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Managing Coastal Aquifers in Selected **Pacific Small Island Developing States** Project (MCAP)

Groundwater investigation in Nui, Tuvalu



FUNDED BY:

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Managing Coastal Aquifers in Selected Pacific Small Island Developing States Project (MCAP)

Groundwater investigation in Nui, Tuvalu

Andreas Antoniou, Peter Sinclair and Lono Leneuoti



Suva, Fiji, 2023

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Key partners and stakeholders that contributed to the implementation of this mission are:

- Tuvalu Department of Climate Change
- Tuvalu Lands & Survey Department, Office of The Prime Minister
- Tuvalu Red Cross Society

Community members of the Nui Kaupule played a key role by participating in community meetings and sharing their views on the proposed work.

Community volunteers of Nui Atoll participated in training workshops to enable them to conduct long-term monitoring of water resources.

The communities of Nui are acknowledged for allowing access to their land and wells and assisting with the surveys.

1. Introduction

1.1 Project background

The project, 'Managing Coastal Aquifer in Selected Pacific SIDS', is supported by the Global Environment Facility and is being implemented by UNDP and executed by the Disaster and Community Resilience Programme (Geoscience Energy Maritime Division) of the Pacific Community (SPC) in the Republic of Marshall Islands, Republic of Palau, and Tuvalu. The four-year (2021–2024), USD 5.2 million project aims at improving the understanding, use, management and protection of coastal aquifers towards enhanced water security, including in the context of a changing climate. More specifically it aims at 1) identifying the extent, threats and the development potential of groundwater resources, 2) increasing awareness of groundwater as a water security supply source, 3) providing options for improved access to groundwater and 4) and improving aquifer protection and management, within Pacific Small Island Developing States.

1.2 Mission objectives and outcomes

The present investigation primarily aimed at identifying fresh groundwater resources on the islands of Fenua Tapu and Meang within Nui that could complement existing water supplies or serve as a backup during dry periods. Additional objectives included a survey of private and traditional wells, a survey of the pulaka (swamp taro) pits, conducting socio-cultural surveys with the island communities and conducting training workshops with community volunteers (including Red Cross) to build local capacity in undertaking water resources monitoring. The purpose of the socio-cultural surveys was to archive the information, location, and status, on culturally important and traditional groundwater infrastructure for (i) preservation of culture and historical infrastructure, (ii) groundwater protection and historical monitoring points, (iii) groundwater awareness, (iv) identifying, appreciating, recognising, and incorporating traditional water resource management practices. The purpose of the training workshops was to build capacity within the community to periodically monitor water resources (i.e., rainwater tanks, cisterns, and wells) to support water resources management within the community and in coordination with Government.

2. Background

2.1 Geographical location and history

Nui is a coral atoll located in the Pacific Ocean within the country of Tuvalu. Its long axis, oriented north-south, is 7.25 km long and the atoll is 2.6 km wide at the centre. The atoll consists of 21 islets, with the main island of Nui (Fenua Tapu) being the largest. Although tidal, the lagoon has no surface channels to it from the open sea; it fills and drains across the reef flat and through subterranean passages (McLean et al., 1986). The atoll has a lagoon that is rich in marine life, including a variety of fish species, sea turtles, and corals. Nui's single village is located on the northwest corner of Fenua Tapu. The economy of Nui is based mainly on subsistence agriculture and fishing, with copra production and handicrafts also playing a role.

Nui Atoll is known for its traditional culture and customs, including music, dance, and handicrafts. The island has several cultural and historical sites, such as traditional meeting houses and ancient stone structures, which are of significance to the local community.

The population of Nui Atoll has changed over the years, reflecting broader demographic and social changes in Tuvalu as a whole. According to data from the Tuvalu National Statistics Department, the population of Nui Atoll was 692 in 1979, 659 in 1991, and 541 in 2002. The most recent population data from the 2017 Census indicated 553 people and 99 households whilst current population estimates indicate 491 people (Department of Disaster Management).

There are several factors that have contributed to these changes in population. One key factor is migration, both within Tuvalu and to other countries. Many people from Nui Atoll, like other parts of Tuvalu, are believed to have migrated to larger countries in the region, such as Australia, New Zealand, and Fiji, in search of better employment and education opportunities, as well as into Funafuti, the capital of Tuvalu, as part of the inward migration trend seen across the Pacific. In addition, natural disasters such as cyclones and rising sea levels have also forced some people to leave Nui Atoll and other parts of Tuvalu.



Figure 1. The islands comprising Tuvalu. Source: UNCS, Gov't of USA (www.reliefweb.int)

2.2 Climate

Tuvalu lies within the southeast trade winds zone but is on the edge of the southwest Pacific equatorial doldrum zone. Prevailing winds are from the easterly quarter and mainly occur between June and August. In most years, between December and March, winds from the northwest usually equal or exceed the easterlies in frequency.

Rainfall in Tuvalu is influenced by the position of the South Pacific Convergence Zone (SPCZ), which is a band of convergence that splits from the Intertropical Convergence Zone (ITCZ) and the Western Pacific Warm Pool, and whose position influences rainfall patterns across the islands of the southwest Pacific Ocean. The SPCZ moves zonally and may be positioned farther east or west as it is influenced by larger-scale climate oscillations, such as the El Niño-Southern Oscillation (ENSO). It is a general observation that La Niña ENSO conditions are likely to result in more reduced rainfall for Tuvalu than Neutral or El Niño ENSO conditions.

