Kingdom of the Netherlands

DRR-Team Mission Report

Kingdom of Tonga

Groundwater availability in relation to water demands in Tongatapu

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DRR MISSION TO THE KINGDOM OF TONGA (14 – 23 November 2016)

Groundwater availability in relation to water demands in Tongatapu

The mission specifically focused on the issue of sustained available water resources for the water supply of Nuku'alofa and the consequences of using scarce groundwater resources for irrigation of crops.

The mission has built on research of the Government of Tonga often supported by the South Pacific Commission (SPC), ADB, EU and bilateral donors. The findings, limited to the island of Tongatapu, may be summarized as follows:

1. In the aquifers of Tongatapu, a layer of fresh groundwater with lower density floats on saline deeper groundwater. This body is called a *freshwater lens* and is recharged by rainfall percolating through the soil and loses water through freshwater sources along the coast. Recharge of groundwater is very low during El Niño droughts and fresh water then has to be abstracted from storage in the freshwater lens thus reducing its thickness. The 2015 drought was much less severe than that of 1983. After the 2015 drought the average freshwater lens thickness in 16 salinity monitoring boreholes was reduced by about 2 m, from 12.4 to 10.3 m;
2. Based on average annual recharge (621 mm, years 1980-2015) on an area of approximately 180 km^2, excluding low lying areas and coastal strips with minor fresh groundwater reserves, and a safe abstraction value of 30% of recharge, the maximum sustainable groundwater abstraction would be 92 Ml d^{-1}. This value is slightly higher than that of White et al. (2011; 72 Ml d^{-1}) because of the higher annual average rainfall and recharge over the period 1980-2015;
3. Part of the domestic use of water (cooking, drinking water) both in urban and rural areas is derived from rainfall harvesting (roof catchments and storage tanks). However, the capacities of the tanks are only sufficient to accommodate the demand during dry periods not exceeding three months. When tanks run dry, people switch to tap water, increasing the demand on the public water supply;
4. The demand for supplying the 30,000 inhabitants of Nuku'alofa is at present satisfied by the 9 Ml d^{-1} day currently pumped from the groundwater lens by the Tonga Water Board (TWB) out of 36 older and 18 new wells in the area of Mataki'Eua;
5. The supplied quantities per capita (about 230 l d^{-1}) for Nuku'alofa are above actual per capita daily use (estimated at about 150 l d^{-1}) and indicate substantial losses in the water distribution system, estimated by TWB at 30%. Recent improvements to the water reticulation network in Nuku'alofa in the form of Japanese funded replacement of the mains have reduced losses to some extent. However, more savings are necessary by targeting leaks in the secondary reticulation network and in domestic leakage. Losses from the water reticulation network infiltrate to groundwater but these cannot be re-used due to pollution and mixing with high salinity groundwater below the coastal urban area;
6. During dry periods several production wells of the Mataki'eua well field show increased salinity, with measured electrical conductivity (EC) values reaching up to 2,350 μS cm^{-1} (fresh-brackish threshold is at 2,500 μS cm^{-1}) at the end of the dry season in November 2016, suggesting that there may be little surplus water available in parts of the well field. This calls for continuous monitoring of the salinity of these wells in the Mataki'eua / Tongamai field for proper operational management. In the future, additional extraction of groundwater is foreseen by the TWB at Fua'motu near the airport. The groundwater lens is substantial in the area and at this stage seems slightly thicker than at Mataki'Eua. Further studies on groundwater availability and aquifer properties (e.g. hydraulic conductivity,

anisotropy) are necessary to better asses salinization risks in relation to pumping rates and to obtain better quantitative information on groundwater resources. If very low continuous abstraction rates are used and skimming occurs from the very top of the aquifer (e.g. using horizontal drains rather than vertical wells), it may well be possible to abstract higher percentages of recharge from well fields used for public water supply or for agriculture;

7. Irrigation practices include hand watering for subsistence farming, sprinkler irrigation and drip irrigation. The high infiltration capacity of the soil prevents use of flood or furrow irrigation. Two irrigation traveller systems have been in operation in Tongatapu. Commercial irrigation to this date has only been of limited magnitude (<0.5 Ml d^{-1}), also because water saving methods as drip irrigation are being applied. Irrigation has contributed to the supply of vegetables and other food crops that augment food security. However large scale irrigation development must be avoided in the areas where drinking water for Nuku'alofa is abstracted. The use of irrigation traveller systems requires a high pumping rate, about 10 times higher than the recommended value of 3.0 l s^{-1} by White et al. (2011). Although the karst aquifer may have the capacity to deliver the required amount of fresh water at low abstraction rates, high pumping rates much increase the risk of upconing of saline water below the well, which would render the well saline and would cause crop damage if salinization remained undetected. Large-scale irrigation development in the SE part of Tongatapu may in the long run conflict with development of a new well field for drinking water supply for urban expansion expected on and around the peninsula along the southern part of the lagoon;
8. There is no public information on daily evaporation rates on which farmers could base their irrigation water demands. Automatic weather stations could provide such data to be published online for better irrigation management.
9. Pollution of groundwater has to be avoided, particularly by chemicals used in agriculture that maintain their poisonous character over time. This requires strict regulations for land use, fertilizer and pesticide application in the influence zone of drinking water sources;
10. Governance aspects. The DRR-Team has observed that agreement exists on the need of a Water Resources Bill between all stakeholders. Differences exists mainly on licensing, capping of abstractions and ownership. Through further consultation of stakeholders, finalisation of the bill is a necessity to arrive at the strongly needed protection and optimal sustainable use of the scarce resources. This should be combined with a National Water Resources Committee with all stakeholders represented. There is currently no means for the Government of Tonga to evaluate the impacts of different climate scenarios (recharge rates) or varying groundwater abstractions on the freshwater lens dynamics and risks of salinization during droughts. As such it is difficult to make long-term water use and management decisions and decisions on permissible abstraction rates.

The following recommendations for future actions to promote sustainable use of the groundwater resources of Tongatapu were drawn up based on the findings of the scoping mission by the DRR-Team.

1. To assist the agricultural sector in irrigating at quantities to satisfy crop needs, automatic weather stations (AWS) should be installed at the Fua'amotu airport and perhaps near Hihifo in Tongatapu for better estimation of agro-meteorological parameters including daily evapotranspiration and recharge. Meteorological services commonly publish regional daily evapotranspiration values on a dedicated web site, together with crop factors for common crops (MAFFF). AWS are readily available on the market and methods for calculating evapotranspiration have been

published by the FAO, together with crop factors for many crop types (Allen et al., 1998; 2005). This could be implemented over a period of several months.

2. The observation programme currently undertaken by the ADB supported project should be continued to maintain regular monitoring of the salinity of the TWB and village wells (MLSNR);
3. Monitoring of existing and future groundwater abstractions should be continued and expanded and include agricultural abstractions;
    a. To increase public awareness about risks of salinization, to promote involvement in water resources management and to enhance monitoring and data availability, a participative groundwater salinity (EC) measurement programme should be established where stakeholders (TWB, MOH - village water supply, farmers) regularly measure salinity in their own wells and make these measurements publicly available on a web-based platform in the form of maps (MLSNR, MAFFF). This monitoring network would also serve as an early warning system for groundwater salinization during droughts or high abstraction rates, on which water-saving policy actions can be based. Participative measurement networks are new and are based on internet becoming more widely available. Development of such a network is very cost-efficient but the technique is still in development. Implementation would be possible within a year including the development of a dedicated web site for displaying collected data;
    b. A Low Power Wide Area Network (LoRa WAN) based network could be implemented, in combination with continuous telemetric salinity measurements made at key pumping sites (MLSNR, TWB). This is novel technology based on the Internet of Things. Such systems are already commercially available on the market and implementation time would be a few months.
    c. Manual observations in the SMBs (MLSNR) could be paired to continuous telemetric water level and salinity observations by installing widely available pressure and EC sensors. Alternatively, less costly LoRa WAN telemetric water level and salinity recorders could be used in the network of SMBs (at the depth of the fresh-salt water interface). These could be connected to the web-based platform. Implementation would take a few months;
    d. The above monitoring strategy of salinity in wells can serve to regulate abstraction rates of individual wells based on observed changes in EC to avoid further salinization. Participative monitoring also increases awareness of salinization risks in the agricultural sector and provide valuable information on the response of the hydrological system to higher agricultural abstractions (MAFFF);
4. To assess and evaluate the long-term impacts of climate change, changes in recharge rates and varying groundwater abstractions, a three dimensional variable-density groundwater model should be developed to simulate the behaviour of the groundwater lens and the effects of extractions, particularly during extended periods of droughts (MLSNR). The model should be calibrated on water level and salinity data from the monitoring networks. Such model could be developed using existing groundwater models (e.g. the USGS SEAWAT model) that are widely used globally for this purpose. Development and training of local staff could be completed in less than two years;
5. Based on the simulations of the groundwater model, a simplified GIS-based water resource management and decision support tool should be developed for use by the Government in the decision making process for well abstraction licensing

(MLSNR). This requires specialist hydrological expertise and can only be done after the groundwater model has been developed. As such the development time would take about three years, including training of local staff;

6. Through joint discussions and consultations with all stakeholders enact a broadly accepted Water Resources Bill, which also addresses pollution risks, including those from activities in quarries. Establish a National Water Resources Committee with representatives of all stakeholders (all parties);
7. Research the necessity and feasibility of the creation of a fresh water body in the western part of the lagoon, taking both the ecological importance of the lagoon (mangroves, sea grass, fish spawning and breeding area) and the future water needs into consideration. This part of the lagoon already at present gets little seawater refreshment due to silting up. Such measure would create an alternative source of fresh water for irrigation purposes. Regulate access to water from such fresh water storage facilities (MLSNR, MAFFF, MEIDECC). This is really a long-term objective and would take 5-10 years to develop and realise;
8. Provide information to all stakeholders on the consequences and dangers of excessive pumping from the freshwater lens (MLSNR, MAFFF).

Many of these recommendations are related to actions that were proposed in the National Water Management Plan (Faka'osi and Takau, 2012) and are therefore in agreement with the formulated policies of the Government of Tonga. A preliminary ToR for actions to implement some of the recommendations above using international assistance is given in Appendix E.

CONTENTS

List of abbreviations

ADB	Asian Development Bank
AWS	Automatic weather station
DRR-Team	Dutch Risk Reduction Team
EA	Environmental Assessment
EC	Electrical Conductivity, proxy for salinity, expressed in µS cm^{-1}
EIA	Environmental Impact Assessment
ENSO	El Niño Southern Oscillation
EIS	Environmental Impact Statement
EQPB	Environmental Quality Protection Board
GDP	Gross Domestic Product
IA	Implementing Agency
LoRa Wan	Low Power Wide Area Network used in Internet of Things and smart city applications for continuous salinity monitoring
MAFFF	Ministry of Agriculture & Food, Forests and Fisheries
MDTF	Multi-Donor Trust Fund
MEIDECC	Ministry of Meteorology, Energy Information, Disaster Management, Environment, Climate Change and Communications, Kingdom of Tonga
MLSNR	Ministry of Lands, Survey and Natural Resources, Kingdom of Tonga
MOH	Ministry of Health
NWMP	National Water Management Plan
PPP	Public Private Partnership
SIDS	Small Island Developing States
SMB	Salinity monitoring borehole
SPC	South Pacific Community - Suva, Fiji. Formerly abbreviated as SOPAC
TWB	Tonga Water Board
WASH	Water, Sanitation and Hygiene
WB	World Bank
WWTP	Wastewater treatment plant
a.s.l.	Above sea level

1 BACKGROUND

1.1 DRR-Team scoping mission Tonga

Many countries around the world face severe threats, often related to climate change. Often, these countries are in urgent need of expert advice on how to prevent a disaster or how to recover from a calamity. For instance, when a country has been struck by severe flooding and the first emergency relief workers have gone, the need for advice on how to build a sustainable and safer water future arises. Also acute or expected shortage of potable water may justify such advice.

To meet these needs with a swift response, the Dutch government (Ministry of Foreign Affairs and the Ministry of Infrastructure and Environment) has initiated the Dutch Risk Reduction Team (DRR-Team). This team of experts advises governments on how to resolve urgent water issues related to flood risks, droughts, water pollution and water supply, to prevent disasters or to rebuild after water related disasters. The DRR-Team enables a foreign government to take action on the basis of sound, objective and non-binding advice and expertise. The DRR-Team is coordinated by the Netherlands Enterprise Agency (RVO.nl).

Like many other Small Island Developing States (SIDS) the Kingdom of Tonga is also vulnerable to the effects of climate change, causing problems related to sea level rise and changes in the frequency of extreme weather events. Currently, Tonga is experiencing the aftermath of a long drought spell, which started with low rainfall in the wet season of 2015 (starting in November 2014) and continued throughout 2015 and the wet season of 2016. These conditions caused the salinity in several village water supply wells to increase and forced producers of agricultural crops to resort to the use of groundwater for irrigating to avoid drought damage and crop failure. The drought directly affected recharge of groundwater resources, at a time when the demand for groundwater by the population, the tourism industry of the country, and by the agricultural sector increased. This vulnerable situation underlines the need for proper assessment and management of the groundwater resource in order to safeguard uninterrupted supply of good-quality water for domestic use.

In April 2016, the Netherlands Ambassador to The Kingdom of Tonga, H.E. Robert Zaagman and Special Envoy for Pacific SIDS, Mr. Sjef IJzermans, visited Nuku'alofa on the occasion of the celebration of 400 years contact between the two Kingdoms. During the visit the Ambassador and the Special Envoy also met with H.E. Semisi Tauelangi Fakahau, the Minister of Agriculture, Food and Forestry and the acting CEO of his ministry, where the water resources issue was discussed. When reference was made to the existence of the Dutch Risk Reduction Team (DRR-Team) facility in the Netherlands, a request was put forward to look into the issue of the utilisation of groundwater for agriculture and the repercussions this could have on the sources for the provision of drinking water to the population of Tongatapu, in particular for the capital Nuku'alofa. The option of DRR-Team support was also discussed with the CEO of the Ministry of Lands. Subsequent communication between the Government of Tonga and that of The Netherlands ultimately resulted in a request made by the Tongan Government (the development and execution of the current mission in November 2016. In the request for DRR support by the Government of Tonga, both Tongatapu and 'Eua were mentioned to be researched by the DRR team. However given the limited time available for the execution of this mission the DRR-Team, in consultation with MAFFF, decided to focus on the water resources of the Island of Tongatapu. Details on the DRR-Team and the request for assistance by the Tongan Government are provided in Appendix A and B, respectively.

1.1.1 Terms of Reference

The scoping mission has focussed on assessing the availability of water and abstractions for the domestic water supply and for agriculture. The present study is based on a review of the literature, on discussions with representatives of the various Government departments that are charged with water issues, as well as representatives of the agricultural sector. In addition, data were collected and analysed for recharge estimations, to determine storage in the freshwater lens and for estimating irrigation demands.

The TOR specified that the DRR Team would provide technical assistance to Ministry of Agriculture, Food, Forest and Fisheries in relation to:

- The state and condition of the limited groundwater resources on Tongatapu and E'ua islands;
- The assessment on prolonged effects of droughts on the groundwater resources;
- The formulation of recommendations on the sustainable use of water resources by public water supply and agricultural sectors;
- Existing irrigation practices and techniques for subsistence and commercial crop;
- Recommendations on sustainable irrigation practices and techniques for subsistence and commercial crop farming;
- The assessment of potential environmental impact of irrigation systems.

A copy of the TOR is attached in Appendix C, whereas an overview of the mission programme is given in Appendix D.

1.2 Country information on the Kingdom of Tonga

Situated to the east of the Fiji Islands in the South Pacific Ocean, the Kingdom of Tonga consists of some 150 islands, of which 36 are inhabited. Most of the islands are of volcanic origin, whereas others are coral atolls (Schofield, 1967). Maps showing the islands of the Kingdom of Tonga, including Tongatapu (inset) and their location in the South Pacific are given in Figure 1.

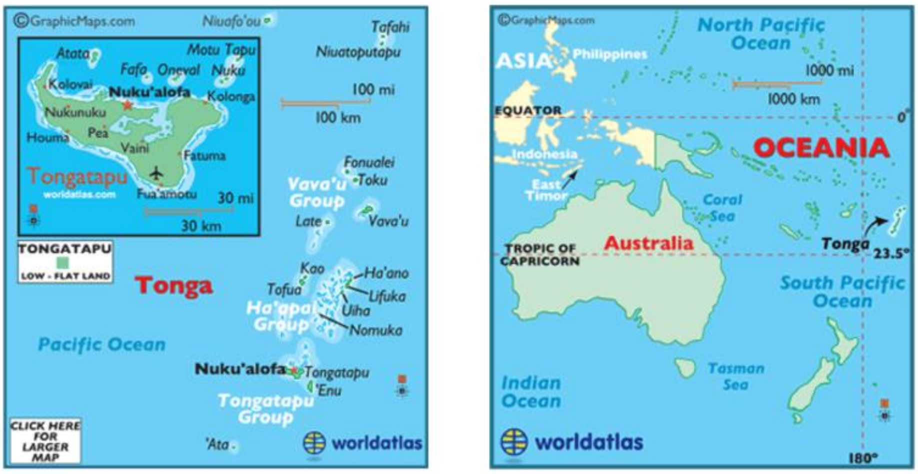

Figure 1. Location of the Kingdom of Tonga and the main Island of Tongatapu in the Pacific (source: http://www.worldatlas.com).

1.3 Groundwater resources management aspects

The water resources of Tonga consist predominantly of groundwater, with additional supplies from rain water harvesting for domestic use. Various actors are responsible for the management of the water resources in Tonga and an overview of the actors is given in Figure 2 (van der Velde, 2006). The Water Section of the Department of Geology of the Ministry of Lands, Survey and Natural Resources (MLSNR) is the lead actor in the coordination between the various actors and for ensuring sustainable water management. For the supply of water for domestic uses, the Tonga Water Board is responsible for the supply to Nuku'alofa, whereas the village water supply is provided by village water committees falling under the responsibility of the Ministry of Health.

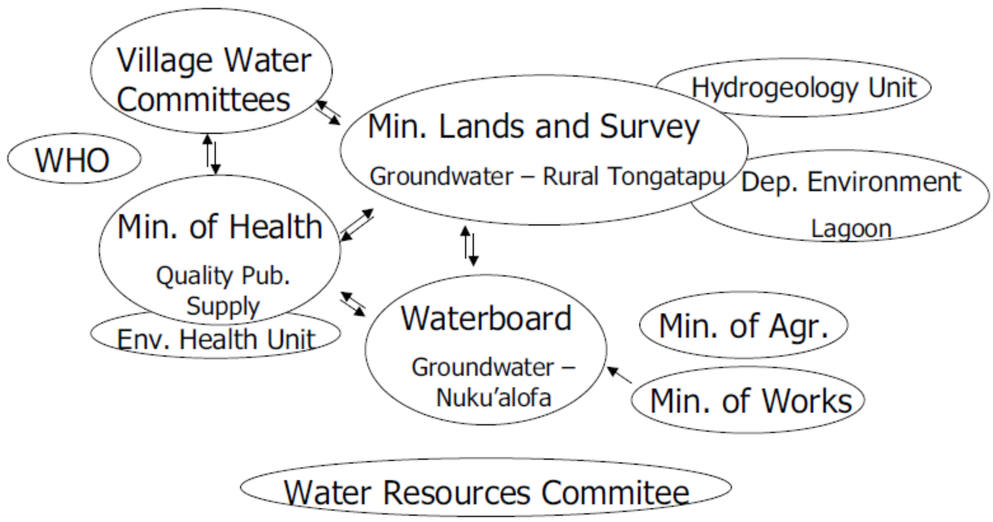

Figure 2. Government bodies responsible for various aspects of water resource management in Tonga (source: van der Velde, 2006; Pers. Comm. Mr. Kula).

A Water Resources Bill was already drafted in 2006 but was never implemented (White et al., 2009). As such, the MLSNR has - as of yet - no legal means to protect groundwater resources from activities that would deplete the resource or would cause pollution. The Ministry of Health (MOH), however, can restrict farmers from using chemicals on their fields if complaints are made about threats to the village water supplies (pers. Comm. Mr. T. Nakao). MLNSR drafted a new Water Resources Bill in 2016. The Water Resources Bill was submitted to the Legislative Assembly in October 2016 and would in essence:

- Regulate ownership of groundwater (vested in the Crown);
- Provide MLNRS with powers over the water resources, establish a National Water Committee that would coordinate and manage water resources, and would implement a Tonga Water Management Plan.
- Require well owners to register and license existing and new wells, and would cap abstractions to prevent over use.
- Provide MLSNR with powers to address groundwater pollution.

The bill was submitted but was subsequently withdrawn in response to opposition by farmer organisations. The arguments were against the licensing and fees for existing wells, the capping of abstractions and the perceived lack of understanding of the dynamics of the fresh water lens and available groundwater due to limited monitoring that would make it difficult to establish caps on abstractions (pers. Comm. Mr. Nakao, Mr. Nishi, Mr. Pousima). Furthermore, the farmers felt that they had not been properly consulted about the 2016 Water Resources Bill before it had been submitted to Parliament. The Water Resources Bill is now on hold until there will be agreement on its submission between the Government and other stakeholders. Agreement may depend on a better scientific understanding of the hydrological system to rationalise licensing and local capping of pumping rates.

