideline value (ANZECC/ARMCANZ 2000)

Figure 24 shows that zinc concentrations were found at only two sites – RapCA 010 and 016. The concentrations at both sites were lower than the guideline values for recreational uses but higher than the guideline for protection of aquaculture species and the guideline value for 99% protection of species.

7.3.3 Nickel

Methodology

The nickel concentration was measured in the Water Resources Laboratory from samples taken at each site.

The concentration of nickel was measured using a Palintest Photometer. The Palintest methodology used here was the Tablet Reagent System. This involves the reduction of nickel salts to the nickelous form, which is then reacted with nioxime indicator to produce a pink coloured complex. A complexing powder is provided to prevent iron interference and there are reagents included in this methodology to prevent copper interference as well. The reagents are provided in tablet form which are dissolved and allowed to stand for full colour development. The sample is then measured using a photometer. The colour produced is proportional to the concentration of nickel found in the sample (Palintest Ltd 2016).

Comparison with Guideline Values

Nickel was found at all eight sites (Figure 25) with concentrations above all the three guideline values: the trigger values for 99% protection of species; specific guideline value for protection of aquaculture species; and the limit recommended for recreational uses.
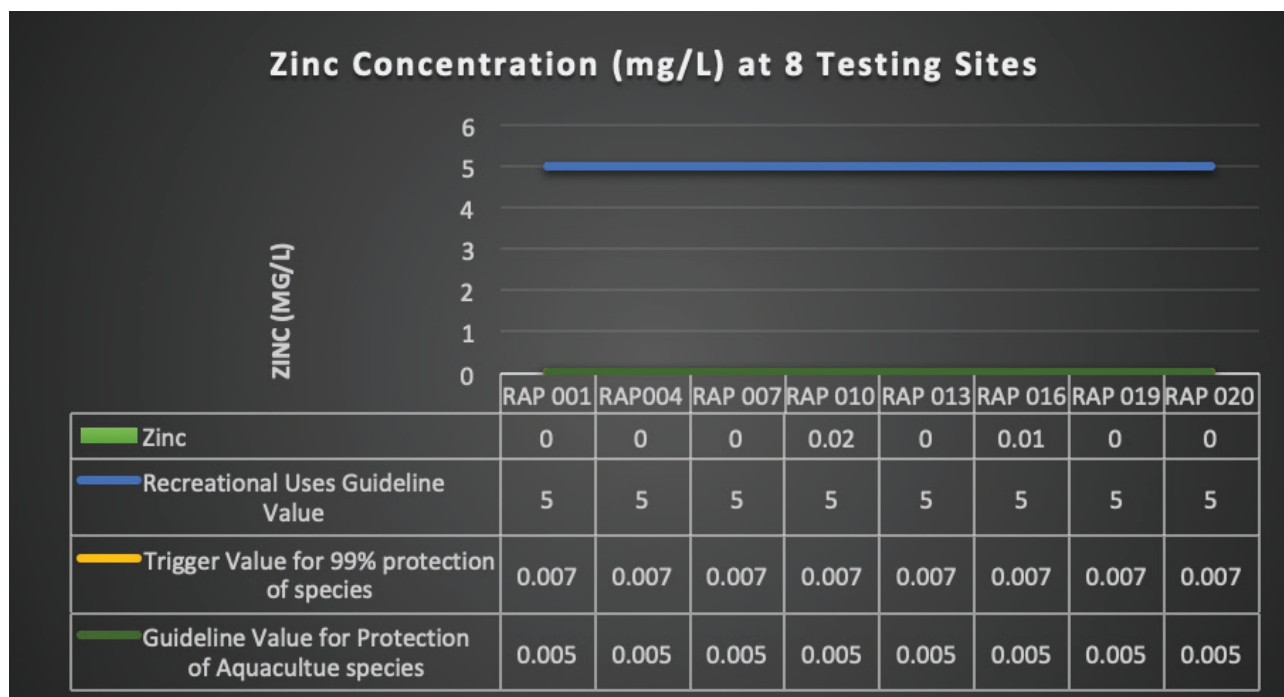

