



# Development of smart water management system using climate information in response to shortage of water in the Kingdom of Tonga

19 October, 2018

Sunkwon Yoon, Ph.D.

- **Water Resources in PIC**
- **Tonga Project Overview**
- **Climate Change and Water**
- **Project Main Outputs**
  - Real-Time GW Monitoring System
  - Tongatapu GW Modeling System
  - Tonga GW Information System (ToGWIS)
- **Conclusion**



# Overview

# I Water Resources in PIC





# Background



- ❑ The Pacific Island Countries (PIC) face diverse and difficult water challenges
- ❑ For example, the supply and demand of water resource in PIC is regionally biased and the quantity and quality of it are at high risk due to the pollution and depletion of surface water as well as seawater intrusion
- ❑ These facts affect PIC, putting it in a very vulnerable status in obtaining sustainable water resources
- ❑ By developing climate-smart groundwater information system for water resources, PIC community members and decision makers will be better understanding and implementation for sustainable water use and management

# Physical characteristics of Pacific Island Countries

Country	Total land area (km <sup>2</sup> )	Number of islands or atolls	Island type according to geology	Highest elevation (m)
Cook Is	240	15	Volcanic, limestone, atolls, mixed	650
FSM	700	607	Volcanic, atolls, mixed	790
Fiji	18,300	322	Volcanic, limestone, atolls, mixed	1,320
Kiribati	810	33	Atolls & reef islands, limestone island	87
Nauru	21	1	Limestone (raised atoll)	71
Niue	260	1	Limestone (raised atoll)	68
Palau	440	Approx. 250	Volcanic, some with limestone	210
PNG	460,000	Approx. 600	Volcanic, limestone, atolls, reef islands, mixed	4,500
RMI	180	34	Atolls & reef islands	10
Samoa	2,800	10	Volcanic	1,850
Solomon Is	30,400	922	Volcanic, limestone, atolls & reef islands	2,330
Tonga	650	176	Volcanic, limestone, reef islands, mixed	1,030
Tuvalu	26	9	Atolls	5
Vanuatu	12,300	82	Volcanic with coastal sands and limestone	1,880

FSM = Federated States of Micronesia, PNG = Papua New Guinea, RMI = Republic of Marshall Islands

# Population summary for 14 Pacific Island Countries

Country	Population estimates in mid-2010	Average population density (people/km <sup>2</sup> )	Population growth rate (%)	Urban population (%)	Rural population (%)
Cook Is	15,700	66	0.3	72	28
FSM	111,000	158	0.4	22	78
Fiji	848,000	46	0.5	51	49
Kiribati	101,000	125	1.8	44	56
Nauru	9,980	475	2.1	100	0
Niue	1,480	6	-2.3	36	64
Palau	20,500	46	0.6	77	23
PNG	6,740,000	15	2.1	13	87
RMI	54,400	301	0.7	65	35
Samoa	183,000	66	0.3	21	79
Solomon Is	550,000	18	2.7	20	80
Tonga	103,000	158	0.3	23	77
Tuvalu	11,100	427	0.5	47	53
Vanuatu	245,000	20	2.6	24	76