Monthly rainfall records for Nui date back to 1953. Mean annual rainfall is 3,040 mm, with 60% of this falling during the wet period of November to April. The highest annual rainfall was recorded in 1987, with a total of 5,089 mm, while the lowest rainfall recorded was in 2011 with 1,268 mm. Annual rainfall shows high variation over the years, with a coefficient of variation (CV) of 0.28, indicating that, on average, annual rainfall can be 28% higher or lower than the mean. Rainfall variability is even more pronounced during the dry period (June to November). Rainfall variation in monthly averages is generally high.

2.3 Drought

Drought in Tuvalu can be defined using the percentile method as being a period of rainfall in which the sum of the rainfall for the specified period (e.g., 3, 6, 12 months), is in the lowest 10% of the summed recorded rainfall for that specified period. In other words, the sum of rain recorded over a three-month period, for example September–November in Nui, will constitute a drought if it falls in the lowest 10% of the summed recorded rainfall for the same three-month period across the entire rainfall recorded history.

Nui relies heavily on rainwater harvesting for domestic and drinking water supplies. It is, therefore, appropriate to use a three-month period of rainfall to assess the impact of drought, using the percentile method, due to the smaller storage sizes, and the "residence" time associated with rainwater harvesting. Groundwater systems, which have a larger storage capacity, are more resilient to the impacts of short-term reductions in rainfall, and it is more appropriate to use 6- or 12-month periods when assessing drought impacts on Pacific atolls and islands.

A statistical analysis of the entire rainfall records for Nui, using a three-month drought index percentile method, is provided in Table 1 to provide some insight into drought occurrence for central Tuvalu.

	Total	El Niño	La Niña	Neutral
Number of droughts	29	2	14	13
Average length of drought (months)	4.8	3.5	5	4.8
Average recurrence (months)	35.6	306	41.6	36.6

Table 1. Analysis of drought statistics for Nui for available rainfall data (Jan 1946 – Apr 2018), using a three-month drought index percentile method.

On average, the central Tuvalu islands receive more rainfall, but, statistically, they are more likely to experience drought conditions than the northern Tuvalu islands. Drought conditions in central Tuvalu are, however, of shorter duration (up to 10 months shorter on average) compared with Tuvalu's northern islands. Drought is most likely to occur during either La Niña or Neutral ENSO conditions. Out of the total 29 droughts over the 72-year rainfall record, drought was experienced during El Niño conditions on only two occasions in central Tuvalu..

Table 2 identifies the top five ranked droughts for Nui based on intensity and duration. The 2010–2015 drought, a neutral ENSO event, was the most severe drought on record. It is interesting to note that during 1998–2000, a significant El Niño event associated with drought across the Pacific, and affected Nui and central Tuvalu, did not have as significant an impact on the northern island group of Tuvalu. In general, it can be stated that drought is more severe in northern and central Tuvalu than in Funafuti and southern Tuvalu, with regards to both duration and rainfall amount.

Nui (January 1946 – April 2018)						
Rank	Drought period	Drought length (months)	Drought ENSO state	Total rainfall during drought (mm)	Average monthly rainfall during drought period (mm)	
1	May 2010 to September 2014	21	Neutral	6658.4	123.7	
2	March 1998 to June 2000	28	El Niño	4037.5	144.2	
3	March 1962 to July 1963	17	Neutral	2773.8	163.2	
4	April 1971 to May 1972	14	La Niña	2202.0	157.3	
5	January 2006 to January 2007	13	Neutral	2448.8	188.4	

Table 2. Historical droughts on Nui (three-month percentile index).

2.4 Geology and groundwater occurrence

According to McLean et al. (1983), five different landform units can be distinguished on Nui (Figure 2).

Oceanside ridge complex: The ridge crests form the highest natural surface features on Nui, typically reaching 2.5 – 3.5 m above reef flat level, with the steepest slope represented by the ocean beach. In the larger islets these ridges are predominantly composed of sand. On Fenua Tapu, a 150 m wide sandy ridge extends continuously along the southern and eastern shores for approximately 2.5 km.

Lagoonside ridge complex: These ridges are of lower elevation (1 – 1.5 m) with lower beach gradients and gentler interior slopes. They are typically composed of finer sands compared to the ocean ridges, suggesting that sediment production and wave-current action on the lagoon side are low.

Interior flats and ridges: As opposed to other atolls in Tuvalu where a distinct central depression is present between the oceanside and lagoonside ridge complexes, the interior in Nui is often hummocky (pattern of ridges and hollows) rather than flat. On Fenua Tapu, the hummocks are primarily composed of coral gravel and rubble.

Pulaka pit – spoil bank complex: Excavated depressions (pulaka pits) and accumulated material (spoil bank) areas occur mainly at the northern end of western Fenua Tapu and in the centre of Meang. Pit floor levels are 20-50 cm above reef flat level whereas the spoil banks can reach a height of up to 5 m. The largest pit on Nui is in central Meang covering an area of 2.5 ha. Most families in Nui have at least one plot.

Saline flats and sandy inlets: Sandy flat areas which get flooded at high tide are typically found on the lagoon side of the larger islets.