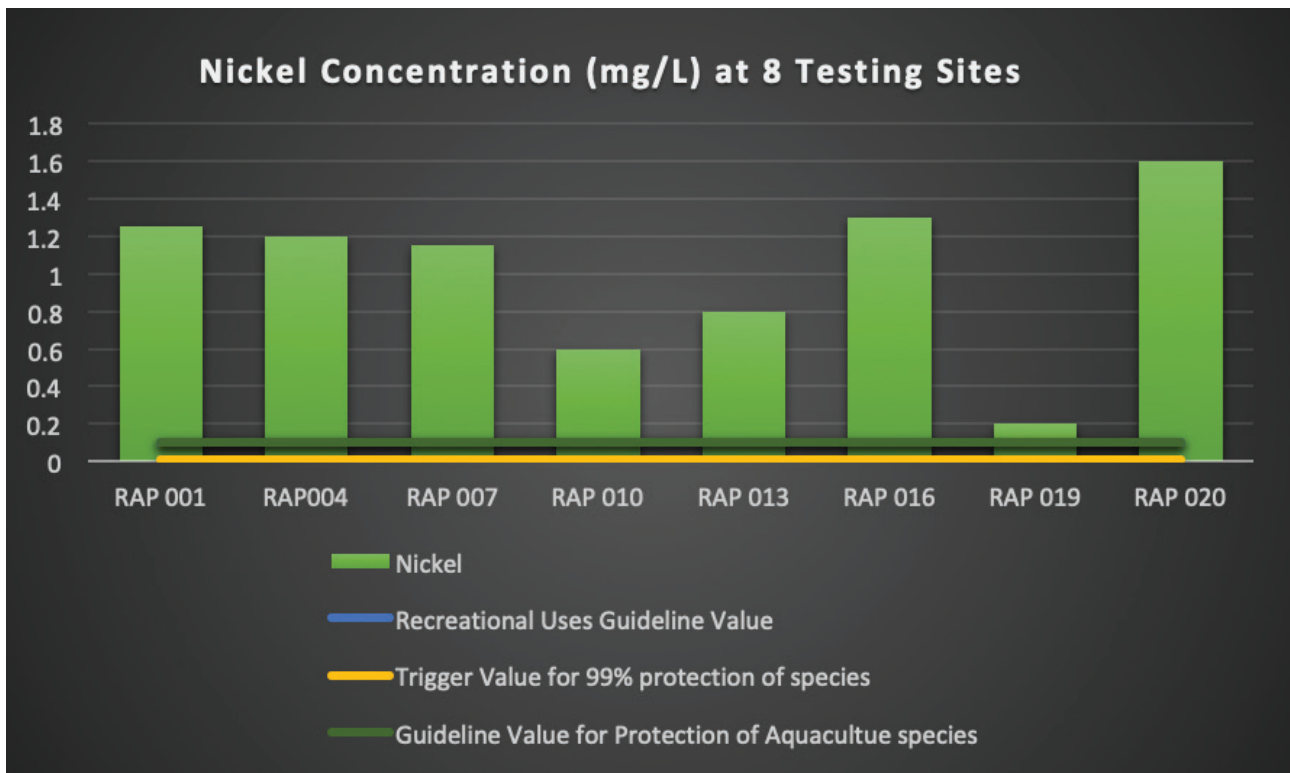Figure 25. Nickel concentration in 8 testing sites graphed against Guideline Values for 99% protection of species, protection of aquaculture species and recreational uses (ANZECC/ARMCANZ, 2000)

Figure 26 highlights areas of high nickel concentrations along the coastline. It is interesting to note that, in sheltered areas, such as at RapCA 013, the nickel concentration was lower than at the other testing sites.
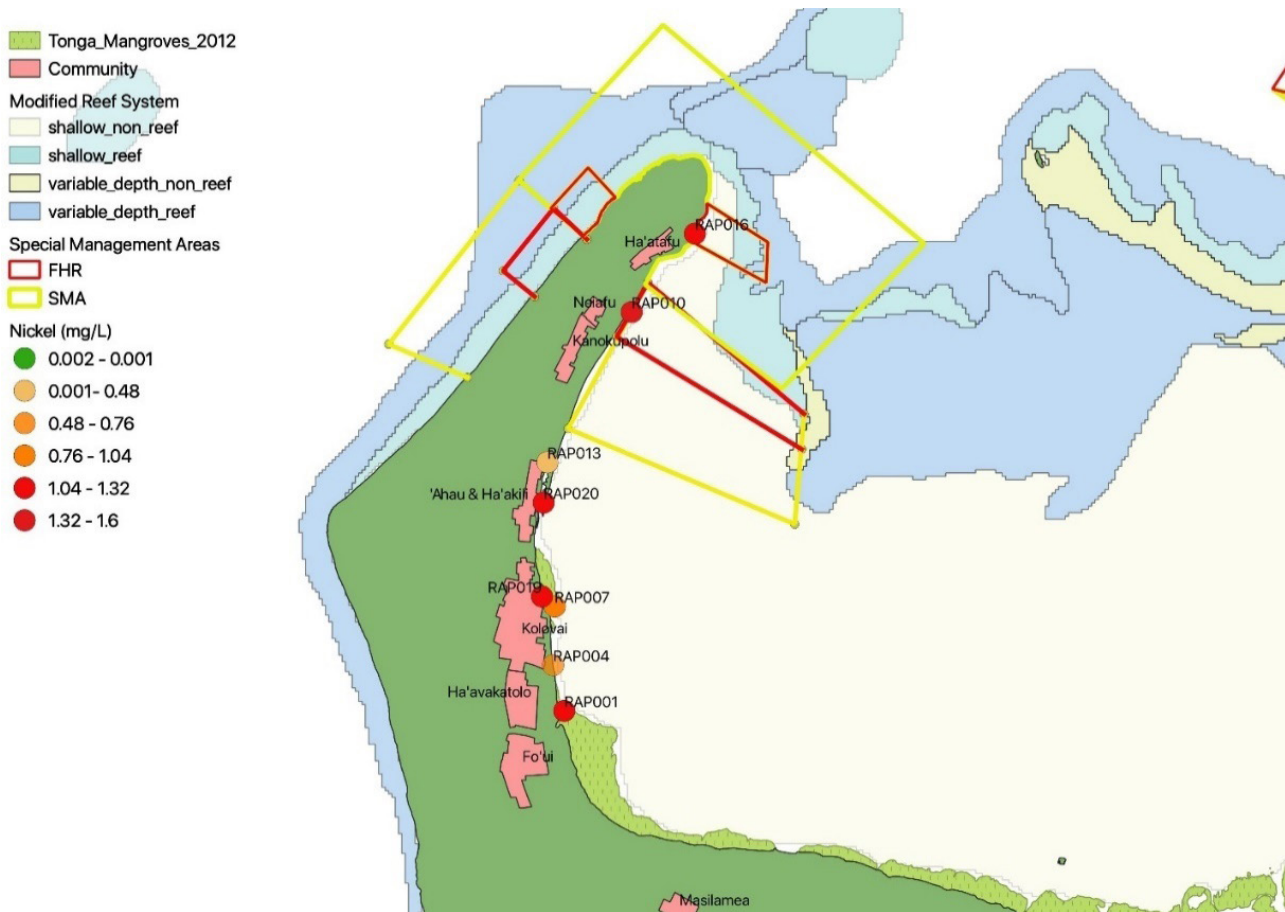
Figure 26. Nickel Concentration mapped depicting the areas of high concentration along the coastline of Hihifo.