Many groundwater resources studies have already been carried out in Tongatapu and the vulnerabilities of the groundwater resources of Tongatapu (*cf.* Hunt, 1979, Falkland, 1991; Helu and Furness, 1993; Furness and Gingerich, 1993; van der Velde, 2006; White et al., 2009; White et al., 2011). In a comprehensive report White et al. (2009) reviewed the hydrological knowledge about Tongatapu, analysed the vulnerabilities of the groundwater resources and provided clear recommendations on how to improve groundwater management. They also noted the institutional issues affecting water resource management by the Government. Many of their technical recommendations are being implemented, but the regulation required for sustainable management of the water resources and to reduce drought vulnerabilities has not yet been implemented and depends on reaching of consensus between the different stakeholders. Guidelines were also given on inter-well distances and maximum abstractions. White et al. (2011) estimated the sustainable pumping rate for Tongatapu at between 54 and 72 Ml d^{-1} and current abstractions for public water use are estimated at 9 Ml d^{-1} by the Tonga Water board and 6 Ml d^{-1} for the village water supplies (pers. Comm. Mr. Q. Fielea, TWB). This amounts to about 21 – 28% of the average sustainable abstraction rate for the island of Tongatapu (White et al., 2011). However, the sustainable abstraction rate depends on recharge and is therefore much lower during droughts, and in the coastal zone where the fresh water lens is shallow.

The focus of the above studies has been mainly on groundwater abstractions for public water supply, whereas studies on the use of water by agriculture have been limited (van der Velde, 2006; squash water use) and do not exist for irrigation practices and water use in Tongatapu. When the soil is sufficiently moist in normal years, evapotranspiration by the vegetation can be considered close to potential and somewhat below the Penman open water evaporation of 1460 mm y^{-1} (Furness and Helu, 1993). Evapotranspiration would become supressed in dry years and irrigation from groundwater sources would then be needed to supplement moisture for sustained plant transpiration and growth. During the scoping mission information was obtained on the current and future developments with respect to irrigation.

A national water management plan (NWMP 2012-2016), detailing threats to the water resources of Tonga, governance and institutional aspects, constraints in public awareness, as well as management actions has been compiled by Faka'osi and Takau (2012). The plan lists indicators and actions for improving governance, research and assessment, technology and infrastructure, raising public awareness, training and capacity building needs and opportunities to foster better water management.

2 PHYSIOGRAPHY OF TONGATAPU

The satellite image in Figure 3 shows the geography, land cover and urban areas of the island of Tongatapu, where about 70,000 of Tonga's 110,000 inhabitants live. Approximately 30% of the people of Tongatapu live in the capital Nuku'alofa. The island of Tongatapu is at 22° S latitude and 175° W longitude, and is therefore in the transition zone from the tropics to the subtropics.

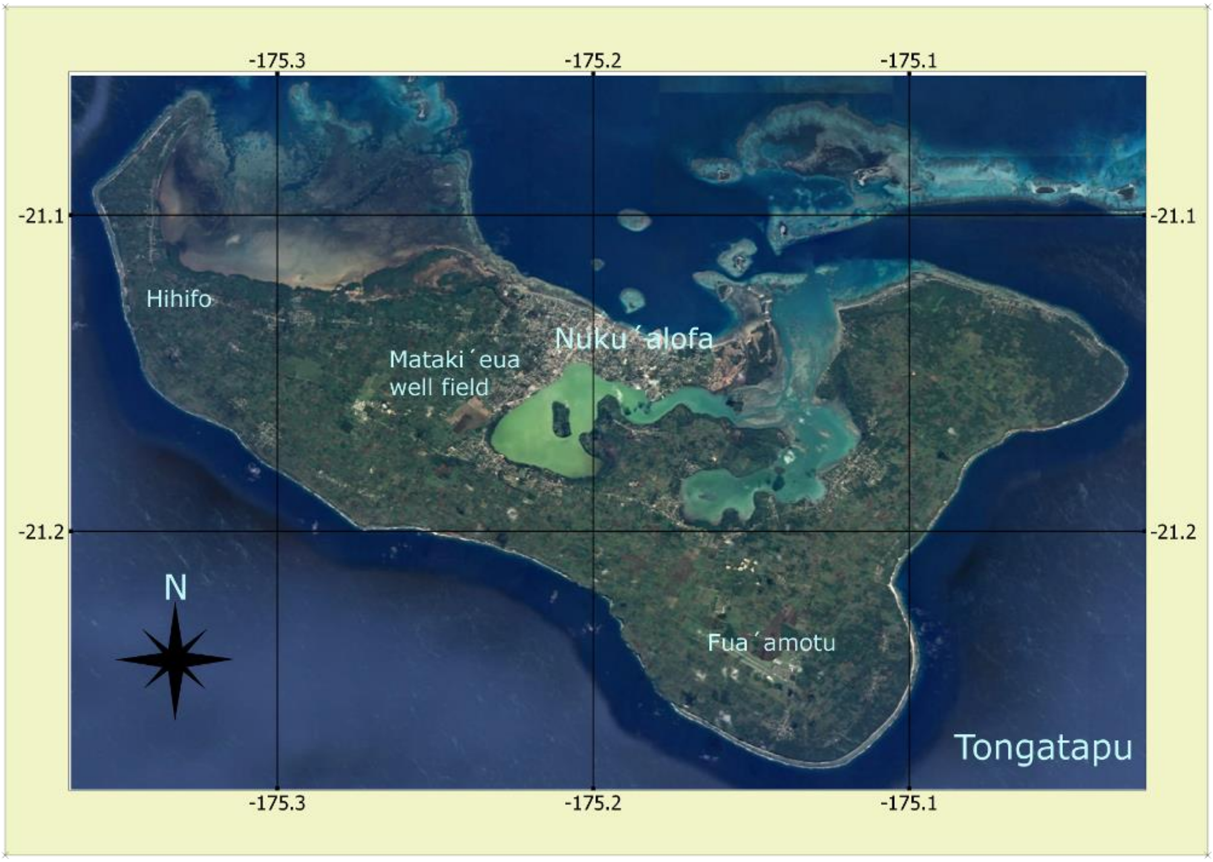

Figure 3. Satellite image of Tongatapu showing the locations of the capital Nuku'alofa, the public water supply Mataki'eua well field and other key areas (source: Google Earth).

2.1 Geological and hydrological characterisation of Tongatapu

Tongatapu is a low island consisting of a coral reef platform (Manu, 2000; Iliffe and Juberthie, 2001) made up of sedimentary limestone formations with a thickness of 130-250 m that were deposited on a substrate of volcanic origin in the Pliocene and Pleistocene epochs (Roy, 1990). These limestone deposits were uplifted and tilted and now reach a maximum height on Tongatapu of about 65 m a.s.l. in the south-eastern part of the island.

During the scoping mission visits to two different quarries were made to assess the limestone aquifer characteristics visually. Distinct layering was observed in both quarries, and exposed layers showed many of the original depositional features such as reef rim and debris deposits, patch reefs with fossilised corals and poorly consolidated sandy lagunal or beach deposits consisting of small shell and coral fragments (Figure 4). The beach sand layers were less consolidated and showed relatively few cracks or small size (1-4 cm diameter) karst dissolution macro-pores.

Figure 4. Picture of the exposed limestone aquifer in a quarry 1.4 km south of the Mataki'eua well field used for public water supply. At the base is a poorly consolidated beach or lagunal sedimentary layer, which is overlain by more consolidated reef deposits with karst dissolution macro-pore features (photo M.J. Waterloo).

The observed layering and differences in material and karstification suggests that the aquifer is heterogeneous and anisotropic, with presumably higher conductivities due to high secondary porosity in the more massive and karstified layers, and lower hydraulic conductivities in the less consolidated sandy layers where matrix flow through the primary porosity seems dominant. Spatial variation in the permeability may therefore be considered high. Due to the many micro- and macro-pores in the material the hydraulic conductivity can be considered invariably high. A pumping test carried out by Waterhouse (1976) yielded a hydraulic conductivity of about 1,300 m d^{-1} (Hunt, 1979) Falkland (1992) estimated the conductivity at 500 to 3,000 m d^{-1} and recommended using conductivities for groundwater modelling in the range of 1,500 to 2,000 m d^{-1}. A high value of 3,600 m d^{-1} was measured by White et al. (2009). In a more recent pumping test carried out in the Mataki'eua well field a relatively low value of around 100 m d^{-1} was observed (pers. Comm. Mr. L. Tufui, MLSNR), which illustrates the large variation in the aquifer hydraulic conductivities.

The high hydraulic conductivity leads to a very flat phreatic water table with a maximum hydraulic head of about 0.5 m a.s.l. as observed in 39 wells by Hunt (1979) on Tongatapu, which was confirmed by later studies. Furness and Gingerich (1993) reported a high specific yield and a porosity for the aquifer of up to 40%. For illustration purposes a N-S elevation profile was made through the well field and a schematic diagram of the fresh water lens is shown in Figure 5. The actual thickness of the lens is most influenced by sea water level changes, temporal variation in rainfall and recharge and local groundwater abstractions.

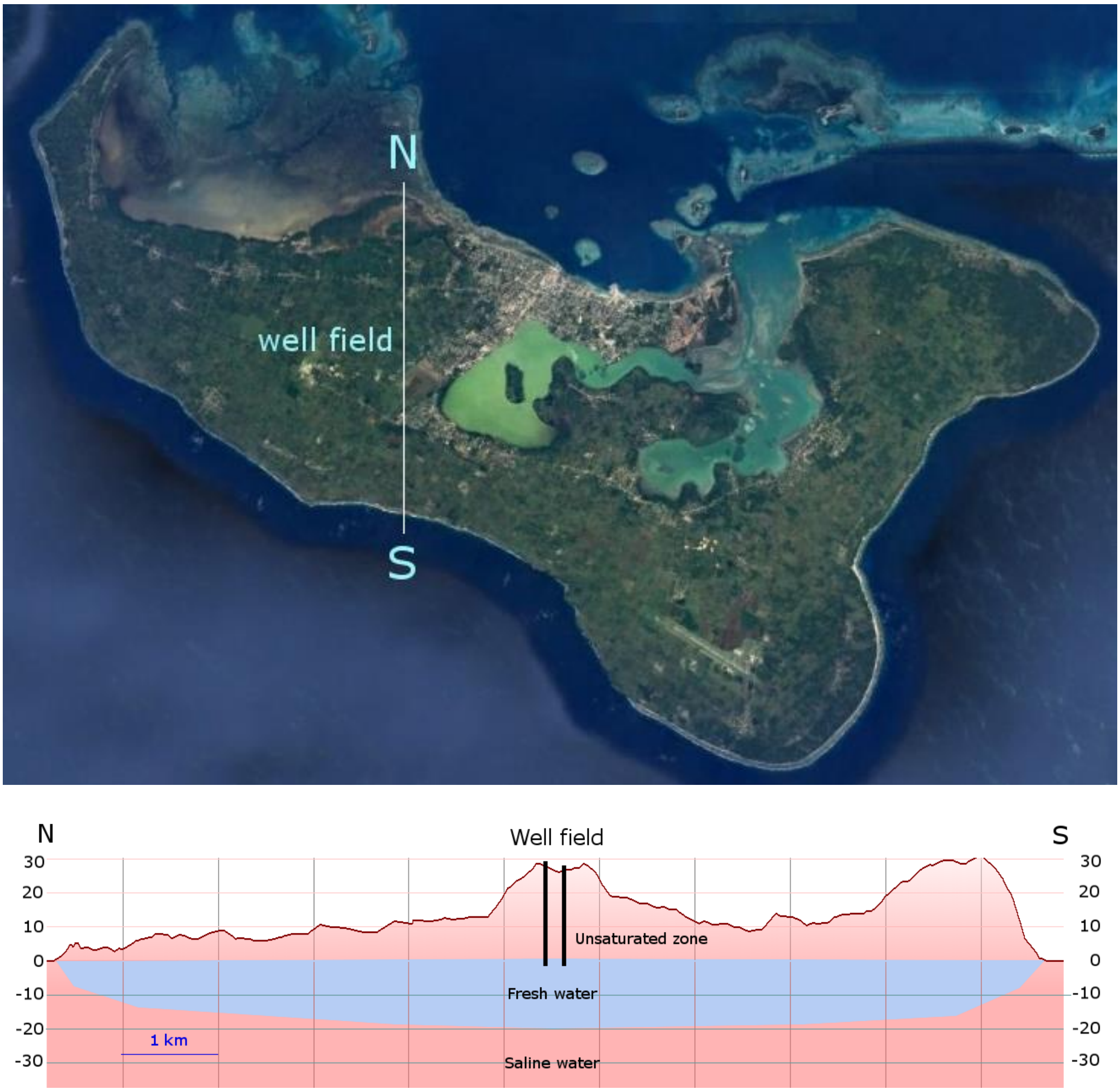

Figure 5. Location of a North-South elevation profile through the Mataki'eua public water supply well field area (above; source: Google Earth) and a schematic diagram of the thin freshwater lens floating on saline water along the profile (below). Depths are indicated in m a.s.l. Note the difference in vertical and horizontal scale.

2.2 **Soils**

The limestone formations are covered by a thin soil mantle derived from fine-grained andesitic tephra deposits deposited during eruptions at the western volcanic islands (Cowie et al., 1991; Manu, 2000). The soil consists of a clayey layer derived from weathering of ashes deposited about 20,000 years go, and a younger more course-textured layer deposited about 5,000 years ago. The thickness of the soil mantle generally decreases from above 2 m in the West closer to the volcanic source areas to less than 1 m in the East of the island (Manu, 2000). The ash soils of Tonga were classified as Typic Argiudoll and Hapludoll soils (Manu, 2000; van der Velde, 2005).

Figure 6. Soil mantle of variable thickness developed in volcanic ash deposits on the weathered and eroded limestone substrate as exposed in the quarry near the Mataki'eua well field used for the public water supply of Nuku'alofa (photo M.J. Waterloo).

Soil thickness may vary locally due to deposition of the tephra on the micro-relief of the eroded limestone surface and subsequent erosion (Figure 6).

2.3 Vegetation and land use

The vegetation on Tongatapu is a result of centuries of agricultural land use, which only left small pockets (3%) of remnants of natural forest in the coastal zone (Manu, 2000; van der Velde, 2006). Many indigenous trees have been exported (e.g. sandalwood - *Ahi*) or used for dye preparation or firewood (e.g. Red Cedar – *Koka,* Mangrove) and have not been replanted (James, 1993). Tongatapu covers an area of about 268 km^2, of which about 11% is covered by village settlements, 56% is under mixed land cover of coconut palms, guinea grass (*Panicum maximum* Jacquin), secondary forest or shrub, about 23% under grass and the remainder under natural forest and regenerating shrubland (Wiser et al., 1999). At present, most agriculture is still based on traditional farming systems in the form of subsistence farming (pers. Comm. Mr. Pousima Afeaki; Dr. Manu). Agricultural land use is therefore dominated by mixed cropping and fallow land, whereas in the coastal zone remnants of mangrove forests are still present (Manu, 2000) and actively protected by the Ministry of Environment & Climate Change (MEIDECC). Most land belongs to the crown and men are entitled to lease an allotment of 3.34 ha. By law coconut palm (*Cocos nucifera L.*) plantations should be established and maintained on the allotments, but this has not been enforced in the recent past (pers. Comm. Dr. Manu). There is little control on agricultural practices, including its water, fertilizer and pesticide use, even though it is practised by about 70% of the community, provides the main export products and covers a large fraction of the land area in the Kingdom (James, 1993).

Figure 7. Intercropping of taro, sweet potato, pineapple and banana in the south-eastern part of Tongatapu (photo: M.J. Waterloo).

Figure 8. Intercropping of cassava and coconut palm trees on Tongatapu (photo M.J. Waterloo).

Traditional cash crops include root crops as taro, yams, cassava and sweet potatoes, but also kava (*Piper methysticum*), breadfruit, papaya, banana, watermelon and pineapple used in an intercropping system (Figure 7 and Figure 8). In more recent years the focus has shifted to export crops including pumpkin squash and vanilla. The former needs irrigation in dry months. The main practice is still subsistence agriculture, but there are several farmers looking to expand agriculture to a more commercial basis (pers. comm. Mr. T. Nakao), which involves implementation of larger centralised irrigation schemes and higher groundwater abstractions during periods of drought.

2.4 Climate

The climate of Tongatapu is humid maritime subtropical with distinct seasonal temperature variations. The temperatures are highest in February and reach their minima in July and August (Figure 9). The relative humidity varies between 65% and 95% on a daily basis (Furness and Helu, 1993) but remains rather constant on a monthly basis at 70-80%.

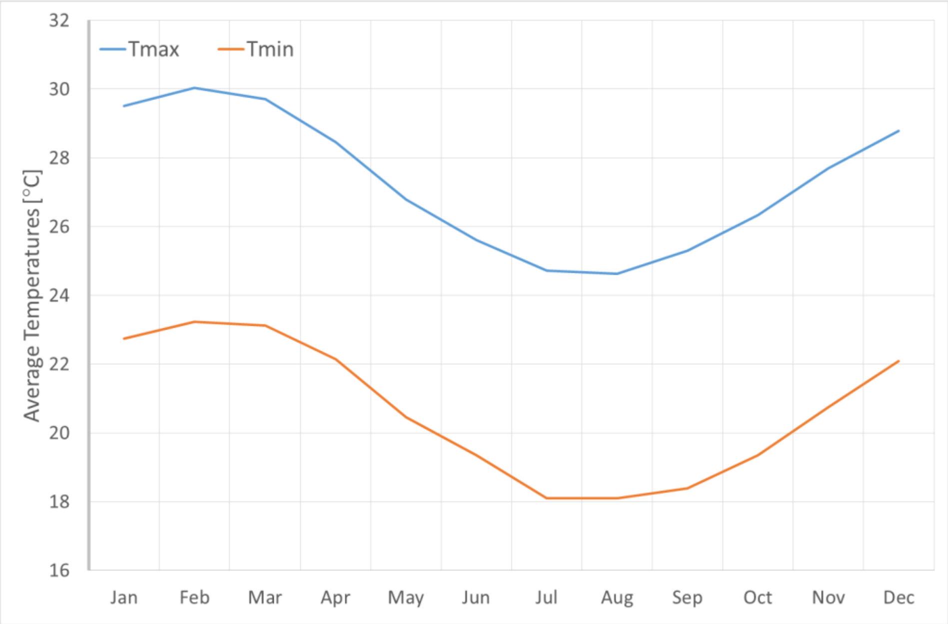

Figure 9. Average monthly minimum and maximum temperatures for Fua'amotu station in the period 1980-2016 (data source: Tonga Meteorlogical Service).

Annual precipitation totals for Fua'amotu station in the southwestern part of Tongatapu and of Nuku'alofa station in the North of Tongatapu (Figure 3) are shown in Figure 10. The data suggest a significantly lower precipitation in Nuku'alofa as compared to that at Fua'amotu Airport station, which have average annual values over the period 1989-2015 of 1760±416 mm and 1928±441 mm, respectively. Over the period of 35 years (1980-2015) the Fua'amotu data showed a significant increase ($p< 0.01$) in annual rainfall. There was no significant change in the annual maximum consecutive dry days over this period. Average monthly precipitation values are highest in January and February at about 224 mm, and reach a minimum of 104 mm in October (Figure 11). On average, monthly precipitation falls below average monthly Penman open water evaporation only in October and November (Figure 11). Low monthly rainfall was recorded over an extended 18-month drought period between July 2014 and February 2016, during which monthly rainfall only exceeded Penman open water evaporation in four months (Figure 12).

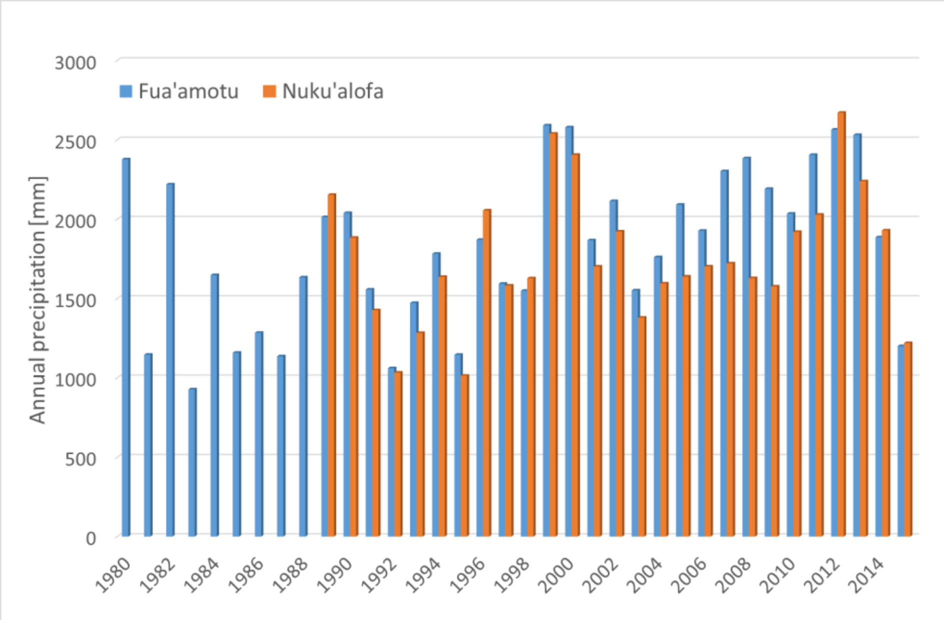

Figure 10. Annual precipitation totals of the Fua'amotu and Nuku'alofa meteorological stations on Tongatapu (data source: Tonga Meteorological Service).