Despite the relatively high annual rainfall, freshwater is a limited resource. Several freshwater wells are present on the larger islets of Fenua Tapu, Meang, Tokinivae, Piliaieve, and Pongalei. These wells are tapping the thin freshwater lens that occurs within the unconsolidated sediments and which is buoyantly supported by dense underlying saline water. The thickness of this freshwater body depends on the recharge rate (rainfall), the width of the island, the hydraulic conductivity of the sediments, the depth of the underlying higher permeability older limestone, and the presence (or absence) of a reef flat plate (Bailey and Jenson 2012). It should be noted that freshwater lens development has been observed within the in-situ weathered low permeability shallow limestone deposits (slightly to highly weathered) in Kiritimati Island (Douglas Partners, 1999; Falkland T., 2016; Murphy P., 1982).

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Mixing between the fresh groundwater and underlying salt water, promoted by tidal forces, is responsible for the presence of a zone of transitional salinity. The zone's thickness largely depends on the hydraulic properties of the aquifer sediments and recharge. Prolonged periods of drought can lead to a thinning of the freshwater lens, as having less recharge leads to the upward movement and broadening of the brackish transition zone. During drought periods, brackish groundwater appears at the bottom of pulaka pits and in the village wells.

The groundwater salinity in various wells has been measured during different surveys (Table 3). Most of these wells are located within the lagoon ridge complex unit, demonstrating higher groundwater potential due to the finer nature of the sands (Figure 2). Salinity levels vary in the wells, reflecting the shallow depth of the underlying transition zone, and thus, the thinness of freshwater lens. As measured in the wells, the freshwater lens is easily susceptible to dry conditions. The 2011 survey (Sinclair et al, 2012) was conducted during a severe drought that forced the Government of Tuvalu to declare a state of emergency. Groundwater salinities obtained during that survey were some of the highest salinity levels that have been recorded in the wells. The March 2023 survey was also conducted during relatively dry conditions; however, some wells maintained low salinity levels during drought conditions, indicating the greater lens thickness in certain areas. the hospital well (Tabontebike) has consistently maintained low salinity levels, even during the 2011 drought. Additionally, the Carlton, Tinilau, and Talivaka (CFC) private wells areas have had relatively low salinity values throughout duration of monitoring, even during dry conditions. These wells seem to be the exception as elevated salinity levels were recorded in the remaining wells

The May 2023 data were collected by Nui community and Red Cross volunteers who were trained on water resources monitoring techniques (see Section 3.2). This data should be treated with caution as some wells recorded unusually low EC values which may suggest technical or human error during data collection.

Table 3. Electrical conductivity of groundwater in shallow wells. For comparison, the average EC of seawater is approximately 50,000 μS/cm. * Indicates potentially inaccurate data as the recorded EC values were well below historical averages.

	Electrical Conductivity of groundwater (µS/cm)			
Well name	Feb 1982 (McLean et al., 1986)	27 Oct 2011 (Sinclair et al., 2012)	10 Mar 23 (SPC)	12 May 23 (Tuvalu Red Cross volunteers)
Talivaka / CFC			500 – 600	
Alopanoi		4,580	6,080	
Alopanoi old well		1,778		
Carlton			369	270
Tinilau			1,440	720
Teuti		10,920	5,360 – 6,065	2,295
Tanrake		8,900 – 10,450	6,095	326*
Peaaliki			2,820	152*
Tabontebike / hospital well	350	986 – 1,446	345 – 421	298
Te Vaimalie / Vaipuna		2,890 – 6,640	2,345 – 2,467	256
Fanani		7,340		
Kiritimati Kaiarake		4,600		
Opeloge		2,350		

	Electrical Conductivity of groundwater (µS/cm)			
Well name	Feb 1982 (McLean et al., 1986)	27 Oct 2011 (Sinclair et al., 2012)	10 Mar 23 (SPC)	12 May 23 (Tuvalu Red Cross volunteers)
Makiti		2,136		
Isumu		3,450		
Maeli		5,175		
Teapaga / Stanley		1,855 – 6,130		
lafeta		Under construction		
Ligo		18,100 – 22,300		

3. Field survey methodology

3.1 Electrical resistivity tomography survey

Electrical resistivity tomography (ERT) geophysics were used to assess, visualize and identify the lateral and vertical variability in electrical resistivity response within the different geological units. The method works on the principle of adding direct current into the ground using a pair of electrodes. The current causes a potential voltage difference in the ground, which is measured by a separate pair of electrodes. The voltage measured can then, using the parameters of the survey, be converted into an apparent resistivity value and provide insight into the underlying geology and hydrogeology. Resistivity of the subsurface is a function of the porosity of the geological medium, hydraulic permeability, electrical conductivity (salinity) of pore fluids, and clay mineralization...

The ABEM Terrameter LS2 from GuidelineGeo Inc. was used in combination with the multiple gradient array as the preferred survey protocol offering a high horizontal and vertical data resolution (Darlin and Zhou 2006). The depth of investigation is a function of the electrode spacing and the Earth's resistance; in general, the greater the electrode spacing, the deeper the investigation. An electrode separation length of 2 m was selected to investigate depths up to 30 m. The orientation of the survey profiles and surveyed distance was guided by the review of satellite photos and existing shallow wells to adequately investigate the groundwater potential of shallow coastal sediments.