7.3.4 Manganese

Methodology

The concentration of manganese was measured at the Water Resources Laboratory from samples taken at each site.

The concentration of manganese was measured using a Palintest Photometer. The Palintest methodology used here was a Tablet Reagent System. This involves using an oxidising agent to oxidise the manganese in lower valency states to form permanganate. The permanganate form is further reacted with leucomalachite green to produce an intense turquoise coloured complex. A catalyst is introduced to allow for rapid and complete colour development and an inhibitor used to ensure interferences are eliminated. The reagents are provided in tablet form which were dissolved, allowed to stand to ensure full colour development then measured using a photometer. The intensity of the colour produced is proportional to the concentration of manganese in the sample (Palintest Ltd 2016).

Comparison with Guideline Values

All testing sites resulted in manganese concentrations that were lower than the guideline value for recreational uses. RapCA sites 001 and 019 were the only two sites with manganese concentrations above the guideline value for protection of aquaculture species (Figure 27). There is no guideline value provided for protection of species for manganese.

Figure 27: Manganese Concentration at 8 sites graphed against Guideline Values for Recreational uses and Protection of Aquaculture Species (ANZECC/ARMCANZ 2000)
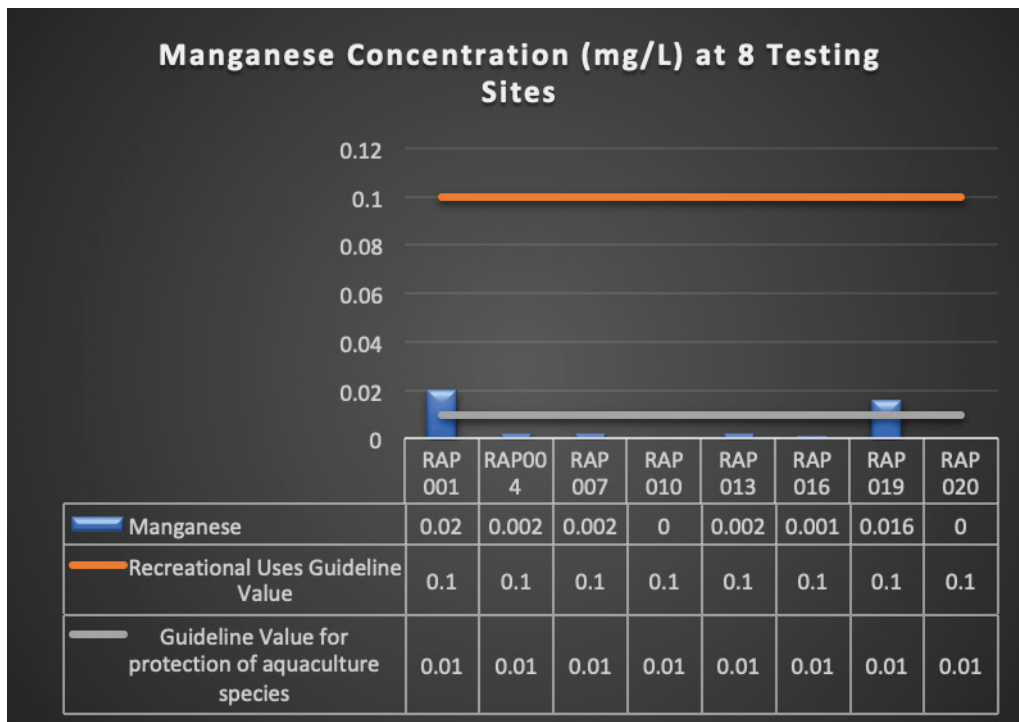
7.3.5 Iron

Methodology

The concentration of iron was measured at the University of South Pacific campus in 'Atele, from samples taken at each site.