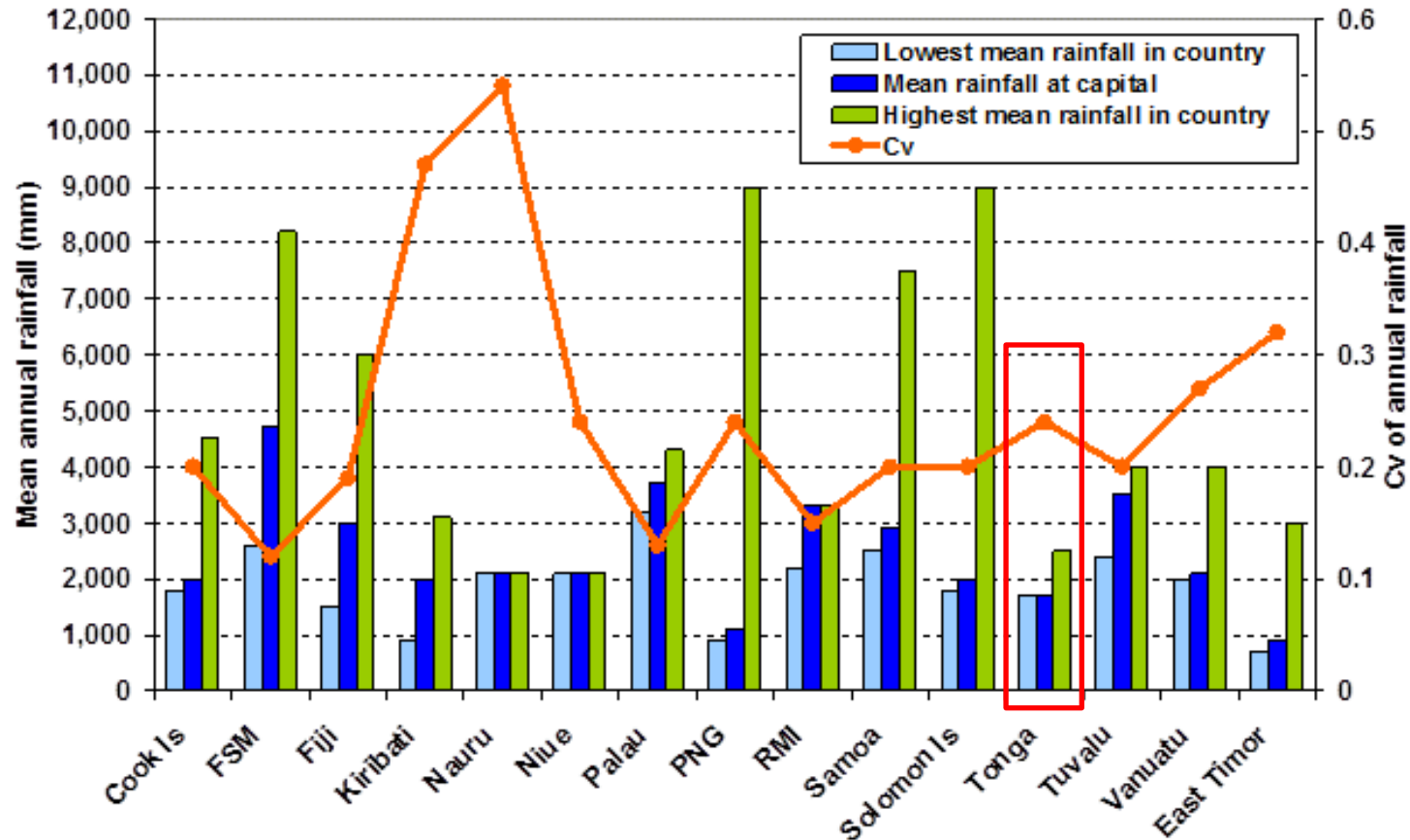
FSM = Federated States of Micronesia, PNG = Papua New Guinea, RMI = Republic of Marshall Islands

# Rainfall summary for Pacific Island Countries

Country	Mean annual rainfall (mm) at capital	Coefficient of variation (Cv) of annual rainfall at capital	Range of mean annual rainfall in country (mm)
Cook Is	2,000	0.20	1,800 – 4,500
FSM	4,700	0.12	2,600 – 8,200
Fiji	3,000	0.19	1,500 – 5,000
Kiribati	2,000	0.47	900 – 3,100
Nauru	2,100	0.54	2,100
Niue	2,100	0.24	2,100
Palau	3,700	0.13	3,200 – 4,300
PNG	1,100	0.24	900 – 9,000
RMI	3,300	0.15	2,200 – 3,300
Samoa	2,900	0.20	2,500 – 7,500
Solomon Is	2,000	0.20	1,800 – 9,000
Tonga	1,700	0.24	1,700 – 2,500
Tuvalu	3,500	0.20	2,400 – 4,000
Vanuatu	2,100	0.27	2,000 – 4,000

FSM = Federated States of Micronesia, PNG = Papua New Guinea, RMI = Republic of Marshall Islands  
Coefficient of variation (CV) = standard deviation / mean