Table 4 illustrates typical sediment types encountered in atolls and the corresponding resistivity ranges that are likely to be measured for different levels of saturation water salinity. Calibration lines were conducted in Majuro and Kiritimati atolls in the countries of RMI and Kiribati, respectively, and reported values were derived by analysing ERT survey lines conducted along existing monitoring bores of known lithology, allowing sampling of groundwater from different depths (Table 4). These results can be utilized with a relatively high level of confidence to translate resistivity values to groundwater salinity in other locations, especially when some geological information is available. In the absence of test holes and monitoring bores in Nui, these values were used to estimate the thickness of the freshwater lens along the ERT survey lines.

Table 4. Typical resistivity ranges for different sediment types derived from ERT calibration survey lines along existing monitoring wells of known lithology (Douglas Partners. 1999; Falkland T. 2016; Murphy P. 1982; Hamlin, S., and Anthony, S. 1987).

Rock and sediment type	Saturation	Indicative EC range of groundwater (µS/cm)	Bulk resistivity (ohm.m)
Coral sediments	Dry		500 – 3000
Foraminiferal beach sand ¹	Fresh	200 – 750	50 – 65
Cohesive mix of foraminiferal sand, gravel-sized coral, and shell fragments ¹	Fresh - upper	500 – 800	40 – 45
Cohesive mix of foraminiferal sand, gravel-sized coral, and shell fragments ¹	Fresh - Iower	1,500 – 2000	6 – 20
Silty gravelly sand and silty sandy gravel ²	Fresh	600	90 – 100
Gravelly coral sand ²	Fresh - Iower	1,700	10 – 12
Calcareous coral limestone, moderately/highly weathered ²	Fresh	550 – 1,400	40 – 200
Calcareous coral limestone, slightly weathered ²	Fresh	640 – 2,400	30 – 100
Calcareous coral limestone, moderately/highly weathered ²	Brackish	3,900 – 6,4 00	4 – 17
Calcareous coral limestone, slightly weathered ²	Brackish	4,000 – 6,000	14 – 40
Calcareous coral limestone, slightly/moderately/highly weathered ²	Saline	8,000 – 30,000	2 – 6

1. Majuro atoll, RMI; 2. Kiritimati atoll

3.2 Model inversion methodology

Model inversions were performed using the Res2Dlnv software. The program automatically creates a twodimensional model by dividing the subsurface into rectangular blocks then calculating the apparent resistivity of these blocks using either a finite difference or finite element method and comparing these values to measured data. The resistivity of the model blocks is adjusted iteratively until the calculated apparent resistivity values of the model agree with the actual measurements. A uniform resistivity color bar was used to allow comparisons between the inverted profiles.

Prior to running the model inversions, the raw exported database was first treated to remove any 'negative resistivity' readings that might affect the accuracy and reliability of the inversion. These erroneous readings indicate the electrode's inability to read a realistic difference in electrode potential, thus contributing substantially to the total absolute error. This is usually related to poor electrode contact, misplaced electrodes, the presence of human-made objects in the ground (e.g., cables or pipes) and above the ground (e.g., metal fences), and noise from electrical fences or power lines. Other reasons for errors are related to incorrect transmitter and/or receiver settings with respect to field conditions, and to highly variable geological conditions in two or three dimensions, forcing the electrical current to travel in unexpected ways and cause negative readings (Fredrik Nyqvist, Product Manager, Guideline Geo Group MALÅ/ABEM, 2017, pers. comm.). The presence of seawater with very low resistivity along the coastal survey lines is another factor that can contribute to 'noisy' datasets. After removing the negative values, a preliminary inversion was carried out using the remaining data points. Absolute

errors related to the inversion were low suggesting the high quality of data obtained and the high confidence in the modelled results.

Lidar data collected under the GCF-funded Tuvalu Coastal Adaptation Project were utilized to include topography in the modeled inversions and correct for lateral changes in elevation along the profiles.

3.3 Community engagement

To enhance the resilience of remote island communities to droughts, a community-based monitoring methodology was developed, and training was given to community volunteers to undertake periodical monitoring of water resources. The objectives were to build capacity of communities to monitor their water resources and, thereby, identify stress levels, prepare for potential drought impacts, and seek solutions to strengthen their longer-term water security. The approach relies on the concept of citizen science – supporting community members to be active participants in the collection and use of reliable, consistent, and timely information on their water resources.

Equipment provided to the volunteers included TPS salinity meters, smartphones with KoBo app installed for recording and uploading of the data to the KoBo Toolbox platform, bacteriological field test kits, and field measurement tools. A customized KoBo survey form was developed to facilitate data collection. The volunteers were trained in surveying water cisterns, rain tanks, and wells. The percentage of water remaining in community cisterns and tanks, and the groundwater salinity of shallow wells serves as a useful indication of the impact of drought on their water resources and vulnerability of the community to water scarcity.

In addition, a focus-group discussion was held with the Nui community with the intention of capturing traditional and current practices and perceptions around water resources use and management. The participants were divided into three groups including men, women, and youth. The conversations were recorded on tape and the main information was captured on paper.