The concentration of iron was measured using a Palintest Photometer. The Palintest methodology used here was a Palintest Tubetest Reagent System. The procedures necessitated the usage of a fume hood due to toxic fumes, which led to the testing being carried out at the University of the South Pacific Laboratory. The methodology was designed for testing of iron concentration in effluents, wastewater, and industrial water samples. In such types of waters, the iron is often present in complexed, colloidal, or particulate form, which meant that certain techniques were required for the total recoverable iron concentration to be measured (Palintest Ltd 2016).

To solubilise the particulate matter, break down the complexes and remove colour from samples, the samples are first digested in a sulphuric acid/nitric acid mixture. The sample is then neutralised and buffered to the correct pH. Addition of a reducing agent allows for the conversion of all iron to ferrous form. This is then reacted with 1,10 phenanthroline to produce an orange-coloured complex. Incorporated into this testing system are de-complexing agents and inhibitors to break down any chelated iron present in the sample and prevent interference from other metal ions also found in effluents and wastewater. The sample is then measured using a photometer. The intensity of the colour produced is proportional to the concentration of the iron present (Palintest Ltd 2016).

Comparison with Guideline Values

Iron concentrations in all testing sites were above the guideline values provided for both recreational uses and protection of aquaculture species (Figure 28). There is no specific guideline trigger value for protection of species at either 90%, 95% or 99% protection, which means there is no defined trigger value for protection of all aquatic species for iron concentrations in water.
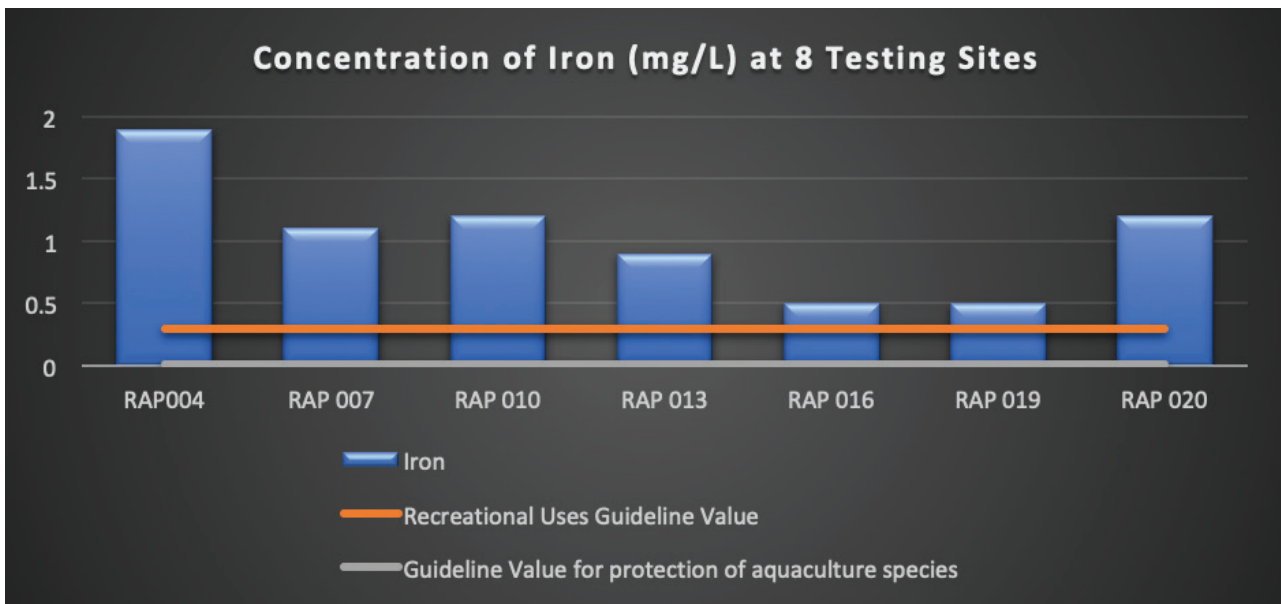
Figure 28. Iron Concentration at 8 sites graphed against Guideline values for Recreational Uses and Protection of Aquaculture species (ANZECC/ARMCANZ 2000)

7.3.6 Hexavalent Chromium

Methodology

The concentration of hexavalent chromium was measured at the University of South Pacific Campus in 'Atele in samples of water taken at each site.