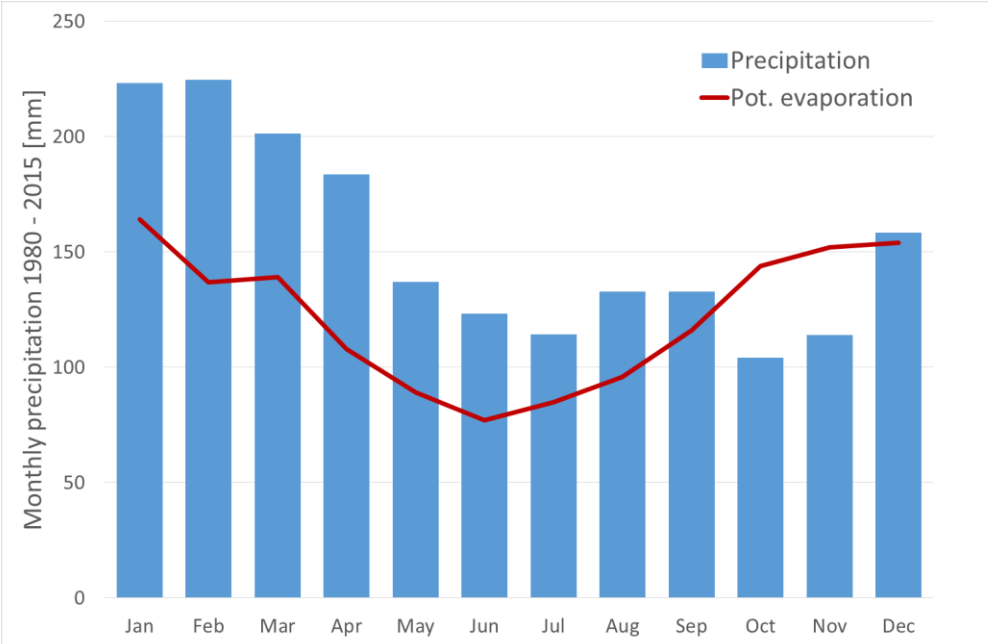

Figure 11. Average monthly precipitation totals for Fua'amotu station for the period 1980-2015 (data source: Tonga Meteorological Service) and corresponding Penman open water evaporation values for Nuku'alofa (Furness and Helu, 1993).

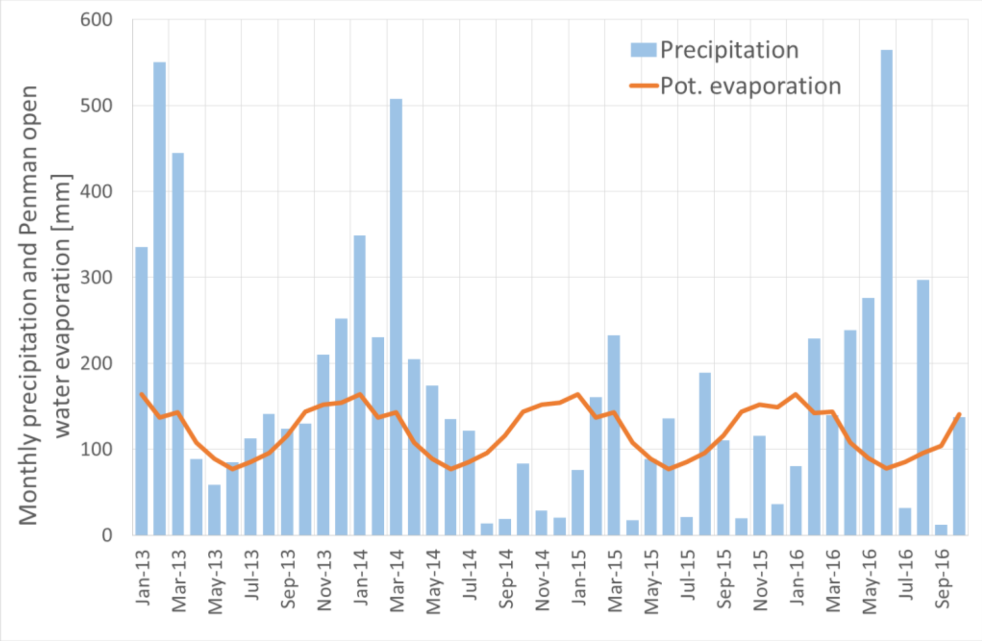

Figure 12. Monthly precipitation totals for Fua'amotu station for the period January 2013 - October 2016 (data source: Tonga Meteorological Service) and corresponding Penman open water evaporation totals for Nuku'alofa (Furness and Helu, 1993).

2.5 Climate Change prospects for Tonga

Changes in rainfall totals due to climate change have a major impact on water resource management as these largely determine the recharge and thickness of the fresh water lens in the aquifers of Tongatapu. In addition, sea level rise also determines the upward pressure on the lens and causes intrusion of saline water along the coast decreasing the extent of the freshwater lens. Based upon discussions with the Director of Meteorology the following observations could be made (Pers. Comm. Mr. Fua'anunu), which pertain to developments in the next decades.

1) Annual rainfall total is likely to remain similar to the present value;
2) Wet season winter rainfall is likely to increase, whereas dry season summer rainfall is likely to decrease;
3) The intensity and frequency of extreme rainfall events is likely to increase;
4) The drought frequency is not likely to change;
5) El Niño and La Niña ENSO events will occur, but it is uncertain if there will be changes in their frequency or their intensity;
6) Due to a rising temperature evapotranspiration may be somewhat increased;
7) Sea level rise continues and has been double the global rate in Tonga over the past two decades.

2.6 Water Resources information

In the absence of surface runoff, the water balance for the island of Tongatapu can be written as:

$$P - ET - Q_{gw} \pm \Delta S = 0$$

Where *P* is precipitation, *ET* actual evapotranspiration, Q_{gw} outflow of groundwater (*e.g.* coastal spring discharge and water supply abstractions) and ΔS the change in soil moisture and groundwater storage (freshwater lens thickness), all expressed in mm over a time period. Over longer periods of time (years) and with limited change in annual rainfall, the change in storage *ΔS* can be considered negligible. The evaluation of Q_{gw} then depends on the balance of *P* and *ET*, which should be equal to the recharge if groundwater is used in a sustainable way.

A very rough estimate of *ET* can be obtained from a combination of the measured potential Penman open water evaporation in combination with a crop factor representing the evapotranspiration by the plant cover. Based on meteorological observations, Furness and Helu (1993), Zann et al. (1982) and Furness (2004) estimated annual Penman open water evaporation at about 1460 mm, a daily variation of the lagoon at between 4.9 and 6.2 mm day^{-1} and a monthly variation ranging from 77 mm (June) to 164 mm in January (Figure 11). A large part of Tongatapu is still under coconut plantations, often used in intercropping system with cash crops. Using a lysimeter study in Kerala, India, Jayakumar et al. (1988) obtained a crop factor for the coconut palm of 0.54, whereas root crops have crop factors of around 0.7-0.9. Applying a crop factor of 0.75 would then result in an actual ET of 1100 mm y^{-1}.

The population of Tongatapu depends on two main sources of water, *i.e.* fresh groundwater for part of the domestic use and for agricultural use, and rainwater harvesting for cooking and drinking water supply. In the villages, precipitation is nearly universally harvested from the roofs of the houses and stored in tanks with capacities generally between 2 and 10 m^3. Rainwater harvesting may be somewhat less common in the city of Nuku'alofa but many tanks were observed in the city as well. The volume of precipitation stored in these tanks after the wet season is usually enough for cooking and drinking water supply for a dry period of three months. If this source runs out, people switch to the use of groundwater.

The amount of groundwater available at any time depends on a number of factors, including local storage in the freshwater lens, recharge and abstractions in the preceding period, geological and soil conditions, and permeability and the location and distance to the coast determining fresh water losses into the ocean. These together determine the dynamics of the freshwater lens. The average recharge on Tongatapu has been estimated to amount between 5% and 35% (van der Velde, 2007) and is generally assumed to be 20-30% of the annual precipitation total or about 530 mm y^{-1} (Hunt, 1979; Furness and Helu, 1993; White et al., 2011). The remainder is lost through rainfall interception and evapotranspiration. The fresh water lens is in dynamic equilibrium with recharge and outflow/abstractions. A change in recharge or in abstractions therefore directly impacts the thickness of the lens.

Due to the high infiltration capacity of the soil and the flat topography, little surface runoff occurs and there are no rivers on the island. However, surface runoff and flooding does occur during high-rainfall events in the coastal poorly-drained parts of the island, or where water accumulates behind infrastructure such as poorly designed roads in Nuku'alofa (pers. Comm. Mr. Kula). Ponding in these rare occasions only lasts for few hours to days in low places. This leads to clay deposition on the surface and further lowering of the infiltration capacity. These surface water events are of short duration and the runoff contains too much sediment or pollutants to be used in artificial infiltration schemes.

In dry seasons the groundwater is also exploited for irrigating crops. Traditionally food crops such as taro, cassava and vegetables were grown in a rain fed agricultural system. With increased demand and the development of export production of cash crops and the increased demand for vegetables, irrigation is becoming more important and the demand for irrigation water is therefore likely to increase in the near future. This means that there will be increasing competing demands for groundwater for domestic use and that for agricultural use.

2.7 **Water supply and sanitation in Tonga**

Water is extracted from the Mataki'eua – Tongamai well field located some 5 km SW of the capital. Initially 36 wells were dug and recently another 18 wells were added. A total of 9 Ml d^{-1} are currently pumped from the well field (pers. Comm. Mr. K. Fielea, TWB). Leakage in the mains of the distribution system has recently been reduced by replacing old pipes in the water reticulation network. On the basis of these numbers, the daily supply per capita is estimated at 225 l. This is high in comparison to the estimated real per capita consumption (about 150 l d^{-1}), suggesting losses of over 30% in the reticulation network. Fresh water lost in the distribution network mostly enters the groundwater reservoir, but this is in a contaminated coastal urban area with saline groundwater and cannot be retrieved.

There is no sewer system in Tonga that would allow collection of municipal waste-water. Waste-water is disposed in non-sealed septic tanks. Leakage from these tanks pollutes groundwater (nutrients, *E. coli*) and has led to environmental degradation in the lagoon and in the coastal zone along Nuku'alofa. There is also little industry producing sufficient quantities of waste-water for re-use. At present, waste-water therefore does not form a significant source of water for re-use. The main water supply and sanitation challenges to this part of Tongatapu may be summarized as:

- How to reduce the amount of non-revenue water in Nuku'alofa from leakage in the water reticulation network;
- How to assess available groundwater quantities in more detail to ensure water availability during droughts;
- How to improve water quality control and monitoring of changes in salinity of abstracted groundwater for better management of water resources;
- How to improve sanitation conditions in Nuku'alofa and villages to ensure environmental sustainability and public health.

2.8 **Groundwater abstraction and upconing of saline water**

Groundwater is pumped up from the fresh water lens that floats on top of the higher density saline water. When water is pumped from a well, a radial pattern of flow towards the well screen is generated in the aquifer with flow velocities depending on the rate of pumping. The lower pressure caused by pumping in the well also draws water up from the area below the well, and upconing of saline water may then occur causing salinization of the well. The risk of upconing is related to the thickness of the fresh water lens, aquifer properties (permeability, layering) and the rate of abstraction.

The Tonga Water Board has been very successful in avoiding salt water upconing even during droughts by using a large number of boreholes from which water is extracted continuously at low rates (3-5 l s^{-1}) from the top of the phreatic aquifer to be stored in several reservoirs for distribution. To avoid salinization of wells, White et al. (2009) recommended a maximum pumping rate of 3 l s^{-1} for licensing, water metering on licensed pumps and a maximum of 210 licensed continuously pumping stations with a minimum inter-distance of 0.8 km.

Until recently, agricultural water abstraction for irrigation occurred at similarly low rates, which limited the risk of saline water upconing below the wells. The use of irrigation systems that can be deployed to irrigate larger areas over short periods of time required higher abstraction rates from single wells, which significantly increases the risk of saline water upconing below the wells and could cause damage to crops.

3 OBSERVATIONS AND FINDINGS

3.1 Estimation of evapotranspiration from measurements

The Tonga Meteorological Service operates a meteorological station at the airport, where daily minimum and maximum temperatures (station thermometers in Stevenson screen), daily sunshine duration (Campbell-Stokes sunshine recorder), daily precipitation totals (standard rain gauge) and class-A pan evaporation observations, as well as three-hourly wind speed and direction (anemometer and wind vane) and cloud cover observations are recorded. The sunshine hours data series shows gaps because the paper strip charts were not always available.

Allen et al. (1998; 2005) recommend that measurements for use in the FAO/ASCE Standardized Reference Evapotranspiration Equation include solar radiation, temperature, relative humidity and wind speed (hourly averages) be made for estimating actual crop evapotranspiration using crop and water stress factors. This equation, in combination with crop factors and stress factors is the standard for calculating reference and actual crop evapotranspiration in agro-meteorology. At present, solar radiation should be inferred using the Angstrom-Prescott formula, which relates solar radiation to extra-terrestrial radiation and relative sunshine duration (Allen et al., 1998). However, in the absence of solar radiation measurements, the regression constants in the Angstrom-Prescott equation for use in Tonga have not been determined.

To provide more reliable estimates of the reference evapotranspiration with the FAO equation that could guide farmers in their irrigation water use, (sub-)hourly average measurements of solar radiation (incoming shortwave), temperature, relative humidity and wind speed should become available. This would require the installation of one or more automatic weather stations at the airport or elsewhere in Tongatapu for making agro-meteorological measurements. These measurements can be used to calculate daily evaporation totals, which could be placed on a public, web-based agricultural platform.

3.2 Estimation of recharge

Long-term recharge has been estimated, based on water balance calculations, at about 20-30% of precipitation (Hunt, 1979; Van der Velde, 2005; White et al., 2009, 2011). Drainage under gravity into the macro-pores of the limestone formations underlying the soil depends on the soil being at or below field capacity (*i.e.* freely draining under gravity with soil moisture tension values below -100 — -300 hPa or at pF = 2.0—2.5). During drought, when the soil dries out and tension falls below -300 hPa, recharge to the underlying limestone may be strongly reduced or even stopped for extended periods of time until the moisture in the soil profile is replenished by sufficient percolation of precipitation.

To evaluate the temporal variation of recharge the Hydrus-1D model (Šimůnek et al., 2008) was used to model drainage through a soil profile on Tongatapu. The thickness of the soil profile was taken as 3.0 m based on the SMB-13 (Tongamai) borehole log soil profile description (Hyland, 2012). The Van Genuchten parameters for five soil layers were based on those measured by Pochet et al. (2007) for a Tongatapu forest soil, whereas the limestone bottom layer was represented by a sandy gravel layer (Khaleel and Freeman, 1995). Rooting depth was taken as 1.5 m, representing the rooting depth of coconut palm trees (Lehmann, 2003) in the intercropping systems. Crop rooting depth is normally less at 0.6-0.8 m. The root distribution was taken as uniform down to 1 m in the profile and then gradually lowered to zero at 1.5 m below the soil surface. The bottom boundary was freely draining and the surface boundary was taken as atmospheric with a surface layer. The atmospheric input consisted of daily rainfall totals measured at Fua'amotu Airport for the period 1980—2015, and values of the Penman open water evaporation (Furness and Helu, 1993). Rainfall interception losses were not taken into account, which may have led to a slight overestimation of recharge.

The average simulated recharge for the 1980-2016 period from Hydrus-1D amounted to 620±380 mm y^{-1}, whereas simulated evapotranspiration was 1225±175 mm y^{-1}. Using the WATBAL model, White et al. (2009) obtained average annual recharge rates of 390-568 mm for the period 1945-2006. The recharge value of the present study is slightly higher than that of White et al. (2009) and Falkland (1992), who arrived an average of 528 mm over a 44-year period. This may be due to the observed higher precipitation totals in the 35-year period between 1980-2015.

The simulations showed that recharge varied considerably during years in response to variations in precipitation. Annual recharge and ET reached minimum values of 79 mm and 790 mm, respectively, during the strongest El Niño event in 1983 and amounted to 171 mm and 997 mm, respectively, in the 2015 El Niño year. In 2015 recharge and evaporation were therefore reduced by 450 mm and 228 mm, respectively, in comparison to the long-term average. It should be noted that the 2015 drought was much less severe than that during the 1983 El Niño. Both evapotranspiration and recharge were reduced during dry years, as shown in Figure 13, but recharge did never cease completely in our Hydrus 1-D simulations. Falkland (1992) estimated recharge to cease when annual rainfall would fall below 800 mm (1982-1983).

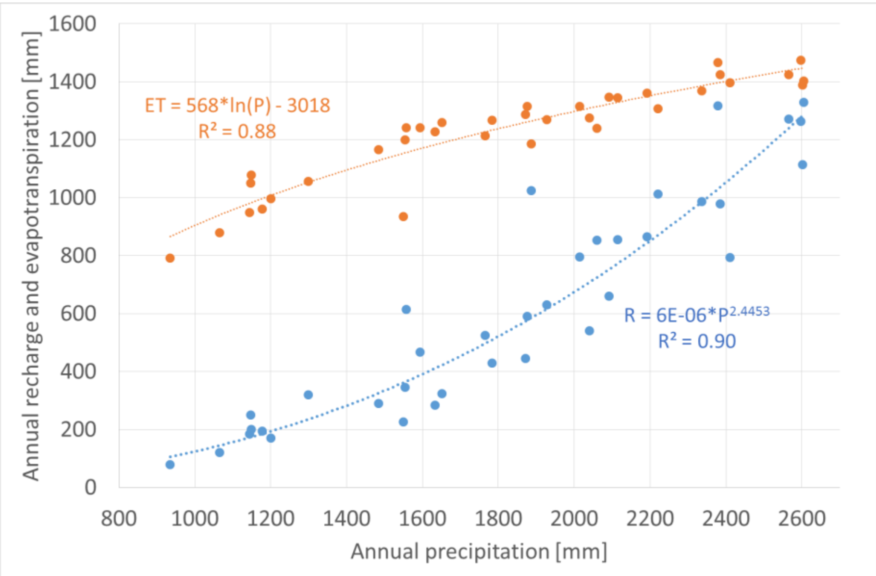

Figure 13. Annual recharge (R) and evapotranspiration totals (ET) versus precipitation and corresponding regression lines.

The simulated annual recharge through the bottom of the profile, expressed as a percentage of precipitation, is shown in Figure 14. Annual recharge was highest at 1,329 mm in the wet year of 2000 (P= 2,605 mm). Daily recharge amounts varied between 0.1 mm d^{-1} during the 1983 El Niño drought to 79 mm d^{-1} after a large storm event of over 400 mm in three days in June 2016 that caused widespread flooding in Nuku'alofa. The daily recharge over the period 2013-2016 is shown in Figure 15, which clearly shows that most recharge occurs during the wet seasons and that little recharge occurred throughout the El Niño period of 2015. Expressed as a percentage of rainfall, recharge was high in 2014 (Figure 14), which may have increased storage in the fresh water lens somewhat, creating a buffer before the drought of 2015.

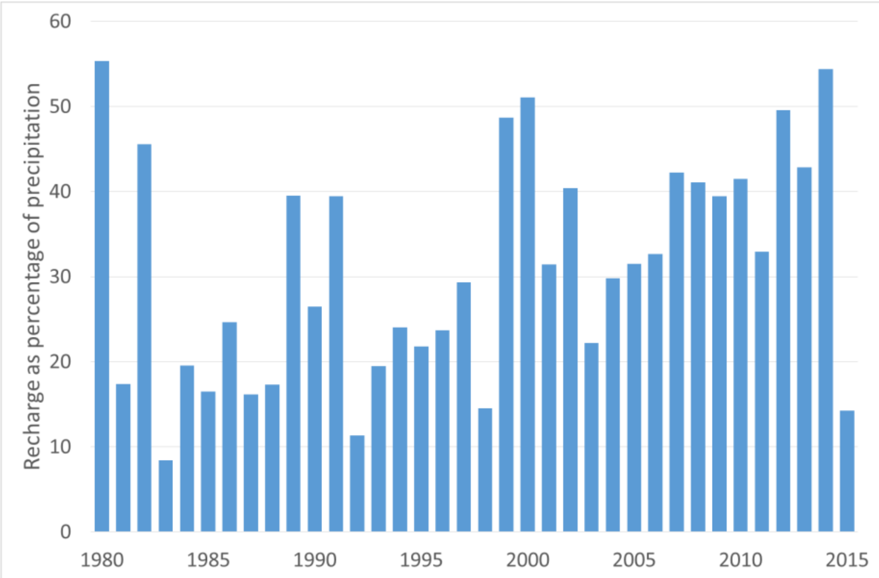

Figure 14. Annual recharge (drainage from soil profile) expressed as a percentage of annual precipitation as simulated with Hydrus-1D for the period 1980-2015.