4. Results and discussion

4.1 Geophysical results and interpretation

Overall, the ERT lines conducted suggest the presence of a thin freshwater lens in the sandy beach deposits (Figure 2). One main fresh groundwater body and two secondary ones were identified on Fenua Tapu. The main groundwater body extends from the northern tip of western Fenua Tapu through to the pulaka pit area and into the village. Several shallow wells, including the Tabontebike (Hospital) well, Teapaga, and Te Vaimalie and existing pulaka pits tap this groundwater body. The thickness of the freshwater lens does not exceed 2 - 3 m. A secondary groundwater body of similar thickness (2 - 3 m) was identified in the eastern side of Fenua Tapu within the ocean ridge complex along survey lines 7 and 8 (Figure 2). No shallow wells seem to exist in this area. A third narrow fresh groundwater body potentially exists within the ocean ridge complex extending across survey line 12.

Although the survey was conducted during a dry period which is assumed to have impacted the thickness of the freshwater lens, overall, Nui does not appear to offer any significant potential for groundwater development at community level. The limited extent and thickness of the freshwater lenses would not be capable of sustaining the level of abstraction required to meet community needs. The main groundwater body identified around the village has been historically capable of sustaining some groundwater use through private and communal shallow wells as well as the farming of pulaka (swamp taro). To confirm its presence, salinity levels and suitability for consumption, the second identified groundwater body in the east could potentially be tapped through the digging of a shallow well. If the presence and potability were confirmed via further assessment, a small infiltration gallery could be installed to allow for a more sustainable groundwater abstraction to complement other water sources during dry periods.

In Meang, the two survey lines conducted (13 and 14) from west to east along the central part of the island, suggest the presence of a very thin lens (1 - 2 m) primarily present in the central part where the old pulaka pits were dug (Figure 3). The limited extent of this groundwater body does not present any opportunities for further development.

Although Fenua Tapu is a relatively wide island (600 m along the village area), the hydrogeological conditions do not favor the formation of a thick freshwater lens. As mentioned earlier, the thickness of a freshwater lens depends on rainfall, island width, hydraulic conductivity of the unconsolidated Holocene carbonate sand sediments, the depth to the limestone, and the presence of a reef flat plate. A reef flat plate is present in Nui and can be seen in the various shallow wells which have been dug through this geological layer. The thin nature of the freshwater lens in Nui can be attributed to the high permeability of the Holocene sediments and/or the shallow depth of the underlying limestone. Rainfall was scarce during the months leading up to this investigation and the freshwater lens thickness was certainly impacted by the lack of recharge. Nevertheless, it is expected that even during a wet period, the freshwater lens in Nui would not be substantially thicker.

4.2 Water resources management options

Traditionally, atoll communities have been primarily relying on groundwater collected through shallow wells, usually dug through the reef rock plate, if present, and just below the water table to keep the salinity inside the well as low as possible. Drinking water supplies from groundwater have been complemented by traditional rainwater harvesting techniques which have been an integral part of the region's water management systems for generations.

In recent decades, there have been initiatives to promote modern rainwater harvesting systems and technologies in the Pacific Islands to enhance water security and resilience. These initiatives often aim to combine traditional knowledge with contemporary approaches to optimize rainwater collection, storage, and distribution. As a result, there has been a shift towards a reliance on rainwater for primary and, often, secondary water needs over the last two generations. This reliance on harvested rainwater has resulted in behavioral changes in which the acceptance, awareness, and application of groundwater as a freshwater source, has been questioned.

This exclusive reliance on rainwater can cause vulnerability to prolonged droughts which can reduce the stored volume of rainwater supplies. Groundwater and desalination should be included as additional freshwater sources to help diversify water resource reliance and increase the water security of the Nui community. Though limited in extent, the fresh groundwater resources, especially the untapped resource potentially present in the eastern part of Fenua Tapu could be developed through a shallow well or even a small infiltration gallery system. The water could be stored in a header tank and made available through a strategically located water collection point. Although the extent of fresh groundwater (1000 – 2000 ppm) for secondary purposes or as a source for desalinated water.

Desalination can provide a reliable source of freshwater, reducing the dependence on limited groundwater resources or rainwater collection. By implementing desalination, the Nui community would diversify their water sources, thereby increasing resilience to climate variability and extreme weather events. At the same time, however, desalination presents a number of challenges:

- Cost: Desalination can be expensive to implement, operate, and maintain. The high energy requirements, infrastructure costs, and ongoing access to highly specialized spare parts pose financial challenges, particularly for small, remote atolls with limited resources.
- Environmental Impact: The brine discharged from desalination plants can be detrimental to terrestrial and marine ecosystems if not properly managed. The delicate ecological balance of coral reefs and marine life in atoll environments needs to be considered when planning desalination projects.

Sustainability: Pacific atolls often have limited renewable energy resources, which means desalination
plants may rely heavily on fossil fuels. Difficulties of transporting fossil fuels to remote location to
run desalination plants is problematic and is currently an unsustainable practice for meeting water
demands. Finding sustainable energy sources to power desalination is crucial to ensure long-term
viability and sustainability of desalination.

To overcome these challenges, a holistic approach is necessary. It involves considering energy efficiency measures, incorporating renewable energy sources like solar or wind power, implementing efficient water distribution systems, and engaging local communities in decision-making processes.

4.3 Community engagement results

The community consultation with a group of men, women, and youth of the Nui community revealed some interesting information around traditional water resource collection, use, and management. A summary is provided below while the entire survey is presented in Annex 1.