The concentration of hexavalent chromium was measured using a Palintest Photometer. The Palintest methodology used was a Tubetest Reagent System. The procedures necessitated the use of a fume hood due to toxic fumes, which led to the testing being carried out at the University of the South Pacific Laboratory. Much as with the testing for iron, the testing for hexavalent chromium was designed for effluent, wastewater and industrial water samples that might contain complexed, colloidal, or particulate forms of metal ions. The samples are first digested in a sulphuric acid/nitric acid mixture using a block heater digester. This is to remove colour, break down complexes and solubilise particulate matter. The acid is then partially neutralised and reacted with diphenyl carbazide to form a purple-coloured complex. De-complexing agents and inhibitors are also incorporated into the test reagent system to break down complexes which may be present in the sample and prevent interferences from other species commonly found in effluents and wastewater. The sample is then measured using the photometer. The intensity of the colour produced is proportional to the concentration of hexavalent chromium present (Palintest Ltd 2016).

Comparison with guideline values

Hexavalent chromium concentrations at all testing sites were found to be above the guideline values provided except for RapCA Site 020, which recorded 0 concentration of hexavalent chromium. This is an interesting find as RapCA 020 is an additional site requested to confirm and assess the extent of pollution seen in this area. Another point of interest is RapCA site 013, which was a site showing one of the least amounts of nickel but had the highest concentration of hexavalent chromium (Figure 29).
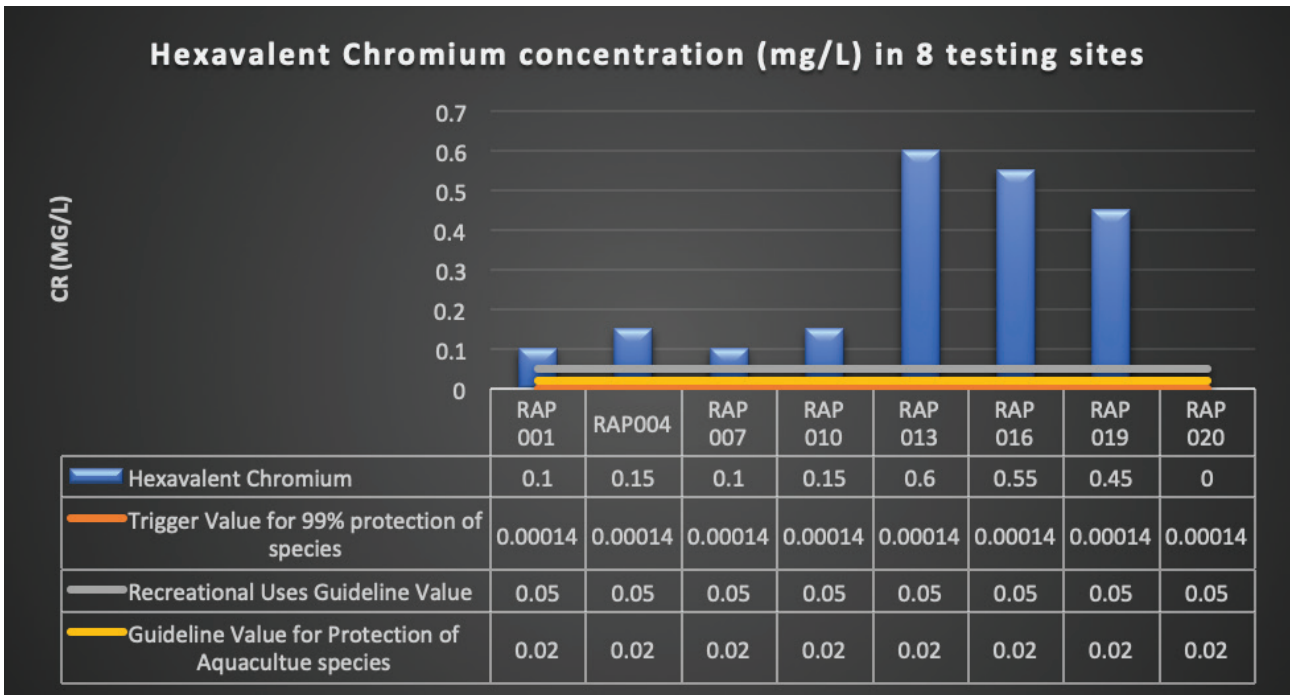
Figure 29. Hexavalent chromium concentration at 8 sites graphed against Guideline values for 99% protection of species, protection of Aquaculture species and Recreational uses (ANZECC/ARMCANZ 2000).
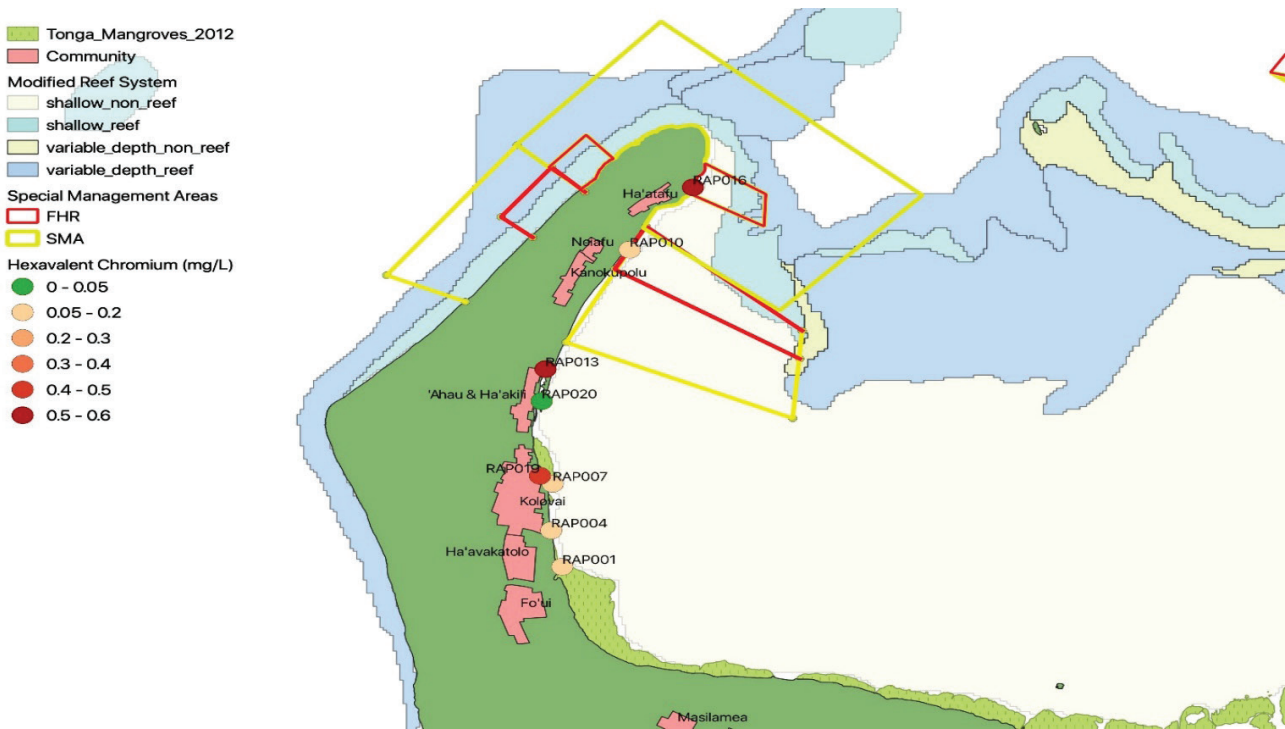
Figure 30. Hexavalent chromium concentration mapped to show areas of high concentration along the coastline of Hihifo.