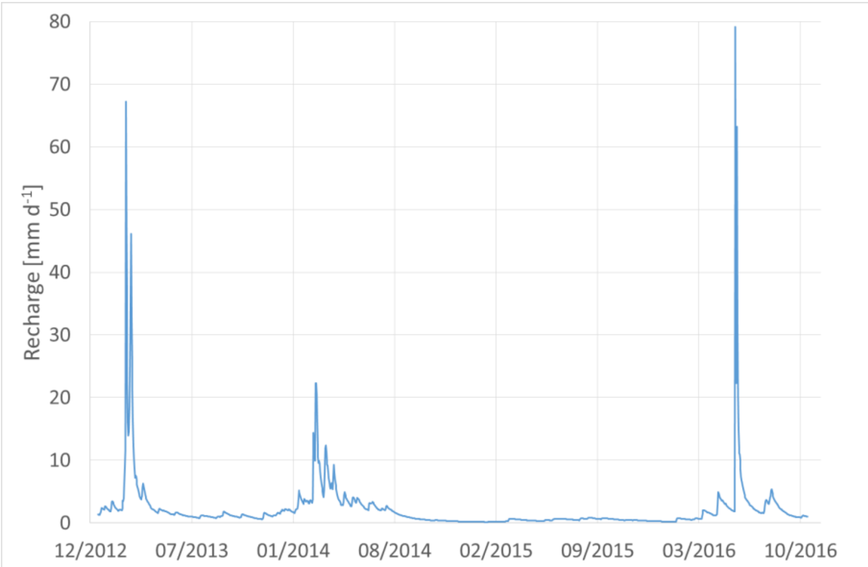

Figure 15. Simulated daily recharge amounts over the period January 2013 - October 2016.

It should be noted that part of the recharge cannot be used for water abstractions as it is discharged into the ocean and the lagoon through springs and diffuse seepage zones along the coast of Tongatapu, and that only part of the storage in the freshwater lens is available during periods with minor recharge. A comparison between the long-term average monthly recharge totals and those in the 1983 and 2015 El Niño years is shown in Figure 16. It is clear that during these dry years, groundwater is being abstracted from storage in the freshwater lens, rather than from recharge, which will decrease the volume of the freshwater lens.

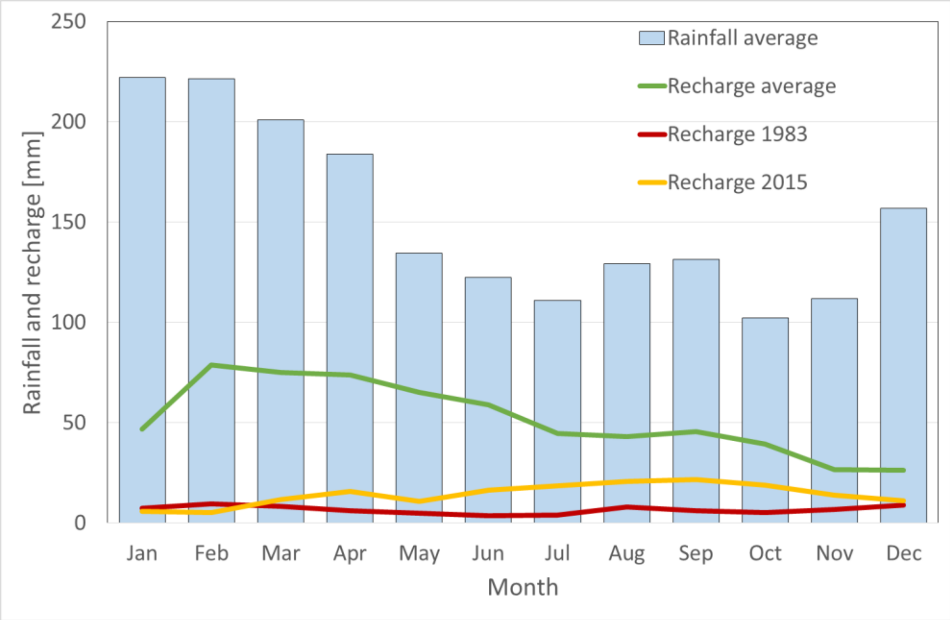

Figure 16. Average long term monthly rainfall and recharge, and recharge monthly recharge totals in 1983 and 2015 based on Hydrus 1-D model simulations.

3.3 Estimation of groundwater abstraction potential

In years with precipitation close to or above normal, part of the recharge is available for abstraction without much impact on the fresh water lens thickness. However, in dry years when recharge is strongly reduced the water is abstracted from the fresh water lens storage. This causes a thinning of the fresh water lens, as observed in 2015-2016, and increases the risk of upconing of saline water into the wells, as observed in the Hihifo area wells, and in several of the production wells of the Mataki'eua well field in which the EC increased to above 2,000 µS cm^{-1}. In their analysis, White et al. (2009) demonstrated the relation between recharge and the salinity of the fresh groundwater.

Due to the high permeability of the aquifer, a large proportion of recharge will be lost as outflow to the ocean along the coast and some is intercepted by the coastal village water wells (Figure 18). The groundwater extraction potential was estimated as 20% of recharge by Lao (1978). If very low continuous abstraction rates are used and skimming occurs from the very top of the aquifer (*e.g.* using horizontal drains rather than vertical wells), it may well be possible to abstract higher percentages of recharge.

Based on salinity monitoring borehole data from between 1997 and 2000, Van der Velde (2006) estimated the freshwater lens thickness at about 12 m. In periods of drought without much recharge outflow from coastal springs and abstractions for domestic and agricultural use will be made from storage in the freshwater lens, causing the lens to become thinner.

The EC in 16 salinity monitoring boreholes (SMB) in Tongatapu was measured by the Water Section of the Department of Geology on a three-monthly basis from 2012 onwards. The time series of SMB09 near the Fua'amotu Airport is shown as an example for the evolution of the EC before and during the El Niño drought period in 2015-2016. For SMB09 the fresh-brackish water interface was at about 15.8 m below phreatic level and the EC at this level gradually increased during the drought, as did the EC at the 12.9 m level below phreatic level, which exceeded the 2,500 µS cm^{-1} brackish water limit value in August 2016. The EC (salinity) at both levels decreased again several months after the end of the drought in October 2016. This showed that the water quality was recovering due to the increased rainfall and recharge after the drought ended.

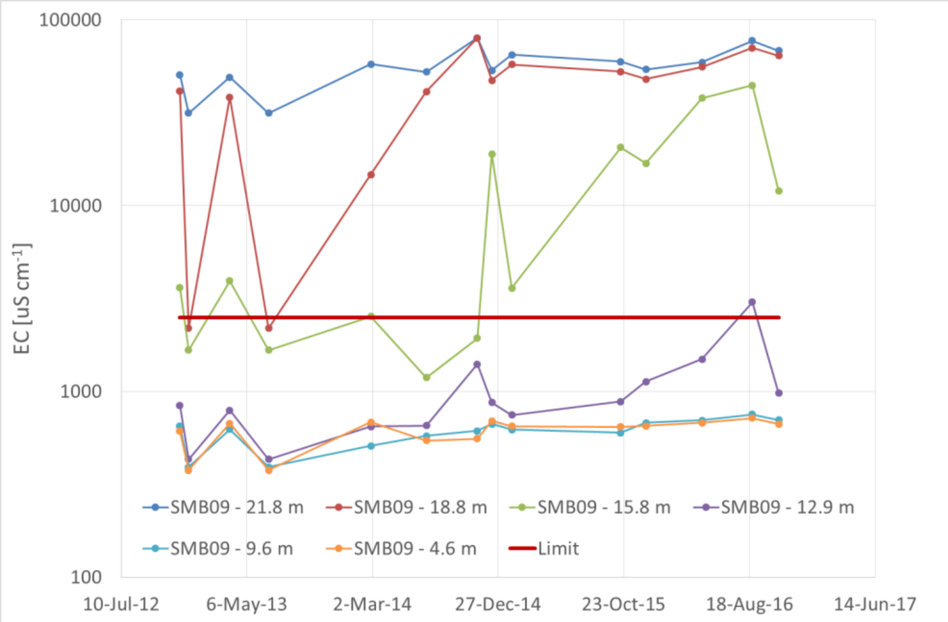

Figure 17. Variations in the EC at different depths in salinity monitoring borehole SMB09 at the Toloua-end of the Fua'amotu Airport Runway.

The SMBs, including those in the Mataki'eua / Tongamai well field from the Tonga Water Board, showed a decrease in the average lens thickness from an average of 12.4±3.4 m in the period 2012 until March 2015, before the drought impacted the salinity, to 10.3±4.0 m during the drought until October 2016. Hence, the reduced recharge of 449 mm in this period apparently caused an average depletion of the fresh water lens reservoir by an equivalent of 2.1 m aquifer thickness. This would suggest an equivalent average porosity (or specific yield) of 21% of the aquifer, which is about half of that observed by Hunt (1979).

Even though the average thickness was still over 10 m, several of the SMBs became brackish throughout the profile, in particular those at the South of the Mataki'eua well field (SMB12 and SMB13) and those in the Hihifo area (SMB15, and SMB16), where the freshwater lens is shallow at about 8 m thickness in normal years.

Fresh water recharge has to percolate through the unsaturated zone before it reaches the water table. Based on a transfer function and salinity well data of the Mataki'eua well field, Van der Velde (2007) obtained medians for lag periods between 305 and 4912 days, which included both travel times through the unsaturated zone and the buoyancy response time of the freshwater lens. For the travel time of recharge through the 3 m soil layer a lag time of about 60 days was observed in the present Hydrus-1D modelling. This suggests that the impact of the 2015 El Niño drought would have continued throughout 2016, as was indeed observed by the rising fresh-salt water interface from December 2014 until August 2016 in most of the SMBs, in which salinity only showed a decrease in the October 2016 measurements and did not return to pre-drought levels yet (Figure 17).

A map of the EC values measured in water supply wells the 3rd quarter of 2016 is shown in Figure 18. No information is yet available on wells used for agricultural abstractions of groundwater. The EC varied between low values of 400 – 700 µS cm^{-1} around Fua'amotu

Airport and in the areas South and West of the Mataki'eua well field and were higher in the near coastal zone (800 – 1,600 μS cm^{-1}). EC varied between 800 – 2,300 μS cm^{-1} in the Mataki'eua well field, with five wells in the south-eastern part of the well field having ECs above 2,000 μS cm^{-1}, suggesting that these five continuously pumped wells were particularly vulnerable to upconing or salt water intrusion from the lagoon area after extended periods of drought. This points to the need of continuous monitoring of salinity in the wells in the well field such that abstraction rates of individual wells can be managed when the EC increases above a certain threshold value to avoid further salinization.

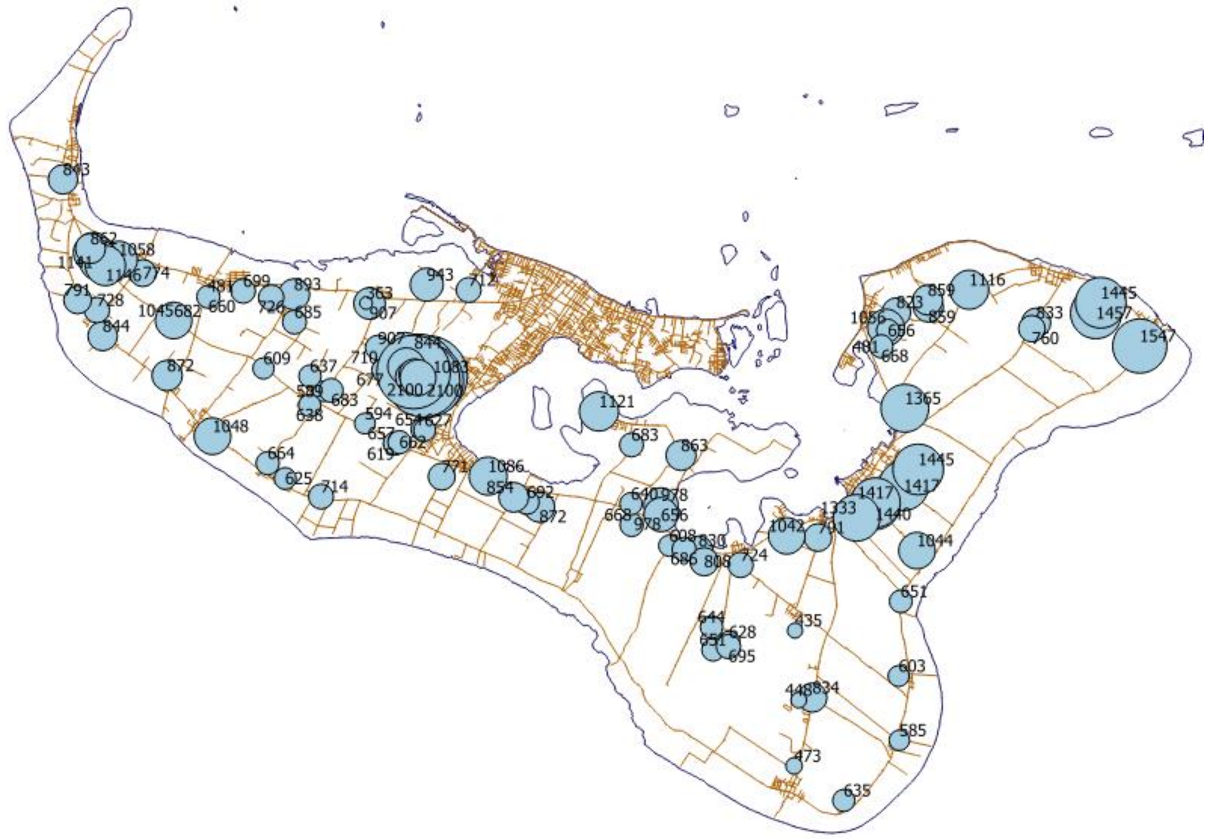

Figure 18. Map of the electrical conductivity [μS cm^{-1}] of water supply wells in Tongatapu, November 2016. The circles indicating the location of each well are scaled to the corresponding EC values.

3.4 **Water quality issues**

Water quality issues were discussed by Van der Velde (2006, pesticides) and by White et al. (2009; 2011). During the scoping mission, threats to the groundwater quality were observed in the forms of diesel fuel spills near village water supply bores, and mechanical equipment used and fuel stored in the visited quarry, where groundwater was at the surface. The proposed 2016 Water Resources Bill would provide the institutional means to control and regulate the use of potential pollutants and go towards reducing risks of pollution. As this subject falls outside the scope of the mission, the reader is referred to van der Velde (2006) and White et al. (2009, 2011) for further information.

3.5 **Water demands for agriculture**

3.5.1 Background

Variations in soil moisture content are normally caused by the infiltration of rain water into the soil, soil evaporation, and moisture extracted by plant roots for transpiration. If a soil becomes too moist an oxygen deficit can develop in the root zone, whereas if the soil dries out too much root water and nutrient extraction becomes limited. In both cases this results in sub-optimal plant growth. An adequate regulation of the soil moisture content in the root zone within certain limits is therefore a condition for optimal plant growth and to avoid crop damage (Shaxon en Barber, 2003; Shock en Wang, 2011). Optimal management of soil moisture to avoid drought damage is normally achieved by irrigation. The most simple type of irrigation is hand-watering, which is widely practiced in subsistence farming in Tonga, but also in more commercial farming as shown for a young citrus tree plantation in Figure 19. The method is time consuming and labour intensive, which poses limits on water abstraction for this type of irrigation, and is not suitable for large-scale intensive farming.

Figure 19. Hand watering of a young citrus tree at the farm of Mr. Minoru Nishi in Tongatapu.

Flood and furrow irrigation, involving the application and flow of water over the soil surface, are not practised in Tongatapu because of the high soil permeability. Other methods of irigation include sprinkler irrigation types and drip irrigation (Figure 20), which are suitable for larger-scale intensive commercial agriculture. Due to the larger amounts of water required, these methods require installation of boreholes and pumps for the abstraction of groundwater. Drip irrigation uses drip tape with regularly spaced nozzles, installed at the surface or below ground, to provide precise application of water (and nutrients) to the plant roots (Thomson et al., 1999). Disadvantages of sprinkler irrigation relative to drip irrigation are higher evaporative losses, potential leaf damage from drop impacts and leaf burn, soil erosion and lower irrigation efficiency due to a less uniform water distribution over the field and drift, in particular during windy periods (Camp et al., 1997). Drip irrigation, however, needs more investment of time and is therefore generally used for more high-valued crops.

Figure 20. Example of drip irrigation applied to a variety of vegetable crops at the farm of Mr. Minoru Nishi.

With irrigation, one of the main questions is when to irrigate to achieve optimal production. This requires knowledge of the soil moisture status that need to be controlled within certain limits. If the treshold moisture content for the crop is known, irrigation can be applied timely such that the treshold is never reached. The moisture content at which insufficient moisture is available to the plant roots depends on the crop and on the soil texture. For a sandy soil a moisture content of 10% may provide sufficient water to the crop, whereas a clay soil can already be too dry at a 30% moisture content. As such the tension with which moisture is held in the soil pores is a much better indicator for a treshold above which stress occurs. The soil moisture tension is usually expressed in (negative) pressure units, such as hPa or cm water column or as its logarithm (pF value).

For optimal plant growth irrigation should start when the moisture content of the soil drops below the 50% plant available water treshold (Singh, 1969; Trotter, 2015). Expressed in pF units, for common crops, Trotter (2015) advised not have soil moisture tension exceed pF= 3.0 to avoid crop drought damage and to start irrigation at pF= 2.7. From the above it is clear that farmers will aim to irrigate to keep the soil sufficiently moist.

The Hydrus 1-D modelled pF values at different depths in the soil during the period 2012 – 2016 are shown in Figure 21. This shows that during the drought between August 2014 and February 2016 the soil moisture tension was often above the pF= 2.7 threshold value indicating that water stress frequently occurred.

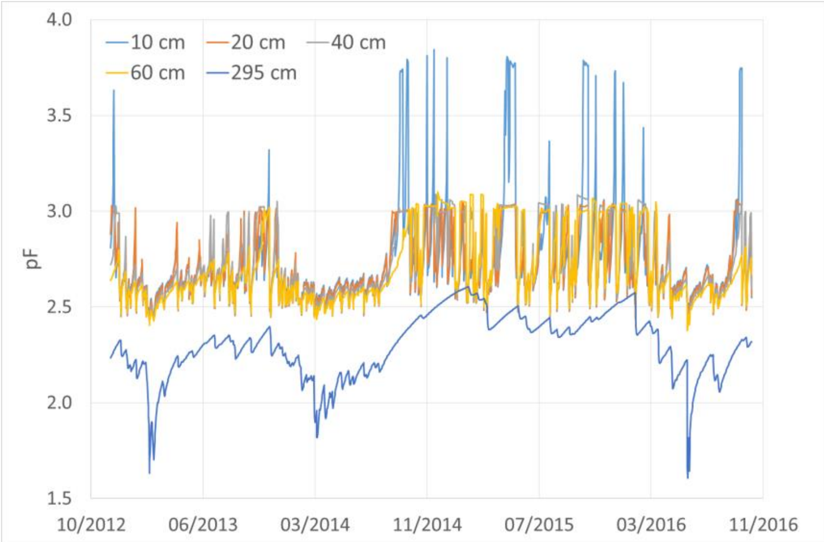

Figure 21. Hydrus-1D modelled variation in soil moisture tension, expressed as pF, for the period December 2012 - October 2016. Note that irrigation is usually required when the pF value increases above 2.7.

3.5.2 Agricultural water demand in dry years

In years with normal rainfall and sufficient soil moisture, evapotranspiration will be close to potential when the crop is mature. Irrigation is used to compensate for evaporative losses during dry periods. In years with rainfall close to average, the soil moisture storage is sufficient to bridge a few dry weeks. However, during extended droughts the soil moisture storage will be depleted and transpiration will be depressed from water stress. The potential water demand during El Niño years for irrigation can then be estimated from a comparison between evapotranspiration in years with normal rainfall and those in dry years. The normal evaporation rate, as modelled with Hydrus-1D, and those in 2015 and in the severe El Niño year of 1983 are shown in Figure 22. In 2015 irrigation would have had to supply about 280 mm to maintain transpiration, whereas this would have been 490 mm in 1983.

3.5.3 Environmental impacts of irrigation

The main environmental impact of irrigation is that on the water resources due to the higher abstraction required to maintain crop evapotranspiration and production during droughts. In Tongatapu, rainfall is sufficient to prevent the build-up of salts in the soil that poses problems in semi-arid or arid regions, and the high soil permeability prevents water logging if excessive irrigation is applied. Fertigation (supplying fertilizer with irrigation water) can be used with drip irrigation and when properly applied can reduce the input of fertilizer and leaching of nutrients to the groundwater.