# Rainfall summary for Pacific Island Countries



FSM = Federated States of Micronesia, PNG = Papua New Guinea, RMI = Republic of Marshall Islands  
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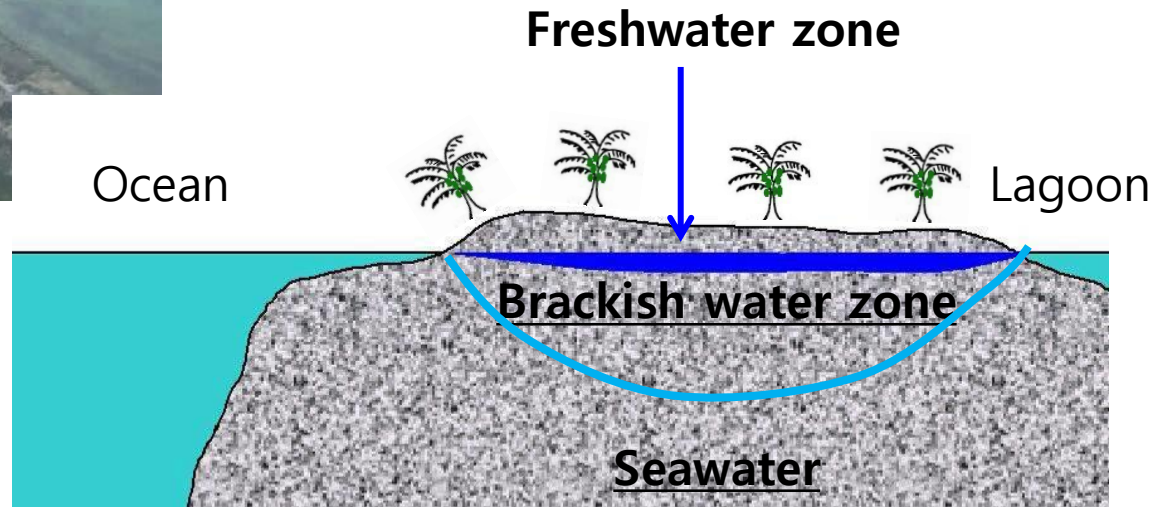
# Summary of main freshwater resources in Pacific Island Countries

Country	Main freshwater resources
Cook Is	SW, GW, RW
FSM	SW, GW, RW
Fiji	SW, GW, RW, D (tourist resort only)
Kiribati	GW, RW
Nauru	D (regular use), RW, GW (limited)
Niue	GW, RW
Palau	SW, GW, RW
PNG	SW, GW, RW
RMI	RW, GW (limited), D (regular & emergency)
Samoa	SW, GW, RW
Solomon Is	SW, GW, RW
Tonga	GW, RW, SW (limited)
Tuvalu	RW (primary), GW (limited), D (emergency)
Vanuatu	SW, GW, RW
<p>SW = surface water, GW = groundwater, RW = rainwater, D = desalination</p>	