Figure 30 depicts the hexavalent chromium concentration along the coastline of Hihifo. Note RapCA Site 016 and 013 where the highest concentration of hexavalent chromium was found.

7.4 Microbiological

Methodology

The testing for faecal coliform was carried out at the Water Resources Laboratory from samples taken at each site.

Testing for faecal coliform was carried out using the membrane filtration method utilising a Palintest Portatest Kit. 100 ml of each sample were filtered through a membrane containing a filter paper. The filter paper was then transferred onto a petri dish containing a pad soaked with enough nutrients for bacterial growth. The petri dishes were incubated at 44°C for 18 hours. The colonies forming units (cfu) was counted after 18 hours of incubation (Falkland 2010b).

Guideline values

Currently there are two guideline values provided for faecal coliform in marine waters:

1. Guidelines for the protection of human consumers of seafood

ANZECC/ARMCANZ (2000) provides a guideline value for the "protection of human consumers of fish and other aquatic organisms from bacterial infection". This guideline is principally aimed at shellfish, which can accumulate bacteria to dangerous levels as they filter large amounts of water to obtain their food (Mosley et al. 2005). The guidelines are that the median number of faecal coliforms should not exceed **14 cfu/100 mL** and no more than *10% of samples exceed 43 cfu/100 ml*. The faecal coliform counts in ANZECC/ARMCANZ (2000) are expressed in terms of maximum probable number (MPN) per 100 mL, which in practice can be considered as equivalent to cfu/100 ml.

2. Guidelines for recreational use of water (bathing, swimming, etc.)

ANZECC/ARMCANZ (2000) provides guideline values for recreational use of fresh and marine waterways in terms of faecal coliforms and other micro-organisms. For primary water contact (e.g., swimming, bathing, and other direct water contact activities) the median number of faecal coliforms should not exceed **150 cfu/100 ml**.

For secondary water contact (e.g., fishing and boating), faecal coliforms should not exceed **1,000 cfu/100 ml**.

Additionally, ANZECC/ARMCANZ (2000) require that the median values should involve a minimum of five samples taken at regular intervals not exceeding one month, with four of five samples containing less than 600 cfu/100 mL and 4000 cfu/100 mL for, respectively, primary, and secondary contact.

World Health Organization (2003) does not have guideline values for thermo-tolerant coliforms (faecal coliforms) stating that there are no adequate studies on which to base guideline values (Falkland 2013).