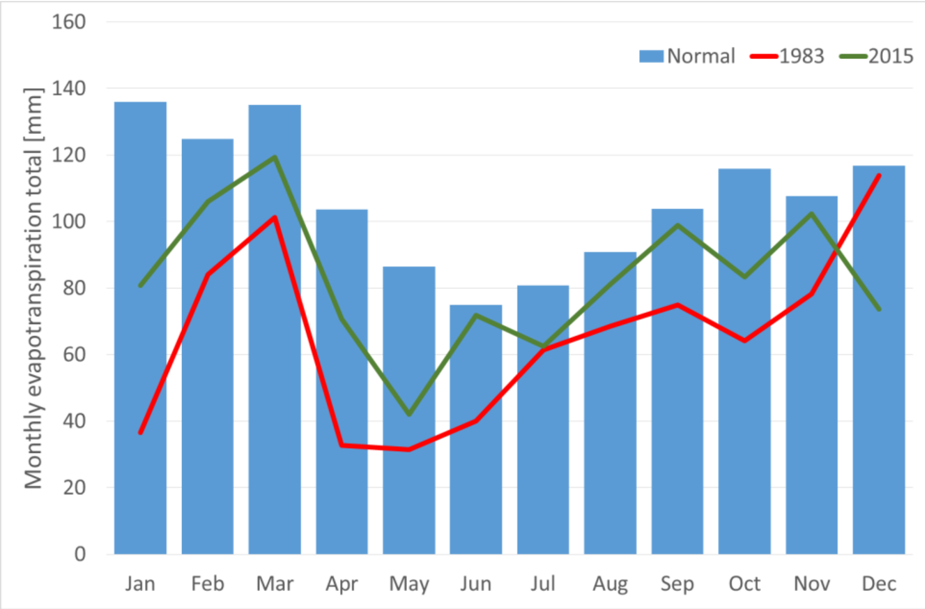

Figure 22. Comparison between average monthly evapotranspiration in years with normal rainfall and those with reduced rainfall due to El Niño events. The red line indicates reduced ET during the most severe 1983 El Niño event, whereas the green line represents the 2015 drought.

3.6 Tourist water demands

On average 50,000 tourists visit Tonga annually. In terms of water demands for Tongatapu, these tourists play a limited role (pers. Comm. T. Kula, MLSNR). Half of these tourists arrive in cruise ships or go to the outer islands and therefore do not visit Tongatapu. Assuming that visitors that do stay for a visit in Nukua'alofa spend on average two days in the town, before or after leaving to other destinations, this would result in an average tourist presence of 137 d^{-1}. Assuming an average consumption of 2.5 times that of a resident, this would result in an extra demand for only about 350 person-equivalents on average per day. According to the Nuku'alofa Water Board, per capita demand FOR Nuku'alofa residents is about 100 l d^{-1}. This means that the demand by the tourist sector on Tongatapu is only some 0.035 Ml d^{-1}, which is negligible compared to that by other users.

3.7 Nuku'alofa and village water supplies

From 1966 onwards Nuku'alofa's drinking water has been supplied from 36 hand dug or tube driven wells in the Mataki'eua / Tongamai well field to the South West of Nuku'alofa. Groundwater is pumped continuously and temporarily stored in six concrete reservoirs located on an elevated area near the well field. The water treatment consists of the manual addition of chlorine before distribution (Nath et al., 2007). Recently 18 new wells were added to the 36 existing wells. Average abstraction is 4.2 l s^{-1} per well from electric pumps (23), whereas the remaining pumps are diesel operated (pers. Comm. Mr. Fielea TWB). The new wells are all electric, with a capacity of 5.2 l s^{-1}. Salinity of the 36 old wells averaged to 1,025 µS cm^{-1}. In extended dry seasons the salinity has been observed to increase slightly. The water supply from the well field gradually increased over the years and is now at about 9 Ml d^{-1} (pers. Comm. Mr. Fielea, TWB) down from a maximum of 10.4 Ml d^{-1} in 2011 (Hyland, 2012) after repairs had been made to the main piping infrastructure. Leakage in the Nuku'alofa water supply system is still a problem and is presently estimated at 3 ML d^{-1}, according to the Tonga Water Board (pers. Comm. Mr. K. Fielea). A project is ongoing to install water meters to find major leaks and repairs these to reduce the abstractions from the well field.

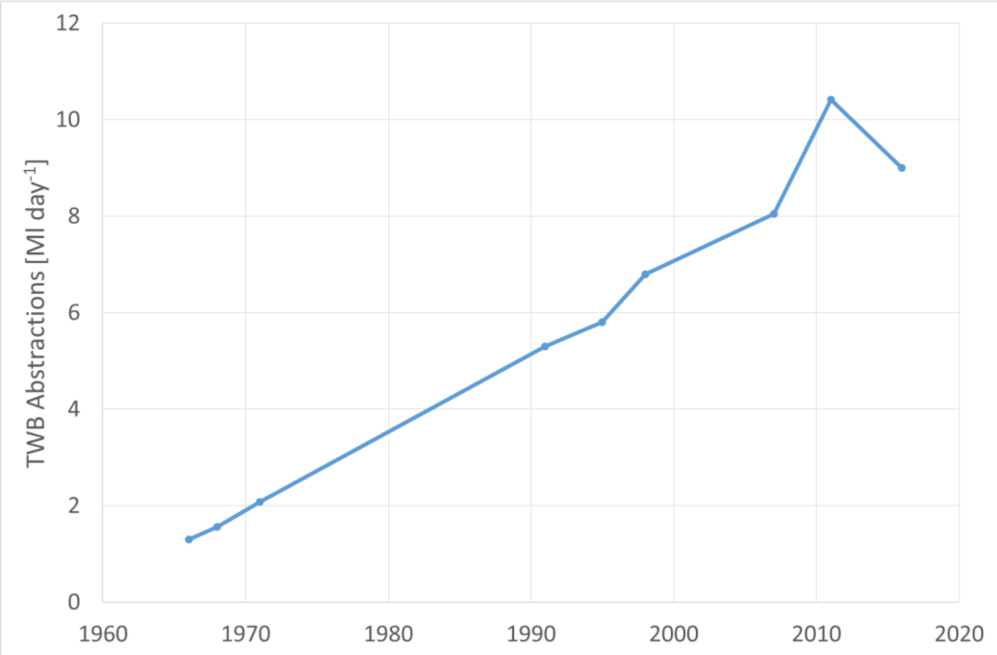

Figure 23. Historical abstractions of water made by the TWB in the Mataki'eua well field (Hyland, 2012; pers. comm. Mr. Fielea).

When compared to the number of inhabitants, the current abstraction amounts to per capita use of 230 l d^{-1}, which is well above plausible demands. Losses due to leakages in the reticulation network and the domestic piping system may therefore be considered high.

The TWB estimated rural Tongatapu per capita domestic water use at 70 l d^{-1}. Given a rural population of about 40,000 the daily demand would be 2.8 Ml d^{-1}. Yet, according to the TWB the total groundwater withdrawn for the rural water supply was estimated at 6 Ml d^{-1}. This suggests that part of the abstracted water may also be used for agricultural application, or that substantial losses also occur due to leaks in the village water supply reticulation system.

The threshold for value for the electrical conductivity in water for human consumption is set at 2,500 µS cm-1 at 20 °C (European Commission, 2006). Good-quality drinking water has a conductivity of 200-800 µS cm^{-1}. Water with a EC-value between 800 and 2,500 µS cm^{-1} can safely be consumed by humans, but most prefer to have water with an EC in the lower half of this range. During the drought several of the village water wells showed increased salinity of above the 2,500 µS cm^{-1} limit set by the European Union for drinking water.

Using an average per capita use of 150 l d^{-1}, the total water demand for domestic purposes would amount to 10.5 Ml d^{-1}. Total groundwater abstraction now reaches 15 ML d^{-1} and optimisation of the water distribution system to reduce losses through leakage could therefore result in a major reduction in domestic water supply demands. The Tonga Water Board has recently implemented a programme to reduce leakage in the water reticulation network of Nuku'alofa (pers. Comm. Mr. Fielea, TWB).

2.4.3 Agricultural development / irrigation

Agriculture is an important sector in Tonga (Tonga Agricultural Sector Plan, 2015). A large part of agricultural production still consists of subsistence farming. Agriculture and Livestock together make up for almost half of the rural income (Table 1).

Table 1. Income sources for the Kingdom of Tonga, given in 1000 Tonga $ (Source: Tonga Agricultural Sector Plan, 2015).

Income Source	Urban	Rural	Total
Agriculture	2,504	15,606	18,110
Livestock	1,727	12,046	13,773
Fish and seafood	2,724	4,639	7,363
Homemade produce	156	904	1,060
Handicrafts	4,870	21,658	26,528
Total Subsistence Income	**11,981**	**54,853**	**66,834**

Source: Kingdom of Tonga, HIES Survey, 2009.

Only a small part is produced for a well-developed market and export is as yet limited as shown in Table 2.

Table 2. Main export products of Tonga (Source: Tonga Agricultural Sector Plan, 2015).

Item	US$ million
Fish - fresh/ chilled	$3.2
Molluscs	$0.7
Plants	$2.9
Manioc, sweet potato, other roots	$1.4
Fish - dried/ salted	$0.7
Locust beans, seaweed, algae	$1.1
Other vegetables - fresh/chilled	$1.2
Coconuts, other nuts	$0.5
All Agriculture Commodities	**$11.7**

Source: FAOSTAT (2011)

Availability of sufficient water is an important issue for all stakeholders and this water needs to be abstracted in a sustainable manner to avoid water shortages during droughts. Population growth, sea-level rise and climate change is likely to limit groundwater availability in the long run. Agriculture in Tonga has historically relied on seasonal rainfall but this cannot be taken for granted anymore with more erratic weather patterns due to climate change. As a consequence a select group of entrepreneurial farmers already started experimenting with using more intensive irrigation to augment agricultural production and to safeguard supply to export markets during droughts (pers. Comm. Mr. T. Nakao). In the TASP alternative ways of production are also explored, but increased irrigation is likely to occur in the near future. On Tongatapu there is already some use of ground water for the irrigation of commercial crops (mainly vegetables) and there is interest in expanding irrigation to increase agricultural production. However this means drawing on scarce groundwater.

Exploitation of groundwater resources is now principally for domestic garden purposes. However groundwater is used for irrigation in Tongatapu, mostly from unmonitored bores. More detailed studies need to be done, but first impressions of the mission show that irrigation is yet of limited magnitude and only over very short periods of time. The total area under irrigation for commercial and export crop production is about 60 ha, and irrigation remains limited to four to five times during the dry season. Nishi Trading is one of the larger farmers who grows different crops including sweet potato, taro, Japanese taro, coffee, squash, tomato, pandana and kava. Irrigation of the vegetables is done with row sprinkler and drip irrigation systems, with abstractions from shallow bores at a rate in the order of 2 – 4 $l\ s^{-1}$.

At present there is no information available about the location of wells used for agriculture, the water quality of these wells and the abstraction rates. A well inventory to be set up for licensing in the Water Resources Bill (Appendix G), will identify in more detail where wells are, depth to water table, water extraction rates (at different times in the year) and water salinity. At this stage, based on data available, water for irrigation over a long dry period is not likely to exceed 1 Ml d^{-1}.

Several farmers have already resorted to more intensive farming using two sets of irrigation traveller equipment, which allow for irrigating 0.6 ha (1.5 acre) of crop (taro, onion) per hour using a groundwater extraction rate of 30-40 l s^{-1} (Pers. Comm. Mr. T. Nakao). The amount of water supplied to the crop represents a total of about 23 mm h^{-1}, which would be sufficient for a 4-5 day dry period before irrigation would have to be repeated. These systems would normally be used 4—5 times over a period of 7 months (pers. Comm. Mr. T. Nakao). The current area under irrigation was about 10 – 15 ha of Taro and Union (pers. Comm. Mr. T. Nakao). The irrigation traveller equipment used was designed to allow irrigation of 160 ha of land per week on a farmer cooperative basis. This would amount to a water use of 4.1 – 5.5 Ml d^{-1} over a period of a week. Currently, two of such irrigation traveller systems are operated in Tonga. Based on a 4-5 week application over the period of a year the average daily abstraction for irrigation travellers would amount to 0.5 Ml d^{-1} for 160 ha of agricultural land, or 0.32 Ml d^{-1} km^2. The farmers that were interviewed did nog have any plans to increase the irrigated area.

The groundwater abstraction for the irrigation travellers is over ten times higher than the recommended abstraction rate for avoiding upconing of saline water (White et al., 2009), as used by the TWB in its well field. Although it may well be possible to sustainably extract 4 – 6 Ml d^{-1} using an array of wells such as done by the TWB, the systems are now fed from a very limited number of wells. Hence there is a high potential for drawing saline water, which would create serious damage to the irrigated crops. The farmers using these high rates of abstraction would therefore be strongly advised to continuously monitor the water quality while using these large-capacity pumps.

Using the strategy of abstraction of groundwater from a larger number of boreholes at low pumping rates to avoid salinization may not be feasible for agriculture due to the higher costs involved in the construction of multiple boreholes and storage reservoirs that would be needed for the safe operation of the system.

The total area suitable for subsistence or ground cash crops agriculture is about 150 km^2 (pers. Comm. Dr. Manu. MAFFF) of the 256 km^2 (Van der Velde et al., 2006) area of Tongatapu. Irrigating these using traveller systems would require an annual maximum demand of 47 Ml d^{-1} in years with rainfall close to normal. If the irrigation frequency would increase to overcome extended periods of drought demand would increase correspondingly. It is unlikely that this scenario would be realised as a number of cash and tree crops are not depending on irrigation.

Water is also commonly transported to livestock. No detailed census data were available to the mission, however first estimates resulted in figures of some 5,000 cows and over 100,000 pigs, large and small. This would require drinking water to the amount of 0.5 Ml d^{-1} as an average figure throughout the year.

From the above we can conclude that at present the abstractions for irrigation seem to be rather small in volume in comparison to those for the public water supply. However, there seems to be a trend to form co-operations to increase the scale of production and to use equipment that needs much higher pumping rates than those used in the past. This could lead to salinity problems, even though the annual total abstracted volume remains low.

3.8 Assessment of availability

The sustainable yield of a freshwater lens depends on recharge, extent (width, depth) and response to pumping (hydraulic conductivity, anisotropy) of the lens. According to White et al. (2009) the sustainability of pumping from groundwater was uncertain for lack of accurate data, but was estimated at a rate of between 54 and 72 Ml d^{-1}, representing 20 – 30% of annual recharge. These calculations were based assuming an effective recharge area of 180 km^2 and sustainable yields of 3 to 4 m^3 ha^{-1} d^{-1}. Based on the current average annual recharge estimate (621 mm) resulting from higher rainfall inputs and using the same 20-30% recharge value for safe extraction, we would arrive at slightly higher values of safe yields of 61 – 92 Ml d^{-1}. During droughts with low recharge totals, abstraction will mainly be from storage through reduction of the lens thickness. Using the 21% specific yield obtained from the observed reduction in lens thickness due to a reduction in recharge during the 2015 drought total storage in the freshwater lens would amount to 2,600 mm, of which only a fraction could be extracted. This indicates that there should be sufficient groundwater available in dry years as long as abstraction occurs from the upper layer of the freshwater lens at low abstraction rates to prevent upconing of saline water below the well screens.

From the average annual recharge (621 mm y^{-1}) and the storage in the freshwater lens (2,600 mm), a hydraulic residence time of about 4.2 years can be calculated for fresh groundwater in the aquifer. This is slightly below the residence values (5.2 – 6.3 years) calculated by Falkland (1992) and White et al. (2009). If upconing occurs causing a well to become saline, the impact may be relatively short-lived due to the short hydraulic residence time of groundwater in the aquifer. However, it does mean that a well that has become saline cannot be used for groundwater abstractions for a period of several months to years.

In years with rainfall close to normal, the thickness of the fresh water lens would remain rather constant as there is limited withdrawal from storage. The drought of 2015 demonstrated that in a dry period with minor recharge, the abstractions and outflow caused a change in the storage in the freshwater lens, representing a change in the local lens thickness ranging between 0.5 m at a site where groundwater abstractions were minimal to 4.5 m where abstractions were high. Under these circumstances the initial thickness of the freshwater lens becomes important, and salinity may increase locally even with low abstractions where the lens is relatively shallow (coastal zone, Hihifo).

While the current abstraction rate remains uncertain in the absence of data, adding up the urban and rural water supply estimates given above, plus water for tourist and animals, the total extraction could be in the order of 16 Ml d^{-1}, or about one third of the sustainable yield. In dry periods, irrigation, including that using traveller systems, could add another 10 Ml d^{-1}, such that daily demand could peak at 26 Ml d^{-1} during droughts. This represents a use of 0.144 mm d^{-1} over the 180 km^2 recharge area, or an effective change in lens thickness of 0.7 mm d^{-1} during the period of abstraction. If this abstraction would be sustained over a full year it would reduce the lens thickness by 250 mm, in addition to the much larger regular reduction caused by outflow along the coast.

Uneven distribution of pumping could create salinity problems in pumped water, particularly during dry periods where recharge does not occur due to absorption of all rain in the upper part of the unsaturated zone of the soil. The household statistics show a dramatic increase in the number of household rain tanks since 1986, indicating a preference of rainwater for drinking.

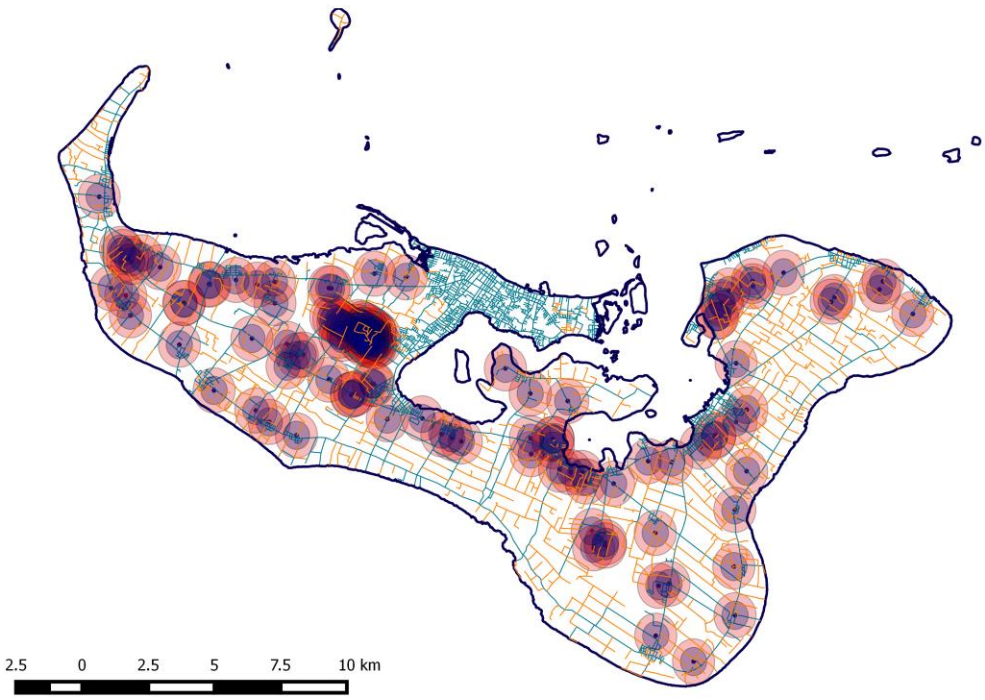

Figure 24. Map indicating the locations of wells used for the water supply of Nuku'alofa and for the villages on Tongatapu. The blue circles represent a 500 m buffer zone, whereas the red circles show the 800 m sphere of influence radius as recommended by White .

3.9 **Climate change impacts**

Climate change affects groundwater availability through impacts of changes in rainfall on recharge, and through rising sea levels reducing the extent of the freshwater lens. Studies have shown that changes in annual rainfall totals will be minor, that extreme rainfall events may occur more frequently and that the winter rainfall may increase, whereas the summer period will be drier. This leads to higher recharge, and changes in recharge can be therefore expected to be small in the future.

The increase in sea level and corresponding encroachment of saline conditions along the coast results in a reduction of the recharge area (currently at 180 km^2; White et al., 2009) and the extent of the fresh water lenses. The rising sea level also causes increased pressure on the fresh water lens and a corresponding increase in the phreatic heads in the wells. The closer proximity of the ocean may cause a higher salinization risk in near-coastal wells.

The impacts of these changes can be only be quantified properly by developing a 3-D variable-density groundwater model of Tongatapu island, in which sea level rise can be taken as a boundary condition.

3.10 **Future outlook for public water supply expansion**

The TWB has indicated area’s for expanding the pumping activities when demand goes up and the Mataki’eua field no longer suffices (Figure 25). This would also make the supply system more resilient. Such expansion would certainly increase the supply security of Nuku’alofa drinking water. Recorded salinity levels after dry periods in the present site indicate the need for augmented security. However, this should have consequences for the zoning of other activities in the area. Large-scale irrigation in the area or intensified agriculture with high loads of fertilizer and pesticides should be avoided. In order to enable to enforce such measures, timely consultations with stakeholders are important and enacting of a water resource management bill is of prime importance to safeguard against competition and overuse.