Water use: Up to the mid 1970's, several wells including the Tanrake, Tevaimalie, Teapaga, and others were used for drinking water purposes. The careful maintenance of the wells by the community in the past reflected their importance. Drinking water supplies were complemented by two rainwater cisterns present near the church chapel. Nowadays, rainwater is considered as the only safe source of drinking and cooking water while wells are only used for washing, bathing, feeding pigs and other non-potable uses, especially during droughts. Groundwater is now considered unsuitable for human consumption due to contamination concerns from potentially leaking septic tanks, uncontrolled burials of the dead in the vicinity of wells, and algae growth resulting from lack of maintenance.

Water management: All wells are currently publicly accessible, and each household collects water based on their needs. Community rainwater supplies are managed by the Kaupule and rationed out monthly. Water resources are regularly monitored by the Island Disaster Committee which additionally conducts inspections of water catchments and carries out water soundings. During droughts, the Sanitation Officer and the Island Disaster Committee decide on the rationing of rainwater supplies. Concerns were raised during the consultation around the current effectiveness of the Disaster Committee and the support it receives from the Falekaupule. Land-use management measures are encouraged, especially around the issue of unrestricted locations for burying of the dead. It was agreed that groundwater needs to be further investigated to assess the potential for usage for potable purposes and what treatment it might require. Women who look after water management at the household level inquired about the potential of piping new groundwater sources closer to the community. Women are also in charge of water recycling at the household level (e.g., using greywater for flushing toilets, using kitchen wastewater for feeding pigs, etc.).

Inundation events: During TC Pam and TC Tino, most of the pulaka pits and a majority of the main settlement were flooded by seawater inundation. Flooding of the pulaka pits lasted for weeks and the impacts lasted for months. It was estimated that it will take 5 years for the pulaka pits to recover from the salinity contamination.





Figure 3. Meang island: mapped landforms, wells, pulaka pits, and ERT survey lines (landforms source: McLean et al, 1986).

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Annex 1 – Community consultation results

Men group

Date: 11th March 2023

Facilitator: Lono Leneuoti

Participants: 14 men (ranging in age from 53 to 76 years of age)

1. What are the main (drinking and potable) water sources and where are they located?

- Old times (up to mid-1970s); wells were used for drinking (Tanrake, Tevaimalie, Teabanga, Tabontebike, Talakiina (3x), Vaipuna, Takalepu, Peau, Koolo, etc)
- Now; well water is not longer used for drinking and food prep. Rainwater is now the main drinking and cooking water source.
- 2. Who owns the water source? Is access to these water sources restricted or open? Does the access change during droughts or other events and why?
 - Wells are open to the public, even privately owned wells. Public access to wells is the same in normal and drought times as well. Well water had no limits, if wells became dry, people would go fetch water in other wells.

3. What water sources do you rely upon during droughts and why?

• During droughts rainwater sources are used for drinking and cooking while well water is used for bathing, washing, feeding pigs and other livestock. Community rainwater sources are rationed to the community.

4. Who collects the water during times of drought and how often?

• Women were the usual household ration collectors but now it is done via Kaupule water truck

5. Are there any wells or traditional rain water harvesting systems that have cultural or historical importance? Where are they and why are they important?

- Wells were very important in the past, well kept and maintained by the community.
- Each household drew well water from the main community wells using a 'pilikan' (aluminum billy cans) and hang these in the local huts by a post with a cup hanging on it. This was the drinking source for the family throughout the day.
- The Tanrake well was traditionally known as having a dedicated family that look after the well with a certain way that they looked after the well. After some time, this role was transferred to the Boys Scout and they continued to maintained and cleaned the well the way the family did in the past.
- In the old days, community feasts (fakaala) used well water for the community to drink. It was usually mixed with local toddy syrup (kaleve kula) to be the drink for the feast (fakaala)

6. Which water sources do you trust in terms of quality and safety of water supply? Has this changed over the last 30 years?

- Obviously in the past, well water was trusted for drinking but not anymore. At some point, investigations into well water found that they were no longer safe; smell bad and algae growth. Now, rainwater is the only reliable drinking and potable water supply.
- During the recent drought, desalination plants have added safe water supply for the community.

• Another source of contamination in recent times has been the burying of the dead in areas close to wells. After TC PAM, when the local cemetery was destroyed, people started burying their dead in their own lands which at times was close to wells.

7. Is there a village water committee? If yes, what is its role, and what is your (as men) role?

• Sanitation Officer and Disaster Committee meet during droughts and decide on rationing of water during droughts. Wells are under the oversight of the Kaupule and the Falekaupule. The Disaster Committee does not function well at the moment, needs to be supported from the Falekaupule to ensure the committee meets monthly and be active. Committee work together with the Kaupule and the MET during the drought to discuss issues relating to the drought and what response is required.

8. How are the women and the disabled supported for their water and sanitation needs?

• Kaupule invites reps from women into management teams and representation within Kaupule systems, however the disability community are somewhat not represented by a member. However, both women and disabled persons' needs are usually supported within each family.

9. What roles do women and the disabled play in water management?

• There is no specific representation of women or disabled persons in water management and committees. These groups can be represented if members are elected into Kaupule positions or other positions that sit in such committees. Women may be better represented than persons with disabilities at the moment because the women community (Matapulapula) is very active in community activities whereas the disability organization is either not active or very small.