Comparison with Guideline Values

There are two interesting findings of the faecal coliform testing (Figure 31):

1. Two sites tested below the guideline values provided by the ANZECC/ARMCANS. These are RapCA 010 and 016.

2. All other sites tested above the guideline values, with Site OO1 having an extremely high value above 160 cfu/100ml.

There is a possible link between the results and wandering animals in the settlement area, as all sites show animal trails throughout, with animal waste seen in testing. High energy areas (active coastal zones) such as RapCA 016 and 010, whereby the water levels at high tide can be 80 cm, will have less counts per litre due to tide movements. RapCA sites 013 and 010 are low energy areas (not part of the active coastal zone) or are sheltered by mangrove forest, have higher counts due to minimal dispersal of pollutant by water currents or tide movements.
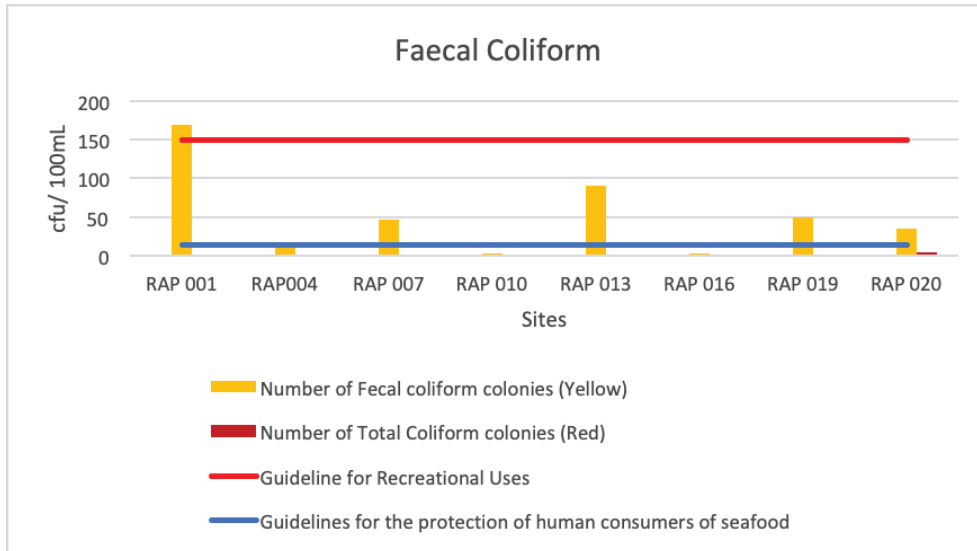
Figure 31. Faecal Coliform Counts graphed against Guideline values for Recreational uses and protection of human consumers of seafood.

Figure 32 explains the results. The two sites that tested below the guideline values are areas of high current movement and part of the active coastal zone. Any form of pollution would be easily dispersed with the turning of the tides. The remainder of the sites are located further in the arm of the peninsula and are sheltered by the mudflats of the lagoon. These are not areas of high energy or current/tide movement (not part of the active coastal zone) and the pollution seen in these areas is not easily dispersed and more likely to accumulate due to the tides slowly bringing in pollutants from other areas in the lagoon.

Figure 32: Mapping of Faecal Coliform results along the Hihifo coastline to show areas of high concentration

CONCLUSIONS AND RECOMMENDATIONS

1. Findings and Conclusions

Physicochemical

The measurements of the physicochemical parameters attest to the vastness of the Hihifo coastline. They also give insight to the various conditions associated with the coastline. The diversity of habitats is further emphasised by the variability of the data set produced in this assessment.

However, this singular data set is not sufficient to do more than provide insight to the unique conditions of each testing site. The results of the physicochemical parameter study confirm the differences between sites and highlight the need to investigate each site further and individually in detail to better understand the processes and complex relationships that exist there.

Nutrients

The findings from the nutrient testing showed an anomaly that requires further investigation. Concentrations of nitrate are readily found in nature. The findings present an environment that does not have background concentration of nitrate but contains phosphate and ammonia. The physicochemical measurements also allude to natural biochemical processes actively occurring in the testing sites, yet the nutrient measurements say otherwise. This could be because the equipment used (Palintest Photometer) was primarily designed for freshwater bodies of water, and nitrate measurement in seawater requires special methods due to the large amounts of other ions present that interfere with measurements. However, verification of this hypothesis is required with more sophisticated equipment.

Metal Contaminants

The abundance of metal contaminants along the coastal waters is a cause for concern. Hexavalent chromium and nickel are not naturally found in water, but their respective concentration per testing site is quite high and with no large industrial area on the Hihifo peninsula, this needs to be further investigated. While copper and iron are naturally occurring in water areas, the concentration per testing site exceeds guideline values. Sources of metal contaminants would require further assessments and monitoring of the coastal water areas on a larger scale with additional sites added to better understand the pattern of pollutant dispersion.

Microbiological

The faecal coliform counts per testing site correlates with the initial assessment of surroundings of each testing site. This result comes as no surprise considering the animal trails seen at each testing site. Special attention should be given to areas of shell fishing, fishing, and recreational activities in the lagoon for further monitoring of faecal coliform. As an indicator of disease carrying bacteria, viruses, and protozoa, it is essential to the health of the human population of Hihifo that this monitoring is carried out in a minimum of five water samples taken at regular intervals not exceeding one month, for each testing site as explained in the microbiological results section above.