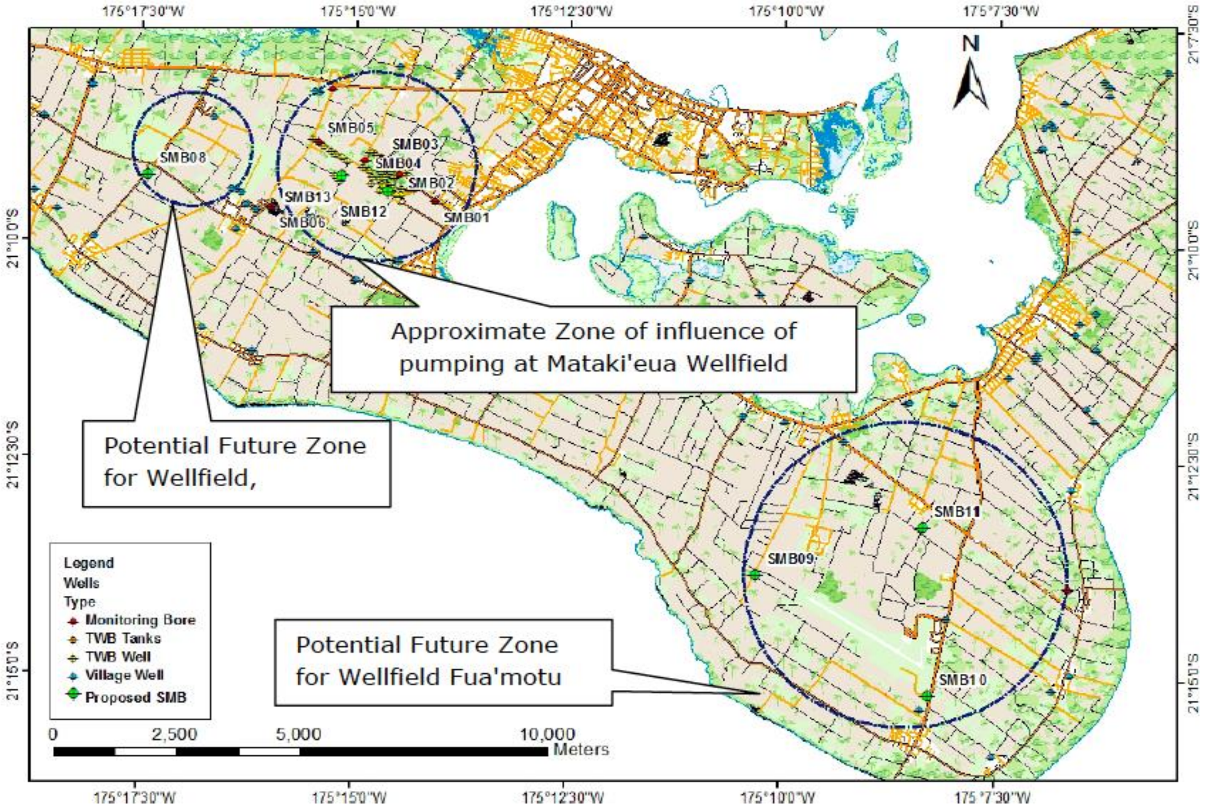

Figure 25. Proposed expansion zones for public water supply abstractions by the Tonga Water Board (source: Hyland, 2012).

3.11 Alternative water supply options

As the demand for fresh water keeps increasing the Government of Tonga is advised to study options to conserve fresh water wherever possible. In years with normal rainfall the groundwater reservoirs seem to be able to supply enough water for the domestic water supply, as well as for the current use for agriculture. During prolonged droughts, when recharge becomes limited for periods of over a year (*Figure 15*), domestic extractions will be competing against the agricultural demands for water. It is at these times, that only occur once every few years during El Niño events, that a buffer of water is required to meet all demands. Such a buffer could be in the form of additional surface water storage, although the quantity stored would be affected by evaporation losses. Various options for the creation of surface water storage were discussed with Government and private sector stakeholders.

1) The option of expansion of rainwater harvesting capacity has already been suggested in earlier reports (GEF, 2011; IGRAC, 2016) but there is still potential for additional rain water harvesting, using larger roof areas and by increasing the capacity of the storage tanks. Many of the concrete storage tanks were installed decades ago and may have to be replaced, for instance by higher capacity flexible storage tanks, which would provide opportunities for increased storage. When the system is properly maintained and the first flush is discarded, the water quality from the roof catchments should be considered excellent and does not have the risk of being contaminated by agricultural activities (fertilizer, pesticides) or

accidental spills that could be affecting the groundwater resource. Enlarging the domestic storage capacity would alleviate the demands for domestic consumption during droughts to some extent. With the construction of solar power plants, such as at the police headquarters in Nuku'alofa, the inclined surfaces of the solar panels could also serve as additional water harvesting area if gutters and storage tanks are installed to collect rain water.

2) New well fields could also be created in areas where relatively thick freshwater lenses are available. Locations were proposed by White et al. (2009, 2011) and Hyland (2012) as shown in Figure 25. However, development of irrigation schemes will compete for water in these areas.
3) The third option was the use of abandoned quarries as water storage reservoirs. As these quarries are in the permeable limestone layers, these should be lined first. One such quarry has been lined and is now used as a waste facility. Filling up such a quarry using precipitation would take a long time and there is no surface runoff that can be used to fill such quarry reservoirs. At present, this option therefore does not seem to be a viable alternative. If in the future the establishment of large solar power plants is being considered, and if these are established in the vicinity of a quarry, rain water running of from the solar panel surfaces could be harvested and diverted to contribute to filling up a quarry reservoir.
4) Artificial infiltration in the unsaturated zone below the root zone. Surface runoff from roofs or paved areas (*e.g.* airport runway) could be collected and infiltrated into shallow wells that penetrate the soil cover and discharge water into the unsaturated zone at depths where it cannot be extracted by evapotranspiration. The water would travel through the unsaturated zone to reach the phreatic groundwater level and could then be extracted later for agricultural use from a deeper well into the groundwater near the infiltration point. This would avoid evaporation losses that normally occur when surface runoff infiltrates into the soil. This option does have the disadvantage that any contamination, such as accidental oil spills on the tarmac, will travel in short time to the groundwater reservoir. There is no significant source of waste-water that could be used for artificial recharge.
5) The fifth option is to create a large buffer of fresh water by closing off part of the lagoon. Within several years the water in the closed section of the lagoon would then freshen because of inflow from springs along the edge of the lagoon, and by rainwater. By keeping the water level in the closed off section of the lagoon slightly above sea level when the water has freshened, losses of groundwater into the lagoon could be limited somewhat, which may have a positive effect on the fresh water lens below the Mataki'eua well field. The fresh water from the lagoon would then be available for use in dry periods for agriculture, and perhaps even as a source for reverse osmosis desalinisation and purification. In addition, the fresh water area could serve as a pond for the breeding of exotic Tilapia fish, which already invaded the lagoon. Private sector and many government officials remarked that this could be an option that should be studied in the long term, also in view of the perceived negative effects on the lagoon water quality on aquatic life as a result of inflow of nutrients and pesticides from sceptic tanks and agriculture. The perception was that the lagoon would be dying anyway. The idea was also presented to the representatives of the MECCC, who are currently working with the villages to conserve the ecosystem and improve water quality through actions along the shore of the lagoon. The part of the lagoon that would have potential for serving as a reservoir is an important ecological area, containing sea grass beds and mangrove forests, that form spawning and breeding areas for mullet and other aquatic species. In The Netherlands there is

much experience with reclaiming coastal areas, which could be made available to draw up a first plan if such a fresh water buffer would be considered in the future.

6) Installation of a desalinisation unit to provide additional water for domestic use. This installation could use brackish groundwater rather than sea water to reduce the costs of desalinisation. A mobile unit is already used by the Government to supply water to the smaller islands in periods of drought. With prices of these installations going down, and with the option of using solar or wind power to reduce the dependence on oil prices, this may be a viable option for the future.

Stimulating the expansion of the rain water harvesting capacity can be achieved with minimal incentives as this already is common practice. The other options, and in particular the option of creating fresh water storage in the lagoon, would need further studies and intensive consultation with the stakeholders to determine their ecological, socio-economic and financial feasibility.

4 CONCLUSION, RECOMMENDATIONS AND PROPOSED FOLLOW-UP ACTIVITIES

4.1 Overall scope

The scoping mission succeeded to discuss the aspects of drought in relation to the public water supply and the agriculture with the main government and private stakeholders. There is general consensus that regulation of the water resources is required and urgent, and that more knowledge about the functioning of the hydrological system is required for proper management of the resources. This is true for both water quantity and quality aspects as overuse of the water resources is likely to happen if increasingly larger pumps are used for irrigation, whereas the risk of pollution of the groundwater is severe when regulations to penalize polluters are not in place. As such there is an urgent need to implement the Water Resources Bill, and with it the management tools needed in the licensing decision making process.

4.2 Availability of water resources

Based on higher average rainfall totals between 1980 and 2016, causing higher recharge (average 621 mm y^{-1}), and a recharge area of approximately 180 km^2, excluding low lying areas and coastal strips with minor fresh groundwater reserves, a safe yield of the groundwater lens equivalent to a maximum groundwater abstraction of 92 Ml d^{-1} was obtained. This yield can only be obtained when pumping rates remain low to avoid local upconing of saline water or salt water intrusion along the coast. During droughts, both evapotranspiration and recharge are reduced.

4.3 Public water supply demands

The demand for supplying the 30,000 inhabitants of Nuku'alofa is at present satisfied by the 9 Ml d^{-1} currently pumped from the groundwater lens by the Tonga Water Board (TWB) out of 36 older and 18 new wells in the area of Mataki'Eua - Tongamai.

Part of the domestic use of water (cooking, drinking water) both in urban and rural areas is derived from rainfall harvesting (roof catchments and storage tanks). However, the capacities of the tanks are only sufficient to accommodate the demand during dry periods not exceeding three months. When tanks run dry, people switch to tap water, increasing the demands on the public water supply at times when recharge is low and water is withdrawn from storage in the freshwater lens.

The supplied quantities per capita (about 230 l d^{-1}) for Nuku'alofa are above actual per capita daily use (estimated at about 150 l d^{-1}) and indicate substantial losses in the water distribution system, estimated by TWB at 30%. Recent improvements to the water distribution network in Nuku'alofa in the form of Japanese funded replacement of the mains have reduced losses by 10-20%. However, more savings are necessary by targeting leaks in the secondary distribution network. A programme has recently been implemented to identify and further reduce leakage in the reticulation network. Losses from the distribution network infiltrate to groundwater but cannot be re-used due to pollution and high salinity of the groundwater below the coastal urban area.

Several village water supply wells showed increased salinity levels that were above the limit set by the European Commission (2,500 µS cm^{-1}) for drinking water (European Commission, 2006) during the 2015 drought. In November 2016 five production wells of the Mataki'eua well field also showed increased salinity, with measured electrical conductivity (EC) values reaching up to 2,350 µS cm^{-1} (fresh-brackish threshold is at

2,500 µS cm^{-1}) at the end of the dry season in November 2016. This suggests that there may be little surplus water available from storage in these parts of the well field due to local upconing or salt water intrusion. Continuous monitoring of the salinity of the extraction wells in the Mataki'eua field would allow detection of salinity changes and improve operational management. Wells showing increased salinity after droughts could temporarily switched off to allow the fresh water lens around these wells to recover after rainfall.

In the future, additional extraction of groundwater is foreseen at Fua'motu near the present airport. The groundwater lens is substantial in this area and at this stage may be slightly thicker than that below the the Mataki'Eua well field.

4.4 Agricultural water demands

Irrigation to date has only been of limited magnitude, also because water saving methods (for example drip irrigation) are being applied. It has contributed to the supply of vegetables and other food crops that augment food security. Large scale development must be avoided in the area's where drinking water for Nuku'alofa is abstracted to avoid over use and salinization.

The recent development of using irrigation traveller systems by farmer's cooperatives that require larger pumps with capacities up to 40 l s^{-1} increase the risk of upconing or salt water intrusion as the abstraction is made from a limited number of wells for economic reasons. The risk results from high pumping rates that could lead to saline groundwater upconing, rather than from the total amount of abstraction (0.5 Ml d^{-1} over the period of a year for 160 ha).

Further detailing of groundwater availability is necessary and involvement of all stakeholders is recommended to optimize the use of groundwater for both agriculture and domestic use. Implementation of the proposed Water Resources Bill is a means to achieve this, as it leads to registration of wells and abstractions.

Large scale development including substantial abstraction of groundwater for agriculture in the south-eastern part of the country may in the long run conflict with developing a new well field for drinking water supply for new urban settlements expected on and around the peninsula in Southern part of the lagoon.

Pollution of the water source has to be avoided, particularly by chemicals used in agriculture that maintain their contaminating character over time. This requires strict regulations for land use and application of pesticides and nutrients in the influence zone of drinking water sources.

The DRR-Team has observed that with reference for the need of regulatory measures and enacting of the proposed Water Resources Bill (prepared as far back as 2006; White et al., 2009), there seems to be considerable concensus between stakeholders on the need for implementation of the bill. However, agreement should be reached on several points (*e.g.* licensing policy and fees, maximum possible safe abstraction rates, ownership) through future consultations. Additional knowledge on the local groundwater lens dynamics and implementation of a groundwater model, or a derived GIS-based system, that can be used to evaluate the impact of abstractions on the local groundwater lens thickness would make it possible to judge the sustainability of requests for well abstractions on a scientific basis. Through further consultation with all stakeholders, finalisation and implementation of the Water Resources Bill is a necessity to arrive at the strongly needed protection and optimal use of the scarce water resources. This should be combined with the establishment of a National Water Resources Committee, in which all stakeholders are duly represented.

Continued efforts are needed to arrive at a better quantitative picture of the groundwater resources. In particular further automatic continuous recording of the salinity of abstracted groundwater on key locations will lead to a much better understanding of the dynamics of the groundwater lens.

4.5 Recommendations

For better estimation of agro-meteorological parameters, such as daily evapotranspiration for use by the agricultural sector automatic weather stations could be installed at the Fua'amotu airport and other locations in Tongatapu. These stations should measure rainfall, temperature, relative humidity, wind speed and direction, solar radiation and air pressure. The daily potential evaporation values should be published on a dedicated web site together with crop factors for common crop types for consultation by farmers.

The ADB-supported groundwater observation programme project should be continued and institutionalised to maintain a regular monitoring network of the aquifer of the TWB and the village wells and establish a historic data collection to be used for future water resource management requirements. The DRR-Team further recommends:

1. A continuation of close monitoring of existing and future groundwater abstractions is continued and expanded;
    a. Increase public awareness about risks of salinization and enhance data availability, by creating a participative groundwater EC measurement programme where stakeholders (TWB, MOH - village water supply, farmers) measure salinity in their wells and make these measurements publicly available on a web-based platform (MLSNR, MAFFF, TWB, MOH);
    b. Facilitate manual observations in the SMBs (MLSNR) and make these more reliable through continuous water level and salinity observations by installing telemetric water level and salinity recorders in the network of SMBs (at the depth of the fresh-salt water interface) and also connect these to the web-based platform;
    c. Install a LoRa WAN system that in combination with EC sensors can be used to continuously measure salinity of abstracted water telemetrically at key location in a very cost-efficient way (MLSNR, TWB, MOH, farmers);
    d. To increase awareness of salinization risks with different stakeholders and provide information on the functioning of the hydrological system in relation to agriculture (MAFFF);
2. Development of a three dimensional variable-density groundwater model to simulate the dynamics of the groundwater lens and the effects varying rainfall, recharge and abstractions, particular during extended periods of drought (MLSNR);
3. Collection of information about aquifer properties such as the hydraulic conductivity and the anisotropy (pumping tests);
4. A National Water Resources Committee to be formed and a broadly accepted Water Resources Bill to be enacted swiftly, which should also address pollution risks, including those from agriculture and activities in quarries (all parties);
5. To promote further rain water harvesting measures to increase domestic rain water storage (MOH, MLSNR).
6. The Tonga Water Board continues with its objective to reduce leakage from the water reticulation system (TWB).
7. Through joint discussions and consultations with all stakeholders enact a broadly accepted Water Resources Bill, which also addresses pollution risks, including those from activities in quarries. Establish a National Water Resources Committee

with representatives of all stakeholders (all parties). The enhanced understanding of the hydrological system achieved by monitoring and modelling provides the basis for sound decisions on licensing;

8. Research the necessity and feasibility of the creation of a fresh water body in the western part of the lagoon, taking both the ecological importance of the lagoon (mangroves, sea grass, fish spawning and breeding area) and the future water needs into consideration. This part of the lagoon already at present gets little seawater refreshment due to silting up. Such measure would create an alternative source of fresh water for irrigation purposes. Regulate access to water from such fresh water storage facilities (MLSNR, MAFFF, MEIDECC);
9. Provide information to all stakeholders on the consequences and dangers of excessive pumping from the freshwater lens (MLSNR, MAFFF). This enhances the awareness, in particular of the agricultural sector, of how different pumping rates affect the flow patterns around wells. The use of horizontal drains that skim water from the surface of the fresh water lens would allow higher abstraction rates than from vertical wells, but the technology for installation of such wells may not be readily available in Tongatapu.

Many of these recommendations are related to actions (e.g. technical support, raising public awareness) that were proposed in the National Water Management Plan (Faka’osi and Takau, 2012).

The feasibility of the creation of a fresh water body in the western part of the lagoon could be investigated, taking both the ecological importance of the lagoon (mangroves, sea grass, fish spawning and breeding area) and the future water needs into consideration. This would create an alternative source of fresh water for irrigation purposes. Regulate access to water from such fresh water storage facilities (MAFF, MLSNR, MOH, MEIDECC. MAFFF);

Terms of Reference for follow-up activities based on these recommendations are given in Appendix E.

5 ACKNOWLEDGEMENTS

This report was compiled over a very short period of the scoping mission, and many people contributed to the contents by making time available to share information with the DRR-Team members. We would like to thank the Honourable Minister of Agriculture & Food Production, Forestry and Fisheries, H.E. Semisi Tauelangi Fakahau for receiving our mission and guiding us regarding the approach to be followed and Dr. Viliame Manu (MAFFF) for the kind reception in Nuku'alofa, for sharing his insights about agriculture in Tonga and sharing maps and data that assisted us greatly in the preparation of this report. Furthermore, he also arranged for us to meet all stakeholders involved in groundwater management. The representatives of the Tonga Water Board, Mr. Simone Helu and Mr. Quddus Fielea, are gratefully acknowledged for sharing information on the operation of the public water supply and future prospects on public water supply in Tonga. Their long-time experience in the safe extraction of groundwater is invaluable for Tonga. Mr. Ofa Fa'anunu (Director of Meteorology) is gratefully acknowledged for sharing his professional Mr. Taniela Kula (MLSNR) is thanked for the discussions on hydrology and the practicalities surrounding the implementation of the Water Bill, for providing office space and interaction with his team. Lopeti Tufui, Asena Foliaki, Sesimani Lokotui and Kaati Hakaumotu, thank you very much for the discussions on salinity monitoring, for providing new data and for showing us the geology and hydrology of Tongatapu in the field. Mrs. Atelaite Lupe Matoto (director Dept. of the Environment), Mrs. Ta'hirih F. Hokafonu (National project co-ordinator UNDP Tonga Ridge to Reef program), Mrs. Dorothy Foliaki, Mrs. Ana Fekau (MEIDECC), and Mrs. Tita Kara (Ministry of Agriculture) are thanked for making time available on short notice to discuss the idea for creating a fresh water buffer in the lagoon and for pointing out the ecological importance of the area.

In the agricultural sector, which forms such an important aspect of the economy of Tonga and has a large influence on groundwater use, Mr. Pousima Afeaki (Tinopai Farm), Mr. Minoru Nishi (Nishi Trading Company) and Mr. Tom Nakao (PHAMA, Market Access Working Groups) are thanked for sharing their knowledge on agricultural practices in Tonga, their experience with groundwater abstraction for irrigation and their views on the future of Tongan agriculture, its water use and the Water Resources Bill.

At SPC in Suva, Fiji, Mr. Mike Petterson (Director SPC), Mr. Akuila Tawake, Mr. Robert Smith, Mr. Inoke Ratukalo, Mrs. Maria Elder and Mrs. Sandra Rodriquez are thanked for their willingness to discuss aspects of groundwater management in the South Pacific region with us and for providing us with useful contacts in Tonga.

Finally, we would like to thank the Dutch Government, Mr. Jaap Kroon and all other RVO staff for making this scoping mission possible and for their support during and after the mission.