# Atoll Groundwater

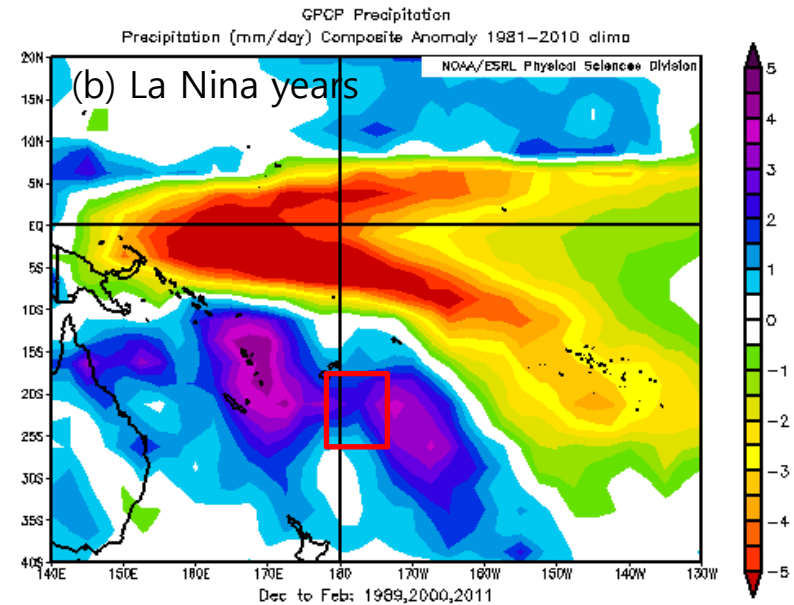
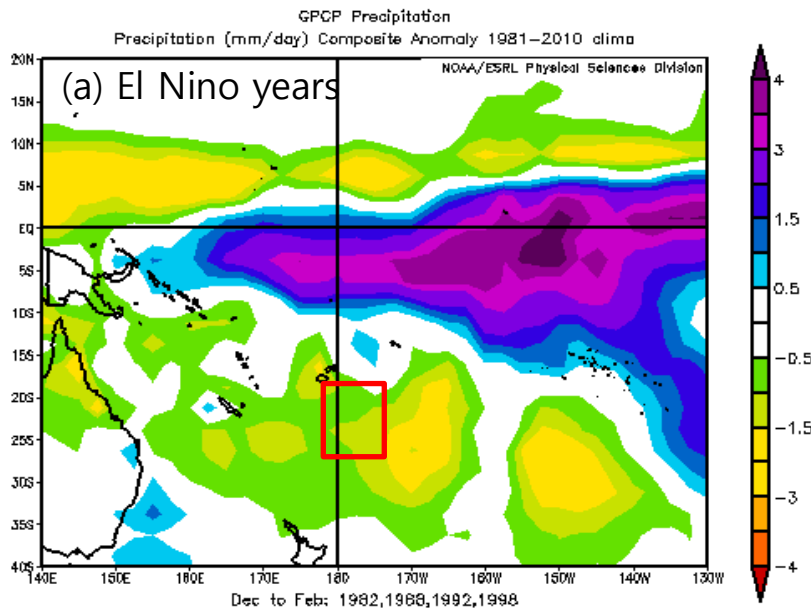