2. Recommendations

Based on the findings above and the conclusions drawn, it is recommended that further assessment and monitoring of the coastal area be carried out preferably quarterly or at least then bi-annually.

It is also recommended that a thorough study of the watershed of the peninsula be carried out as well, using a more sophisticated method or laboratory testing that is adapted to seawater (for nitrates for instance). This study would provide much needed background information on the various processes of water in the area which would better inform and guide the management of the coastal areas.

The findings from this study can be linked with the Socio-Economic, household surveys report for a more in-depth understanding of the social and gender status of the population concerned.

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ANNEXES

1. Terms of Reference

The Terms of Reference for the Water Quality Assessment Component of the RAPCA are shown below.

Consultant for the Collection, Analysis and Reporting on Coastal water quality in the Hihifo District, Tongatapu

The Consultants roles and responsibilities include:

- Drafting the programme of work for conducting the water quality assessments as outlined under the R2R Regional Programme
- Provide status updates as needed on programme activities
- Compilation and analysis of data collected
- Compilation of draft report
- Editing and assistance to the completion of the final joint report

2. Rapid Assessment of Priority Coastal Areas (RAPCA)

Suggested List of Indicators for the Water Quality Assessment Component under RAPCA.

Figure 33. Suggested Indicators for Water Quality Assessment Component under RAPCA

3. Raw Data Results for Water Quality Assessment

i. Physicochemical Data

Sites	Time	Coordinates		Temperature (°C)	ORP (mV)	Ph	DO (%)	DO (mg/L)	EC (ms/cm)	TDS (g/L)	Salinity (ppt)	SSG (Δt)
RAP016	07:13AM	-21.0689	-175.325	22.9	214.9	7.01	87	6.44	46.63	30.2	30.1	20.7
RAP010	07:58AM	-21.0754	-175.33	23.38	207.5	7.52	81.5	5.96	43.12	30.63	30.59	21.1
RAP020	08:30AM	-21.0911	-175.338	21.3	194.5	7.64	47	3.66	45.69	29.7	29.6	21
RAP013	08:52AM	-21.0878	-175.337	23.35	236.6	7.74	86.3	6.58	45.82	29.92	29.74	20.8
RAP019	09:08AM	-21.0988	-175.338	22.83	213.9	8.81	28.6	2.53	1371	890	0.65	0
RAP007	09:23AM	-21.0996	-175.337	22.88	-75.7	7.62	78.5	6.04	44.57	28.96	28.9	20.5
RAP001	10:20AM	-21.1081	-175.336	25.08	51.9	7.98	71	5.37	41.69	27.41	23.22	18.8
RAP004	10:32AM	-21.1044	-175.337	23.8	23.7	8.31	102.6	7.51	45.2	29.37	29.21	20.2

Table 7. Physicochemical Raw Data

ii Nutrient Data

Sites	Phosphate (mg/L)		Nitrate (mg/L)		Ammonia (mg/L)		
	P	PO$_4$	N	NO$_3$	N	NH$_3$	NH$_4$
RAP016	0.04	0.11	0	0	0.69	0.83	0.89
RAP010	0.01	0.02	0.012	0.053	0.77	0.93	0.99
RAP020	0.04	0.13	0.009	0.04	0.78	0.94	3.09
RAP013	0.07	0.21	0.003	0.013	0.32	0.39	0.41
RAP019	0.08	0.24	0	0	0.78	0.94	1.01
RAP007	0.11	0.33	0.007	0.031	0.21	0.97	1.03
RAP001	0.25	0.75	0	0	0.8	0.97	1.03
RAP004	0.06	0.19	0	0	0.07	0.08	0.09

Table 8. Nutrient Results - Raw Data

iii. Metal Contaminants Data

Sites	Copper (mg/L)		Zinc (mg/L)	Nickel (mg/L)	Manganese (mg/L)	Iron (mg/L)	Hexavalent Chromium (mg/L)
	Free Cu	Total Cu					
RAP016	0.06	0.12	0.13	1.15	0.001	0.5	0.55
RAP010	0.1	0.1	0.11	1.6	0	1.2	0.15
RAP020	0.08	0.08	0.18	1.2	0	1.2	0
RAP013	0.16	0.1	0.16	0.2	0.002	0.9	0.6
RAP019	0.22	0.22	0.15	1.25	0.016	0.5	0.45
RAP007	0.04	0.1	0.12	0.8	0.002	1.1	0.1
RAP001	0.16	0.12	0.15	1.3	0.02	0.3	0.1
RAP004	0.06	0.14	0.19	0.6	0.002	1.9	0.15

Table 9. Metal Contaminants Results - Raw Data

iv. Microbiological Data

Sites	Faecal Coliform (cfu/100 mL)
RAP016	2
RAP010	3
RAP020	34
RAP013	90
RAP019	50
RAP007	46
RAP001	169
RAP004	15

Table 10. Microbiological Results - Raw Data