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APPENDIX A. DRR-TEAM

Dutch Risk Reduction Team: reducing the risk of water related disasters

Many countries around the world face severe water threats. Often, these countries are in urgent need of expert advice on how to prevent a disaster or how to recover from a calamity. For instance, when a country has been struck by severe floodings and the first emergency relief workers have gone, the need for advice on how to build a sustainable and safer water future arises. To meet these needs with a swift response, the Dutch government has initiated the Dutch Risk Reduction Team (DRR Team). This team of experts advises governments on how to resolve urgent water issues related to flood risks, water pollution and water supply, to prevent disasters or to rebuild after water related disasters. With climate change and a fast growing world population, water issues are becoming more urgent. As a country renowned for its' expertise on water and delta management, the Netherlands feels a responsibility to share its' knowledge worldwide. That is just what the DRR team does; sharing expertise with governments to come up with the best possible approach/solutions for tackling urgent water issues. Because of the unique cooperation between government and sector, the best experts can be fielded quickly. The Dutch government offers a specific number of advisory missions each year.

Advice for all water issues
The Netherlands has brought its best water experts together in the Dutch Risk Reduction Team. It consists of high level advisors supported by a broad base of technical experts who can provide top quality and tailor made expertise to governments that are confronted with severe and urgent water challenges. The Dutch are experts in adapting to water in a changing world; from delta management to water technology, from urban planning to governance, public private partnerships and financial engineering.

How does the DRR team work?
Governments that have to deal with an urgent water issue are encouraged to contact the Dutch embassy in their region. The embassy will liaise quickly with the Dutch government. Interventions will only take place after a request from a central government has been received by the Dutch government, and after a recent calamity or to prevent a threatening disaster. The DRR team does not focus on emergency relief, but on sustainable solutions. If the decision to respond to the request is made, relevant Dutch experts will be rapidly fielded to the area that is under pressure. Together with the government and local experts, the situation will be assessed and analysed after which the team will come up with a set of recommendations. For example advice on technical interventions including immediate measures and long term sustainable solutions, advice on governance and advice on financing options. The DRR team enables a foreign government to take action on the basis of sound advice and expertise.

Team members

The team members for the for the scoping mission in Tonga are:

- Team Leader: Sjef IJzermans
- Senior Hydogeologist: Dr. Maarten J. Waterloo

APPENDIX B. REQUEST OF THE GOVERNMENT OF THE KINGDOM OF TONGA

Office of

The Hon. Minister of Agriculture & Food, Forests and Fisheries

Hon. Semisi Tauelangi Fakahau
Minister for Agriculture, Food, Forests and Fisheries
Tel: (676) 23-038
Fax No. (676) 27-401
Email: minister@mafff.gov.to

Ministry of Agriculture, Food, Forests& Fisheries
P.O. Box 14
Nuku'alofa
KINGDOM OF TONGA

Ref No.: MIN/37/16

DATE : 26th May, 2016

Mr. Rob Zaagman
Ambassador,
Embassy of the Kingdom of the Netherlands,
Wellington ,
New Zealand.

Your Excellency,

Subject: Requesting DRR for Urgent Scoping Study on Tongatapu and Éua Water Resources and Agricultural Irrigation

Thank you for the opportunity to hold the meeting with yourself, your spouse and the special envoy for Pacific SIDS, Sjef IJzermans on the 18th of May and the productive discussions we had. I also appreciate the follow on meeting that Mr IJzermans had on 19 May with the Ministry of Agriculture, Food, Forests and Fisheries (MAFFF) Acting CEO, Dr. Viliami Kami and Deputy CEO, Mr Sione Foliaki.

It became clear from our discussions that you have had an insight into the challenges posed by climate change that our small island kingdom faced in the past 2-3 years. Our kingdom encountered an array of tropical cyclones with one category 5 destroying the Ha'apai group of islands and two Category 5 cyclones that went pass Tonga and caused devastation in Vanuatu and Fiji respectively.

In late 2014 Tonga suffered one of its most severe droughts which was followed by El Nino resulting in prolonged dry conditions. This prompted local farmers and exporters to seriously consider introducing suitable irrigation systems to the subsistence and commercial farming systems. This is an area that, until recently, has been considered a new and difficult topic to examine in detail due to Tonga's very limited ground water resources. The Ministry of Agriculture, Food, Forests and Fisheries acknowledges the need to address the impacts of climate change on the agriculture sector and is fully aware of the need to treat irrigation as an integral component of its future work programme. Accordingly, further studies on irrigation are recommended in the Tonga Agriculture Sector Plan (TASP) 2016 – 2020.

During the follow on meeting between Sjef IJzermans and MAFFF staff, and a subsequent meeting with the CEO of the Ministry of Lands & Natural Resources, MAFFF staff were informed of the "Capacity building programmes for SIDS". Both MAFFF and the Ministry of Lands & Natural Resources (MLNR) agreed that that there is need to have an urgent scoping study undertaken on Tonga's water resources and the use of agricultural irrigation systems.

The Government of Tonga is therefore very keen to look at the sustainable management of its limited water resources and hereby formally request the Government of Netherlands to provide the expert services of 3 specialists under the DRR scheme to conduct a scoping study on Tongatapu and Éua islands. The main objective of the scoping study will be to assess the state and condition of current water resources and the potential for use of suitable irrigation systems in both subsistence and commercial crop farming. The specialists should include:

i) a Hydro-geologist;
ii) Water resource specialist; and
iii) Irrigation specialist.

The task of this team would be to:

- conduct a desktop survey and assessment of the state of ground water resources in Tongatapu and Éua;
- provide a report with recommendations on sustainable utilisation of the water resources;
- the potential for use of suitable irrigation systems and equipment; and
- the potential environmental impacts, in particular on soil salinity, damage to soil texture, soil structure and fertility, etc.

I would be very grateful if the Netherlands Government could provide the assistance referred to above.

Thanking you for your kind cooperation.

Yours sincerely,

....

Hon. Semisi T. Fakahau
Minister for Agriculture, Food, Forests and Fisheries

APPENDIX C. *TERMS OF REFERENCE*

Title: Scoping mission Kingdom of Tonga on groundwater resources and irrigation systems

Project code: DRR16TO02

1. Introduction

Request

An official request from the Minister of Agriculture, Food, Forest and Fisheries for support from the DRR-Team was sent to the Dutch Embassy in New Zealand on the 30th of May 2016. The detailed request of the Minister of Agriculture, Food, Forest and Fisheries is asking for an assessment of the ground water resources on Tongatapu and Éua and an advise on sustainable utilisation of ground water resources, including advice on suitable irrigation systems for agriculture and an environmental impact study. Further specifications are provided in the following chapters. Please see Annex A for further background information.

Background

The Kingdom of Tonga is experiencing changed rainfall patterns caused by El Niño (drought and increased rainfall) and faced severe tropical cyclones in the last 3 years. These climate change effects have a major impact on available water resources – particularly groundwater – and dependent farming activities. In late 2014 and subsequently in 2015 extreme droughts triggered and awareness amongst local farmers and exporters to consider the introduction of irrigation systems. The limited ground water resources of Tonga in relation to this situation has stimulated the Ministry of Agriculture, Food, Forest and Fisheries (MAFFF) to assess the impacts of climate change on the agricultural sector and to integrate irrigation into the Tonga Agriculture sector Plan (TASP) for the period of 2016 – 2020. The Special Envoy for Pacific SIDS, Mr Sjef Ijzermans and the ambassador met with the Minister of Agriculture & Food, Forest and Fisheries (MAFFF), Mr. Semisi T. Fakahau in May 2016. During the same visit Mr Sjef IJzermans had a subsequent meeting with MAFFF staff and the CEO of the Ministry of Lands and Natural Resources (MLNR). The MAFFF and MLNR agreed that there is an urgent need for a scoping study of the water resources and the agricultural irrigation systems.

The Kingdom of Tonga is a Polynesian sovereign state in the Southern Pacific Ocean and archipelago comprising 169 islands of which 36 are inhabited. Tonga's relations with Oceania's regional powers, Australia and New Zealand, are good. The economy of Tonga is characterised by a large non-monetary sector and a heavy dependence on remittances from the half of the country's population who live abroad. Agriculture and forestry (together with fisheries) provide the majority of employment. Rural Tongans rely on both plantation and subsistence agriculture. Plants grown for both market cash crops and home use include bananas, coconuts, coffee and root crops such as cassava, sweet potato and taro.

The relations between the Netherlands and Tonga are stable but also limited in economic scope. The Dutch honorary consul resides in Nuku'alofa, the capital of Tonga.

Date:

Date: August 24, 2016

2. Mission specifications

a. Scope

The main task of the mission is to perform an assessment of the available water resources – with special emphasis on groundwater - on Tongatapu and Éua and to advise on suitable irrigation systems for agriculture.

b. Objectives

The DRR Team will provide technical assistance to Ministry of Agriculture, Food, Forest and Fisheries on:

- the state and condition of the limited groundwater resources on Tongatapu and Éua islands;
- the assessment on prolonged effects of long droughts on water resources
- recommendations on sustainable use of water resources
- review of existing irrigation practices and techniques for subsistence and commercial crop
- recommendations on sustainable irrigation practices and techniques for subsistence and commercial crop farming
- assessment of potential environmental impact of irrigation systems
- In addition the DRR Team will produce for internal use:
    1. if applicable and feasible propose follow up activities on the elements of the scoping mission with support of the Netherlands (depending on the findings and opportunities for follow-up)
    2. perform a quick scan of the actual possibilities for the Dutch water sector on Tonga.

c. Activities

The DRR-Team members will perform the following activities:

- Collection of available data on geological, hydrological and meteorological characteristics of the Tongatapu and Éua islands;
- desktop study of the collected geological, hydrological and meteorological data;
- plan and discuss the groundwater resources and irrigation systems with all relevant stakeholders on Tonga;
- field visits to relevant locations for groundwater resources on Tongatapu and Éua islands;
- field visits to relevant locations for review of currently used irrigation systems for subsistence and commercial crop farming on Tongatapu and Éua islands;
- generate an overview of the state and condition of the limited ground water resources on Tongatapu and Éua islands;
- generate an overview on the currently used irrigation systems for subsistence and commercial crop farming on Tongatapu and Éua islands;
- identify and specify potential Follow Up possibilities related to the focus of the mission.
- represent the Dutch Water sector and the DRR-Team in a professional and constructive way.

d. Expected deliverables

The DRR-Team is expected to deliver the following output:

1. Mission report with recommendations for the Tonga authorities with:

    a. Executive summary

    b. description of conducted activities (meetings, field trips, surveys etc.)

    c. observations and results related to above-mentioned objectives

    d. Conclusion & recommendations, based on observations

2. Opportunities for the Dutch water sector, specifying the following:

    a. Differentiation between short term and long term

    b. Brief description (< 1 paragraph per opportunity)

    c. Priority of action (advisable – urgent – extremely urgent, or +, ++, +++)

    d. Identification of Dutch companies – subsector that would benefit from said opportunity

3. Copy of the debrief presentation at the end of the mission with the preliminary results and advice of the mission for the National Authorities of Tonga

4. A summary of the visit of maximum 2 pages, which can be used for publication on websites of EKN and RVO.nl/drrteam.nl.

APPENDIX D. MISSION PROGRAMME

2 November	- Telephone conversation with Mr. Amit Singh from SPC who is studying at IHE n The Netherlands. Mr. Singh referred to the Whycos project and suggested to contact Mr. Peter Sinclair from SPC in Fiji.
14 November	- Arrival Sjef IJzermans in Nadi (13/11) - Arrival Maarten Waterloo in Nadi. Joint taxi trip to Suva; Meeting with SPC staf: - Mike Petterson Director SOPAC/ Akuila Tawake, Head Geo survey: Info on water resources in Tonga; provided several contacts in Tonga; important cooperation NL and SPC. - Robert Smith, Sen. Advisor Geosciense Division. General info on Tonga and other PSIDS (Kiribati). - Dr. Inoke Ratukalo Director of Land Resources and Maria Elder on water use of crops and irrigation; experience in Fiji; contacts in Tonga
15 November	- Courtesy call to Mr. Semisi Fakahau, Honourable Minister for Agriculture and Food & Forests. Briefing on the purpose of the mission. - Dr. Viliame Manu, CEO MAFFF. TOR briefly discussed. Confirmed to focus only on Tongatapu due to time restrictions. Programme discussed. Emphasis on Bill of Water presented to Parliament, subsequently withdrawn because of pressure of farmers that reject interference on existing wells. - Mr. Pousima Afeaki, Member of AGS (PPP). Emphasis on water rights of farmers with existing wells; discussion of farming system and irrigation practices. - Ministry of Lands, Survey and Natural Resources, Dept. of the Environment: Mr. Asipeli Palaki. Stresses importance of our work. Further co-operation with staff.
16 November	- Mr. 'Ofa Fa'anunu, Director Meteorology (Fua'amotu Domestic Airport). Rainfall patterns changing; more droughts and intensive rainfall. More rain SE of capital than at Airport. Will make available rainfall and other met data. - Viliame Manu, CEO MAFFF. Discussion on soils in Tongatapu. - Taniela Kula; Geologist Lands. Overall water situation; Description of groundwater lens and it's fluctuations; well monitoring of 76 wells; Water Resources Bill.
17 November	- Meeting with Mr. Taniela Kula and water section staff (Lopeti Tufui; Asena Foliaki; Sesimani Lokotui; Kaati Hakaumotu) at Dept. of Geology and Natural Resources of Min. Lands; data review; monitoring systems discussions.
18 November	- Ano Tobi, IT expert Water Resources Geology and Natural Resources. Data on monitoring by ROK supported project. - Saimone Helu, CEO / Quddus Fielea Operation Manager Water Board of Tonga. Info on general plans, future demands and pumping data of the Water Board.
19 November	- Field visit with Sesimani Lokotui and Asena Foliaki to Special Monitoring Boreholes, village supplies, springs at lagoon side and cave in western side.

	- Meeting with Mr. Minoru Nishi at his farm on actual irrigation practices and WR Bill.
20 November	- Reporting.
21 November	- Geology Dept. Round up with Taniela Kula and his staff. - Visit to the Ministry of Meteorology, Energy Information, Disaster Management, Environment, Climate Change and Communications. Meeting with Mrs. Atelaite Lupe Matoto (director Dept. of the Environment), Mrs. Ta'hirih F. Hokafonu (National project co-ordinator UNDP Tonga Ridge to Reef program), Mrs. Dorothy Foliaki, Mrs. Ana Fekau, and Mrs. Tita Kara (Ministry of Agriculture). Mr. Renie Vaiomo'unga was also present to represent the Dept. of Lands water section. discussions on the possibility of fresh water storage in Western part of the lagoon. Seagrass beds and mangroves are important for fish breeding in that area and there are village community plans to address nutrient inflow into the lagoon.
22 November	- Visit to Min. of Lands Geology Dept. for final discussions with Mr. Lopeti Tufui, Mrs. Asena Foliaki and Mrs. Sesimani Lokitui and for data retrieval. - Visit to Min. Foreign Affairs; - Meeting with Mr. Tom Nakao (Growers Federation of Tonga Incorporated) to discuss agricultural expansion plans for Tonga. Mr. Nakao provided information on his groundwater use and type of irrigation; - Visit to the Tonga Meteorological Service and to the Fua'amotu airport meteorological station. Mr. Ofa Fa'anunu provided more information about the climate change prospects for Tonga; - Mission debrief with Dr. Viliami Manu by e-mail (appointment for oral presentation was cancelled due to calamity requiring Dr. Manu's immediate attention). - Return flight to Nadi/Fiji
23 November	- Return flight to Manilla (Sjef IJzermans) - Visit to SPC (Maarten Waterloo). Meeting with Mrs. Sandra Rodriguez. Mrs. Rodriguez works close together with Mr. P. Sinclair (SPC Head of Water Section). Tonga and Bonriki water management options were discussed. Mrs. Rodriguez provided additional SPC documents on meteorology and salinity monitoring done by SPC in the past. She informed us that a groundwater model SEAWAT is successfully being used to better manage the Bonriki water supply well field in times of drought.
25 November	- Return flight to Netherlands (Maarten Waterloo)

APPENDIX E. TERMS OF REFERENCE FOR POTENTIAL FOLLOW UP ACTIONS

The scoping mission Tonga has drawn up general conclusions about the status of the water resources, their use and management in Tonga. Recommendations were made concerning the approach to be followed to improve long-term water management and to safeguard public and agricultural water supply. The main issue is the risk of local salinization of fresh groundwater in periods of drought due to increased abstraction rates. The investments to be undertaken and the technical expertise required for their implementation are such that financial and technical assistance from donors and expert companies or institutes will be needed. The following details what steps could to be taken to implement improved water resources management by the Government of Tonga, such that access to fresh water during droughts for both the public water supply and agricultural sectors is guaranteed.

Background
In 2015-2016 Tonga was affected by a severe and extended drought, which resulted in reduced recharge to the freshwater lens and caused constraints to the water supply service. In some cases, the drought caused increases in the salinity of village water wells such that the electrical conductivity of the water increased well above the limit set for drinking water quality in Europe.

In November 2016 the Dutch government responded to the request by the Government of Tonga in fielding a brief reconnaissance mission specifically focused on the evaluation of the water resources and public and agricultural demands to promote increased resilience in available water resources.

The findings of the DRR mission may be summarized as follows:

- The existing production capacity of approximately 16 Ml d^{-1} for the combined Nuku’alofa and village water supply is expected to be adequate in the mid-term to even long-term future, if the issue of leakage in the reticulation network can be addressed;
- The 2015 drought revealed that agricultural production is affected, leading to crop failure and a higher demand for irrigation water. Currently, this demand is rather low in comparison to that for the domestic water supply, but new developments in irrigation may lead to more intensive groundwater use for agriculture;
- The proposed Water Resources Bill aims to provide the legal framework that will allow a better regulation of water resources and their use. Registration and information about abstractions of private wells is a condition for better water resources management. The well registration and the granting of abstraction licenses in particular, as provided for in the bill, requires a tool to evaluate the local impact of private and public sector applications for groundwater abstractions on the freshwater lens;
- The current salinity monitoring programme includes the Nuku’alofa and village water supply wells, but no private sector wells. A participative salinity measurement network, of which the measurements are publicly available on an online platform, provides a cost-effective means to obtain more information and to involve and inform stakeholders on the salinity status of different parts of the island. Such a public monitoring network should be implemented also to serve as an early warning system for salinity risks and as a basis for making decisions on local groundwater abstractions;
- To gain more insight into the response of the fresh water lens to recharge, drought and abstractions, a variable density groundwater model and corresponding decision support system should be developed for Tongatapu. The model could be calibrated

and validated on the participative salinity measurements. The enhanced understanding of the functioning of the hydrological system and the risks of salinization would create a basis for better acceptance of the Water Resources Bill;
- The option of creating a large fresh water buffer in part of the lagoon as a measure to safeguard supply in the long-term needs investigation;
- The status of water resources in ‘Eua could not be studied in the present scoping mission due to lack of time, a follow up scoping mission may be needed to fulfil this request by the Government of the Kingdom of Tonga;

These suggested Terms of Reference for future actions respond to both a demand for institutional/data preparedness for making decisions within the framework of the Water Resources Bill and for assessing the need and initial implementation of measures for groundwater resources conservation and development.

Objective

To increase the resilience of Tonga’s water supply service by promoting better understanding of the functioning of the hydrological system and water resources management and by developing additional water resources, to be specifically exploited during extended periods of severe drought.

Results

- Preparation and phase 1 of implementation of participative salinity monitoring network, groundwater modelling framework and decision support tool;
- Institutional framework for data collection and information management on water resources monitoring;

Output

- A first step towards fact-based groundwater management and decision support on the Island of Tongatapu.

Human resources input

Effective conduct of the ToR will require substantial national and international expertise. The following input is foreseen:

- Team Leader (INT): 30 % time input over 18 months
- Junior Hydrologist (INT): 12 months
- Junior Hydrologist (NAT): 18 months, includes training and capacity building

APPENDIX F. WATER RESOURCES BILL 2016, KINGDOM OF TONGA

Tonga

WATER RESOURCES BILL 2016

Tonga

WATER RESOURCES BILL 2016

Arrangement of Sections

Section

WATER RESOURCES BILL 2016

A BILL FOR AN ACT TO PROVIDE FOR THE MANAGEMENT, PROTECTION AND CONSERVATION OF THE WATER RESOURCES OF THE KINGDOM

BE IT ENACTED by the King and the Legislative Assembly of Tonga in the Legislature of the Kingdom as follows:

PART I - PRELIMINARY

1 Short Title

This Act may be cited as the Water Resources Act 2016.