Freshwater lens drawing at more realistic scale



## ➤ ENSO teleconnection

## GPCP Precipitation



**Wetter and Drier regions associated with El Niño and La Niña episodes**

## Common, naturally occurring

- *GROUNDWATER*
- *RAINWATER*
- *SURFACE WATER*

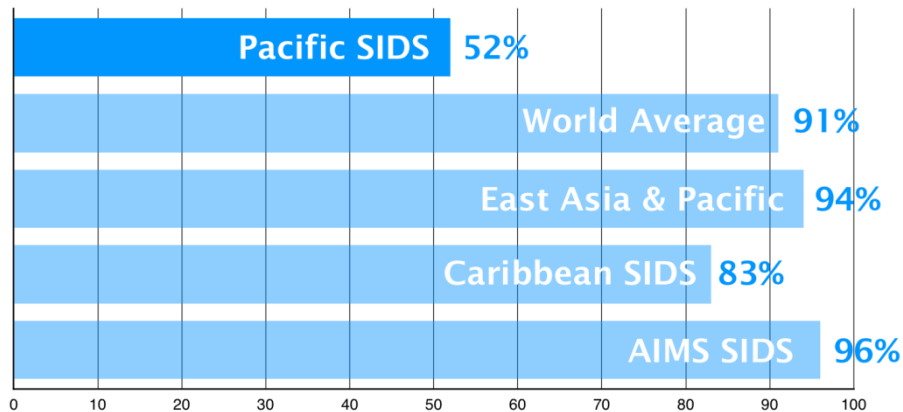
## Less common or more expensive

- *DESALINATION*
- *IMPORTATION*
- *USE of SEAWATER or BRACKISH WATER*
- *WASTEWATER REUSE*

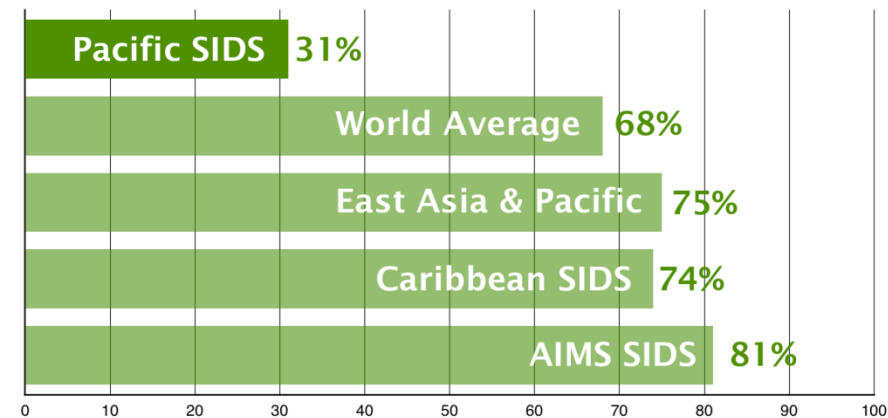


# % of Population with improved water sources and sanitation facilities in 2013

## ➤ Water sources



## ➤ Sanitation facilities



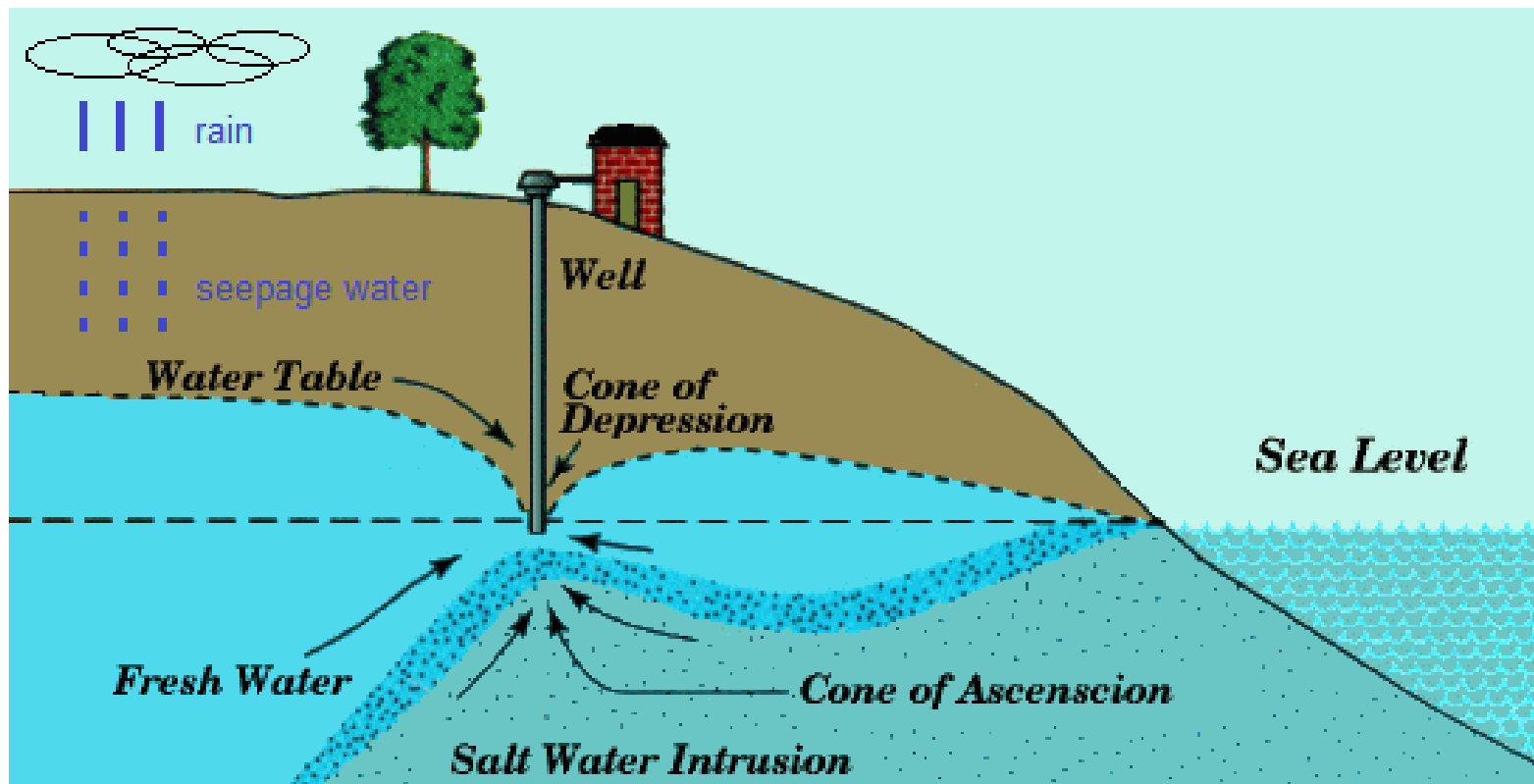
Source: WHO & UNICEF Joint Monitoring Programme