10. What improvements in the water management can you suggest?

- Kaupule is in charge of water management on behalf of the Falekaupule, so maybe to strengthen Kaupule work and systems.
- Encourage more developments such as this project, to improve well water usage and also to support desalination unit water supply as well.
- Better land-use management and particularly with the issue of unrestricted locations for burying of the dead.

11. In the last 30 years, list the major hazards that have impacted or damaged water supply system or water resources?

• Droughts, TC PAM, TC TINO, (wells and pulaka pits inundated with salty sea water). Older cyclones include OFA, NINA, KINA.

12. Can you map the extent of the inundation that occurred under TC Pam and TC Tino. Which areas were flooded and which were not?

• Most of the pulaka pits were flooded and most part of the main settlement were also flooded. Even towards the bushy unsettled side of the island. The pulaka pits were flooded for weeks and the impact lasted months. If planting beds are dug too deep, the plants will not survive. It is estimated that it will take 5 years to recover. Even now, the impacts are still experienced in the pulaka pits.

13. What information source or signs are used to predict or indicate a drought or stormy condition? How much lead time or warning time is given for communities to prepare for such hazards?

- There are some skilled individuals who have traditional knowledge of such natural hazard prediction, but this knowledge is normally kept within families.
- Some generally known signs and predictions include;
 - If it is exceptionally calm, there usually will be some bad weather coming
 - There are certain insects that are normally found on the beach, their behaviour sometimes predicts weather events such as rain, storms, etc.

Information to warn about weather event is not sufficient, sometimes it is late and people do not get enough time to prepare for the event.

14. What is the role that the Kaupule plays in water management?

• Plays the central role in water management and executes this important role on behalf of the Falekaupule (leaders) for the community.

15. Does this change in normal and drought periods?

• It does not change, the Kaupule is still the key central point for water management, during normal and drought times.

16. How often is information on water sources and quality shared between island council and community?

• Information on water sources within the local setting is very quickly dispersed as this is a small island and the roles being clear between the community, the Kaupule and the Falekaupule.

17. What improvements would you like to see in your water supplies in the future?

- Rainwater storage is not sufficient and needs to be increased; community cisterns and even household storage. Support is required to enable this increase in storage.
- Well water needs to be investigated to see the potential for usage for potable purposes such as the practice in the past. Are there chemicals or treatments that can be applied to groundwater to bring the quality back up to levels where they can be used for drinking and other potable use. If rain stop for an extended period of 4 months or so, most rainwater storage would have already run out. Rainwater tanks are preferred over cisterns for maintenance purposes. Cisterns are harder to maintain compared to plastic tanks. Emphasis on groundwater as a security supply was also raised, particularly if droughts go for longer periods (7 months or more) and desalination units break down. Caution must also be taken to ensure that groundwater is not overdrawn to the point that it starts to adversely impact vegetation and particularly the pulaka pits.





Women group

Date: 11th March 2023

Facilitator: Faafetai Namoto

Participants: 14 women (ranging in age from 36 to 72 years of age)

1. What are the main (drinking and potable) water sources and where are they located?

- Back in the old days (1970s or so) there were only 2 rainwater cisterns (Church chapel) and the rainwater from these cisterns was rationed to babies (a bucket). When the two cisterns were full, the community will get rations from it. People then were still drinking from the well water, especially Te Vaimalie and Tanrake wells. Sometimes Teapaga well for people living closer to it. Even as late as in 1977, accounts are that the Tanrake well was still used for drinking. Now these wells are no longer safe to drink, especially the Tanrake well has a foul smell lately. There were also clean water pools within the pulaka pits (koloaka??) that are sometimes used as a water source for bathing.
- Now, wells are no longer used while the community rely on rainwater. Only during drought that well
 water can be used again but for washing and bathing and other non-potable uses. People are worried
 about the quality of well water due to the contamination of groundwater from household septic
 leakages and also from the shift in the burial practices for dead people. Since the destruction of the
 cemetery during TC PAM, people are now burying their dead in their own lands, sometimes within the
 proximity of existing wells.
- 2. Who owns the water source? Is access to these water sources restricted or open? Does the access change during droughts or other events and why?
 - Some wells are owned by the island (communal); Vaimalie, Tanrake and Tabontebike, while other wells belonged to the family (landowners).
- 3. What water sources do you rely upon during droughts and why?
 - The same water sources were still used during droughts also but the poor quality of well water nowadays have made people rely more on rainwater.

4. Who collects the water during times of drought and how often?

- Usually, women were the main ration collectors but now both men and women help each other with the ration collections.
- 5. Are there any wells or traditional rain water harvesting systems that have cultural or historical importance? Where are they and why are they important?
 - There was a way that wells were cleaned and this is the role of a particular family, later this role became that of the boy scout and girl guides (at the Tanrake well)
- 6. Which water sources do you trust in terms of quality and safety of water supply? Has this changed over the last 30 years?

Due to the groundwater contamination from septic tanks and other contaminants, well water is no longer a safe water supply for drinking and food preparation. It is now rainwater that has become the main water source that has the quality and safety level for potable uses.

7. Is there a village water committee? If yes, what is its role, and what is your (as women) role?

It's the Kaupule that manages communal water sources, no special committee for this.