2 Interpretation

In this Act, unless the context otherwise requires –

"**aquifer**" means any naturally occurring underground source of freshwater;

"**Chief Executive Officer**" means the Chief Executive Officer responsible for lands and natural resources;

"**climate change**" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods;

"**Committee**" means the National Water Resources Committee established under section 10;

"**disaster**" means an actual event, or a high probable risk, involving serious disruption to the functioning of a community causing widespread human, material, economic or environmental loss and which exceeds the ability of the affected community to cope using its own resources;

"**discharge**" means to throw, place, put, pump, allow, pour, permit or otherwise cause any pollutant to enter or affect the water resource, either directly, indirectly or through run-off;

"**groundwate**r" means water naturally stored or flowing beneath the surface of the ground and which is not apparent on the surface of the ground;

"**lens**" means an underground sheet of freshwater suspended above saline water;

"**Minister**" means the Minister for Lands and Natural Resources;

"**Ministry**" means the Ministry of Lands and Natural Resources or such Ministry with that primary responsibility;

"**overdraft**" means the extraction of water within a particular geographic area at such a rate or in such a quantity that the extraction exceeds the sustainable rate of extraction of water from the groundwater aquifer from which the water is extracted;

"**pollutant**" means any liquid, gaseous or solid substance that contaminates the water so as to change the physical or chemical condition of it in such a manner as to make the water unclean, noxious, offensive or impure, or so as to be detrimental to the health, safety or welfare of persons using, consuming or residing in the vicinity of the water;

"**Principal Hydrogeologist**" means the person holding, from time to time, the office of Principal Hydrogeologist in the Ministry or such other person nominated by the Minister to conduct such duties and functions of the most senior hydrogeologist officer;

"**resilience**" means the capacity of a system to withstand external shocks and retain its essential characteristics;

"**salinity**" means the total dissolved salts in water. Salinity is most conveniently monitored by measuring the electrical conductivity of the water;

"**Tonga Water Board**" means the Tonga Water Board established under the Tonga Water Board Act 2000, and includes any other body that might later assume the role of the Tonga Water Board under law;

"**water resource officer**" means a public servant whose job is to monitor and manage water resources;

"**water resources**" means the surface and ground waters in aquifers, lakes, streams and springs, vested in the control of the Ministry by section 5(2);

"**water source**" includes all sources of water from wells, aquifers, streams, springs and any other source of freshwater within the Kingdom which is or may be used for water supply purposes, excluding domestic and communal rain water tanks for private use; and

"**vulnerability**" means a condition resulting from physical, social, economic, and environmental factors or processes, which increases the susceptibility of a community to the impact of a climate change and disaster risk.

3 Act binds the Crown

This Act shall bind the Crown.

PART II - OWNERSHIP AND MANAGEMENT OF THE WATER RESOURCE

4 Vesting water resources in the Crown

(1) The water resources of the Kingdom are vested in the Crown.

(2) Nothing in this section shall prevent any person from claiming ownership of water which has been lawfully taken and stored on any land or premises.

5 Ministry to manage the water resources

(1) The management of the water resources of the Kingdom is the responsibility of the Ministry, in conjunction with the other agencies of the Government provided for under this Act, and any other law, or where necessary.

(2) The right to use or to permit the use of water in aquifers, lakes, streams and springs, excluding rain water tanks for private use in the Kingdom for the purpose of supplying water for domestic, agricultural, pastoral, industrial or commercial uses is vested in the Ministry.

(3) The granting of rights to take or use water referred to in sub-section (2) shall only be done in accordance with the provisions of this Act.

6 The Rights of State Utilities to take water

The Tonga Water Board and any other ministry or agency of the Government shall be entitled to take and use water for serving the purpose of their respective functions in accordance with law, but they shall comply with any conditions, standards, requirements or procedures imposed in the exercise of any power under this Act.

PART III - POWERS OF THE MINISTRY OVER THE WATER RESOURCES

7 Objectives of water resources management

The Ministry shall implement this Act and manage the water resource so as to achieve the following objectives –

(a) the sustainable management of the water resource through coordinated and scientifically sound planning of water resource development and regulated water use for all lawful purposes;

(b) the avoidance of overdrafts of available water supplies through the establishment of an inventory of water resources and the regular monitoring, assessment and reporting to the Minister of extracted volumes of water per reporting period, groundwater salinity (electrical conductivity) and water levels;

(c) the improvement of the chemical, physical and biological integrity of the water resource by -

(i) regular monitoring, assessment and reporting to the Minister of water quality;

(ii) promoting coordination amongst all agencies of government having roles and functions associated with the testing and monitoring of water quality and supply;

(iii) recording the results of monitoring and maintaining records of other matters associated with the management of the water resource; and

(iv) the control of pollutant discharges;

(d) the proper assessment of the impacts of proposed developments on the water resource, and the implementation of effective urban and rural planning regimes that take account of water supply and water quality issues;

8 Powers of the Minister

(1) In order to meet the objectives stated in section 7, the Minister shall have the power to -

(a) consider applications for the taking and use of water in accordance with Part IV of this Act;

(b) grant approvals, and to vary and revoke any approval, in accordance with Part IV of this Act;

(c) consider competing claims for the taking and use of water and make determinations in relation to disputes between water users, such determinations being binding and final on the parties competing for the use of water;

(d) place restrictions on the right to take or use water, either in relation to particular users or so as to apply generally, if circumstances require that water conservation measures be imposed;

(e) set standards applying to any activity or equipment associated with the taking of water or the development of the water resource, and regulate or prohibit any such activity or the use of any such equipment;

(f) declare any area to be a water source protection zone on the recommendation of the Committee, and determine that the designated area shall be managed in accordance with a management plan approved by the Committee to apply to the water source protection zone;

(g) regulate and control the use of water, and any activity that may affect the quality of water or the quantity of water supply;

(h) give notice to persons to cease activities or practices having a detrimental effect on the quality of water or the quantity of the water resource, including the power to require the removal of any structure or thing having such an impact;

(i) arrange for the removal of any structure or thing not having been removed in accordance with a notice given under paragraph (h), and to recover the cost from the person in default; and

(j) require that certain matters relating to the water resource be considered in the assessment of environmental impacts of proposed developments required under the Environmental Impact Assessment Act 2003.

(2) The Minister may, by written notice, require any person who has drilled any borehole or who has been taking water prior to the commencement of this Act to comply with any requirement imposed by the Minister under sub-section (1), and the written notice delivered to that person shall state a date by which compliance with any power exercised under this Act is to be achieved.

(3) The powers of the Minister under this section may be exercised –

(a) by the making of written determinations and orders under the hand of the Minister; or

(b) in accordance with regulations made by the Minister with the consent of Cabinet to give effect to the objectives stated in section 7, and to facilitate the exercise of the powers conferred by this section.

(4) The Minister may delegate, by instrument in writing, any of the powers provided for by this section to the Chief Executive Officer or any other officer of the Government.

9 Offences against this Part

Any person, group of persons, company or corporate body who -

(a) fails to comply with a determination made by the Minister under section 8(1)(c) in relation to competing uses of the water resource;

(b) fails to comply with any restriction placed by the Minister under section 8(1)(d);

(c) fails to comply with any standard set under section 8(1)(e) while undertaking any activity or using any equipment associated with the taking of water;

(d) unlawfully undertakes any activity or uses any equipment which has been regulated or prohibited under section 8(1)(e);

(e) fails to comply with any notice given by the Minister under section 8(1)(h);

(f) fails to meet the cost of complying with the requirement of any notice given by the Minister under section 8(1)(h); or

(g) fails to comply with a notice given under section 8(2),

commits an offence and shall upon conviction be liable to a fine not exceeding $5,000 or to imprisonment for a term not exceeding 3 years, or both, if the offence is committed by an individual person or group of persons, or fine not exceeding $10,000 if the offence is committed by a company or a corporate body.

PART IV – NATIONAL WATER RESOURCES COMMITTEE

10 The National Water Resources Committee

(1) The National Water Resources Committee is hereby established under the leadership of the Ministry and shall be responsible to and report to the Minister.

(2) The membership of the Committee shall comprise -

- (a) the Chief Executive Officer; who shall be Chairperson;
- (b) the Chief Executive Officer for Health; who shall be Vice-Chairperson;
- (c) the General Manager of the Tonga Water Board;
- (d) the General Manager of the Waste Authority Limited;
- (e) the Chief Executive Officer for Finance and National Planning;
- (f) a representative of a relevant Non-Government Organisation; and
- (g) the Principal Hydrogeologist who shall be the Secretariat.

(3) Meetings of the Committee shall be held at such times and at such places as the Chief Executive Officer shall determine.

(4) Every meeting of the Committee shall be presided over by the Chief Executive Officer or any person deputising in the absence of the substantive Chief Executive Officer.

(5) The Committee may regulate its proceedings in such manner as it thinks fit.

11 Functions and Powers of the Committee

The functions of the Committee are to -

(a) advise the Minister on any matter affecting the quantity and quality of the water resource;

(b) promote coordination amongst government ministries and agencies having responsibilities relating to the water resource;

(c) ensure that there is effective monitoring of the water resources by the responsible ministries and agencies and that records of such monitoring are maintained and made accessible;

(d) establish a multi-agency National Water Resources Technical Committee chaired by the Principal Hydrogeologist to carry out monitoring and analysis of the condition and use of the Kingdom's water resources, and to review and make recommendations to the Committee on applications for water resource development and extraction;

(e) ensure that an annual report detailing the condition and use of the Kingdom's water resources is presented to the Minister;

(f) promote the dissemination of information about the water resource to government agencies and the general community;

(g) recommend to the Minister that an area be declared to be a water source protection zone in accordance with section 8(1)(f);

(h) approve a management plan to be applied to any designated water source protection zone in accordance with section 8(1)(f);

(i) arrange for the preparation, confirmation and implementation of the Tonga Water Management Plan in accordance with Part V, and for regular reporting to the Minister of progress against the planned objectives and the periodic review and amendment; and

(j) identify, review and, where appropriate, endorse projects to be undertaken with the aim of protecting, conserving and improving the water resource.

PART V - TONGA WATER MANAGEMENT PLAN

12 Elements of the Tonga Water Management Plan

(1) The Tonga Water Management Plan shall address the following matters –

(a) an assessment of the available water supply and the sources of the water supply;

(b) an inventory of the groundwater resources for each island or island group;

(c) a determination of the average quantity of water pumped from existing wells on a daily, monthly and annual basis;

(d) a determination of the average quantity of water consumed on each island or island group on a daily, monthly and annual basis;

(e) a determination of the losses of water that occur between the water source and the consumer;

(f) a consideration of water wasted by domestic, commercial, industrial and agricultural users, and also by the reticulated water schemes;

(g) water conservation measures and a timetable for their implementation;

(h) a projection of demand for water by domestic, commercial, industrial and agricultural users;

(i) mandatory well construction standards, including provisions for the sealing and fencing of wells;

(j) a water quality monitoring programme of existing and proposed wells, and the clear identification of the role in such a programme for the responsible government agencies;

(k) procedures for the recording and assessment of information about water quality and quantity, for the sharing of this information amongst the responsible government agencies and for its public disclosure;

(l) contingency plans to be used in the event of threats to the quantity and quality of the water resource; and

(m) appropriate cost recovery proposals to redress problems of salinity and other adverse environment effects that arise from the taking of water from the water resource.

(2) When preparing and approving the Tonga Water Management Plan, the Committee shall apply the following principles –

(a) the extraction of water from any groundwater lens shall not exceed the sustainable rate of extraction of the lens;

(b) wastage of water by any person, company or corporate body shall be kept to a minimum;

(c) water use shall be beneficial and based on principles of sustainability;

(d) use of water for domestic purposes is the highest priority, and in the case of competing uses of the water resource, the domestic use shall prevail;

(e) the water resource shall be safeguarded from all types of pollutants; and

(f) conditions may arise when the water resource shall be safeguarded by the imposition of restrictions applying to all or to specific water users.

13 Environment Impact Assessment and Planning Schemes

(1) The provisions of the Tonga Water Management Plan shall be considered and reported upon in relation to all assessments of impacts to the environment from proposed developments undertaken under the Environmental Impact Assessment Act 2003.

(2) All urban and rural planning schemes prepared in accordance with any law shall be consistent with the provisions of the Tonga Water Management Plan, and all such planning schemes shall have the objective of protecting and conserving the water resources in accordance with the objectives stated in section 7 of this Act.

(3) No approval may be given under the Environmental Impact Assessments Act 2003 or any law making provision for urban and rural planning schemes if the effect of the approval is to breach any provision of the Tonga Water Management Plan.

PART VI - REGULATING THE TAKING OF WATER

14 Permits to take water

(1) No person, group of persons, company or corporate body may –

(a) drill for water;

(b) make or use a bore for the purpose of taking water from the water resource; or

(c) take water from the water resource of the Kingdom,

unless he is the holder of a valid licence to do so issued by the Ministry in accordance with this Act.

(2) Categories of permit may be prescribed by regulations.

(3) The regulations may exempt from the requirements of sub-section (1) any person, group of persons, company or corporate body, either individually or collectively, in all areas or specific areas, and for specified activities or categories of extraction, either completely, or subject to conditions specified in the regulations.

(4) Every application for a licence under sub-section (1) shall –

(a) be made in writing to the Chief Executive Officer in a form prescribed by regulation made under this Act;

(b) be accompanied by an application fee as prescribed by regulations made under this Act;

(c) include such additional information in relation to the proposed drilling or the proposed or current water taking activities, as may be required by the Chief Executive Officer; and

(d) be accompanied by a signed undertaking by, or on behalf of the applicant, that the drilling or water taking activities shall be in accordance with the provisions of the Tonga Water Management Plan and the requirements of this Act.

(5) All applications made under this section shall be referred to the Principal Hydrogeologist for confirmation that the drilling or water taking activities shall –

(a) be in accordance with the provisions of the Tonga Water Management Plan;

(b) not contravene any standards, control, prohibition or requirement determined by the Minister; and

(c) not adversely affect the water quality of the water resource or any aspect of the water supply in the Kingdom.

(6) Upon confirmation of the matters specified in sub-section (3), the Chief Executive Officer may authorise that a permit be granted.

(7) A permit granted under this section –

(a) may impose any conditions as to the means of extraction, quantity of water to be extracted, placement of the bore and any other matter that may assist in the protection, conservation and sound management of the water resource;

(b) shall, if the permit authorises the taking of water, state –

(i) the category of the permit, if specified;

(ii) the quantity of water that may be extracted;

(iii) the rate at which the water may be extracted; and

(iv) the permissible means by which the water may be extracted; and

(c) permits the right for a water resource officer to enter the property where the licence is applicable for the sole purpose of monitoring the borehole and extract water whenever required for the purpose of the Act.

(8) A licence granted under this section shall be valid for a period of 3 years, but may be varied, suspended or revoked by the Minister for any purpose that is consistent with the protection, conservation or sound management of the water resource.

(9) All drillers of water bores are required to be licensed by the Ministry and shall demonstrate their competence and knowledge of and adherence to this Act, its intent and their understanding of prevailing geological conditions.

15 Requests for review of decisions

(1) An applicant who is aggrieved by a decision of the Chief Executive Officer made under section 14 may, within 28 days of the decision being made, request the Minister or Chief Executive Officer to reconsider of the application by –

(a) giving written notice to the Chief Executive Officer stating the grounds upon which the request is made and providing evidence in support; and

(b) paying any fee prescribed by regulations made under this Act.

(2) The notice and supporting evidence given under sub-section (1) shall be referred to the Committee for consideration in such manner as the Committee determines, and the Committee shall then advise the Minister to either dismiss the application, vary the Chief Executive Officer's decision or grant the application and grant the permit.

(3) The Minister may make a decision in relation to a request made under this section based upon the recommendation of the Committee.

16 Environment and health standards applying to water

(1) Environmental standards relating to –

(a) the taking of water; and

(b) any activity that may affect water quality or the integrity of any water source, including waste management operations and any commercial enterprise;

may be prescribed by the Minister, and the Ministry shall be responsible for the monitoring and enforcement of the approved standards.

(2) Public health standards relating to the taking of water and any aspect of water quality may be prescribed by the Minister of Health in consultation with the Principal Hydrogeologist, and the Ministry of Health shall be responsible for the monitoring and enforcement of the approved standards.

(3) Standards imposed under this section may be applied to any ministry or agency of Government whose activities relate to, or impact upon, the water resource and their contractors, and to any other persons identified in the applicable standard.

(4) Any person to whom an approved standard applies who fails or refuses to comply with the standard commits an offence and shall be liable upon conviction to a fine not exceeding $2,000.

(5) In addition to any fine imposed under sub-section (4), the failure to observe or comply with an approved standard shall be grounds for –

(a) suspending or revoking any registration or licence applying to the person in breach;

(b) refusing any subsequent registration or licence sought by the person in breach; and

(c) shutting down access to the water resources either on a temporary or permanent basis;

17 Offences against this Part

Any person who -

(a) gives any false particular in an application made to the Ministry for a permit under this Part;

(b) takes water from the water resource of the Kingdom without a permit given under this Part;

(c) fails to comply with conditions imposed in relation to a permit given under this Part;

(d) fails to comply with any aspect of the undertaking to observe the provisions of the Tonga Water Management Plan,

commits an offence and shall upon conviction be liable to a fine not exceeding $5,000 or to imprisonment for a term not exceeding 3 years, or both, if the offence is committed by an individual person or group of persons, or fine not exceeding $10,000 if the offence is committed by a company or a corporate body.

PART VII - MISCELLANEOUS PROVISIONS

18 General offences

(1) Any person, group of persons, company or corporate body who -

(a) discharges any pollutant into the water resource of the Kingdom;

(b) causes or permits any pollutant to be discharged into the water resource of the Kingdom; or

(c) does any act which is inconsistent with any provision of an approved management plan applying to a water source protection zone,

commits an offence and shall upon conviction be liable to a fine not exceeding $20,000 or to imprisonment for a term not exceeding 7 years, or both, if the offence is committed by an individual person or group of persons, or fine not exceeding $50,000 if the offence is committed by a company or a corporate body.

(2) If a director of any company which commits an offence under sections 9, 17 or this section, is found to have knowingly authorised the commission of that offence, then he, as well as the company, shall be guilty of the offence.

19 Regulations

(1) The Minister may, with the consent of Cabinet, make regulations for the effective implementation of this Act and the protection, conservation and proper management of the water resource.

(2) Without limiting the generality of sub-section (1), regulations may be made which -

(a) provide for additional functions and powers of the National Water Resources Committee;

(b) facilitate the exercise of any power of the Minister under this Act;

(c) impose fees relating to the taking of water including –

(i) application fees;

(ii) licence fees;

(iii) extraction fees based on the duration of the licence or the quantity of water taken; and

(iv) special fees and levies to address salinity and other adverse environmental effects; and

(d) provide transitional arrangements to ensure continuity of water supply.

(3) The regulations made under this section may prescribe offences and impose penalties being fines not exceeding $2,000 or imprisonment for a period not exceeding 1 year, or both.

Passed by the Legislative Assembly on this day of 2016.

Explanatory Notes

(This note does not form part of the Bill and is intended only to explain its purpose and effect)

This Act makes comprehensive provision in relation to the ownership, management and regulation of water resource of the Kingdom of Tonga.

Section 1 This section sets out the short title of the Act.

Section 2 This provides for definitions of certain words and terms used in the Act.

Section 3 This section provides that the Act shall bind the Crown.

Section 4 The water resource of the Kingdom of Tonga is vested in the Crown. Individuals may claim ownership of water that has been legally taken and stored by them.

Section 5 Management of the water resource is a responsibility of the Ministry of Lands and Natural Resources. The Ministry may grant rights to take and use water from aquifers, lakes, streams and springs.

Section 6 The Water Board and other water supply agencies have a right to take water for their functions. They must comply with restrictions and requirements imposed under this Act.

Section 7 The objectives of sound water resource management are stated and must be observed by the Ministry.

Section 8 A wide range of powers are given to the Minister of Lands and Natural Resources to manage, protect and conserve the water resource. The powers cover the following matters –

- Approvals for the taking of water
- Determination of competing claims to the water resource
- Placing restrictions on taking and using water
- Setting standards applying to the taking of water
- Declaring water source protection zones and providing for their management
- Regulating and controlling the use of water and activities which affect the quantity and quality of water
- Ordering that activities which adversely affect the water resource cease.

These powers may be exercised by Determinations, Orders or the making of Regulations.

Section 9	Breaching any requirement imposed by the Minister is an offence. Fines of up to $5,000 apply to individuals and $10,000 to companies. Terms of imprisonment for up to 3 years can be imposed.
Section 10	A National Water Resources Committee comprising representatives of the key government agencies is to be established as part of the Ministry of Lands and Natural Resources.
Section 11	The functions of the National Water Resource Committee to promote the effective management of the water resource are stated.
Section 12	The Tonga Water Management Plan must address a wide range of management issues and practices applying to the water resource.
Section 13	The provisions of the Tonga Water Management Plan must be considered and applied in all processes involving the assessment of environmental impacts (EIA) and urban and rural planning.
Section 14	Persons who drill for water, use boreholes or who take water must have a licence under this Act. Provision is made in relation to applications for licences. Applications must be considered by the Principal Hydrogeologist and may be granted if the proposed water taking activities are in accordance with the Tonga Water Resources Plan. Licences to take water must state the quantity of water that may be extracted and the rate at which it can be extracted.
Section 15	Persons who are aggrieved by decisions concerning licence applications may request a review of the decision by providing additional information.
Section 16	Environmental and health standards applying to the water resource may be imposed by the Ministry and the Ministry of Health.
Section 17	Offences for breaching the licensing provisions of this Act are imposed.
Section 18	General offences are provided for.
Section 19	A general power to make regulations is provided for, and some specific regulations are identified.

Lord Ma'afu

Minister for Lands and Natural Resources