8. How are the women and the disabled supported for their water and sanitation needs?

There seem to be no special treatment for women and disabled, same treatment as other members of the community.

9. What improvements in the water management can you suggest?

- Groundwater gallery to support water needs, and especially safe water to drink. Some wells in the islets (Tokinivae) is still fresh and this can be further explored for use as water supply.
- To have household cisterns for added water supply at household level. This can help reduce the burden of collecting ration for women. If groundwater is found, can this water be piped so that it gets closer to the community, even into households.

10. In the last 30 years, list the major hazards that have impacted or damaged water supply system or water resources?

TC PAM, TC TINO, droughts.

11. Can you map the extent of the inundation that occurred under TC Pam and TC Tino. Which areas were flooded and which were not?

Most of the island was inundated with sea water, there were some areas that did not get affected.

- 12. What information source or signs are used to predict or indicate a drought or stormy condition? How much lead time or warning time is given for communities to prepare for such hazards?
- Sometimes warnings are received in time, other times the warning is late. Also, sometimes nothing happens after warnings. Sometimes there was no warning at all.
- Some natural and traditional warning signs includes birds' movements. When more birds gather on the island, then this is a sign that a storm is about to arrive.

13. What is the role that the Kaupule plays in water management?

There is a Disaster Committee that is also under the Kaupule oversight that deals with water issues during drought times.

14. Does this change in normal and drought periods?

It is the same, the Disaster Committee is activated during disaster

15. How often is information on water sources and quality shared between island council and community?

Sanitation officer provides information sometimes about the quality of water. Information provided is not frequent, should be more frequent. Households may need to get their water tested.



Youth group

Date: 11th March 2023

Facilitators: Sapolu Tetoa & Kitty Yee

Participants: 13 youth members; 4 male and 9 female (ranging in age from 20 to 42 years of age)

1. What are the main (drinking and potable) water sources and where are they located?

- Rainwater cisterns at; Manatuamaiau Falekaupule, CFC, Kerupi Church, Tabontebike Clinic, Vaipuna School, Tanrake, R2R tanks (Project) no longer
- Wells at; Tanrake, Vaimalie, Tabontebike, Pealiki, Tokinivae islet
- 2. Who owns the water source? Is access to these water sources restricted or open? Does the access change during droughts or other events and why?
 - Island (Fenua). Wells are open while rainwater cisterns are restricted and managed by the Kaupule so that they are not misused by the public

3. What water sources do you rely upon during droughts and why?

- Wells and rainwater cisterns are the main sources relied on during droughts as they are the only options available.
- Wells are an endless supply and mostly used for laundry, bathing and to feed pigs. Rainwater cisterns are used for drinking and cooking.

4. Who collects the water during times of drought and how often?

Each family will collect their water needs from wells while the Kaupule rations out rainwater supplies on a monthly basis. Wells are open at any time, while Kaupule mai ration rainwater either once or twice a day.

5. Are there any wells or traditional rain water harvesting systems that have cultural or historical importance? Where are they and why are they important?

- The wells at Vaimalie and Tanrake are traditionally significant because they were historically the main source of water of Nui communities over the years till now.
- The practice of weaving a palm frond around the trunk of a coconut tree and hanging the weave into a kumete or drum to collect rainwater, was used in the past

6. Which water sources do you trust in terms of quality and safety of water supply? Has this changed over the last 30 years?

Right now, we only trust the water from our own raintanks and the rainwater rationed by the Kaupule

7. Is there a village water committee? If yes, what is its role, and what is your (as youth) role?

Yes, the Island Disaster Committee monitor water resources while youth mainly play the role of support. The committee also conduct inspections of water catchments and carry out water sounding

8. How are the women and the disabled supported for their water and sanitation needs?

No support from the Kaupule specifically for women and disabled persons, families are the ones providing this support.

9. What roles do women and the disabled play in water management?

Disabled persons have no role in water management. Women are the household managers of water and can use recycling techniques to reuse water, e.g; using dirty water from laundry for flushing toilets, using kitchen waste water for feeding pigs, etc.

10. What improvements in the water management can you suggest?

Build up protective cement walls for wells. Increase rainwater tanks at households and communal rainwater cisterns. Improve rainwater catchment systems.

11. In the last 30 years, list the major hazards that have impacted or damaged water supply system or water resources?

TC PAM (2015) and TC TINO (2020)

- 12. Can you map the extent of the inundation that occurred under TC Pam and TC Tino. Which areas were flooded and which were not?
 - Tanrake, Tabontebike, Manutalake, Apoa, Fakaifou (flooded)
 - A few houses in the Alamoni side were not flooded
- 13. What information source or signs are used to predict or indicate a drought or stormy condition? How much lead time or warning time is given for communities to prepare for such hazards?

Radio Tuvalu (weather forecasts), usually 3 days in advance. There were old local methods in which bad weather could be predicted.

14. What is the role that the Kaupule plays in water management?

Manage communal rainwater resources and ration to families

15. Does this change in normal and drought periods?

Yes

- **16.** How often is information on water sources and quality shared between island council and community? Monthly. Some youth believe that this information is never shared to the community
- 17. What improvements would you like to see in your water supplies in the future?

Increase rainwater storage (tanks and cisterns) for families. Improve the quality of wells



Annex 2 – ERT inverted profiles



Project9 NUI05.







Project9 NUI10



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Project9 HEANG01



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