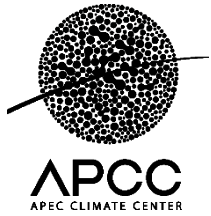
Notes: SIDS = Small Islands Developing States

AIMS = Africa, Indian Ocean, Mediterranean & South China Seas

# Scheme with saltwater and groundwater

Scheme with saltwater and groundwater with a well near the coastline, sea saltwater will reach the tube of the well soon





# Water security in Pacific Island Countries



- **Crowded urban and peri-urban areas**  
*(often lack adequate water supply and need to use polluted sources)*
- **Remote islands**  
*(at risk during droughts or after cyclones if local water resources are depleted or damaged (e.g. rainwater tanks) or become saline (groundwater) and require importation of water)*
- **Remote parts of larger islands**  
*(at risk during droughts if water resources are depleted and food crops fail)*
- **Very low level parts of islands**  
*(at risk of overtopping & temporary salinisation of groundwater from waves caused by cyclones or tsunamis in addition to potential inundation from projected sea level rise)*

# II Tonga Project Overview

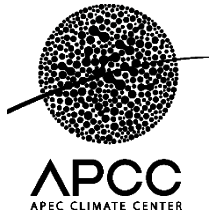




# Background



- ❑ The Kingdom of Tonga face diverse and difficult water challenges
- ❑ For example, the supply and demand of water resource in Tonga is regionally biased and the quantity and quality of it are at high risk due to the pollution and depletion of surface water as well as seawater intrusion
- ❑ These facts affect Tonga, putting it in a very vulnerable status in obtaining sustainable water resources
- ❑ By developing climate-smart groundwater information system for water resources, Tonga community members and decision makers will be better understanding and implementation for sustainable water use and management



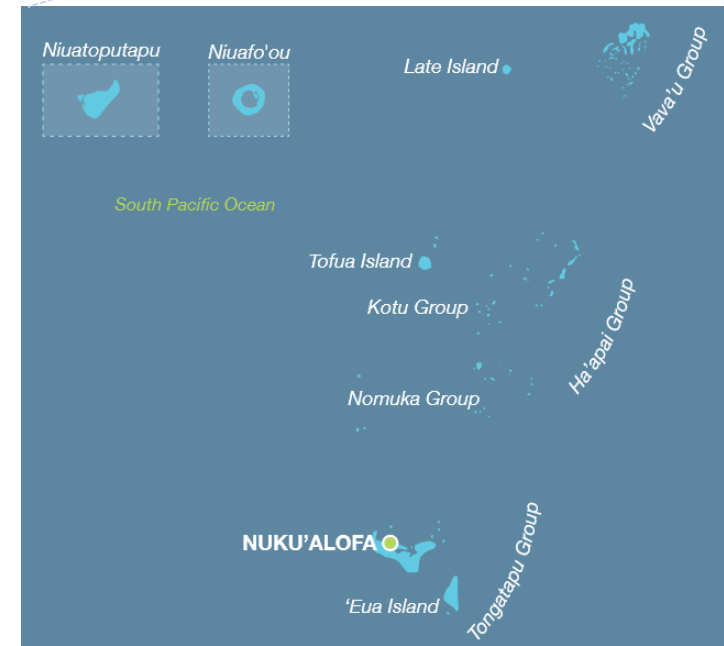
Background

# Water Project Overview



## ❖ Project Outline

- Title : Water Resources Forecasting and Risk Assessment in the Kingdom of Tonga
- Partner country : Kingdom of TONGA
- Period : 2016 ~ 2018
- Potential Participants : APCC, Dong-a Univ., Hydronet(Univ. of Seoul)



## ❖ Technical Road Map (TRM)

1<sup>st</sup> (2016-year)

Installing, GW Modeling, and Web GIS-based Monitoring System



2<sup>nd</sup> (2017-year)

Extending Web-based System and Developing GW Seasonal Forecasting System



3<sup>rd</sup> (2018-year)

Development of Smart Tonga Water Information System & Funding from KOICA



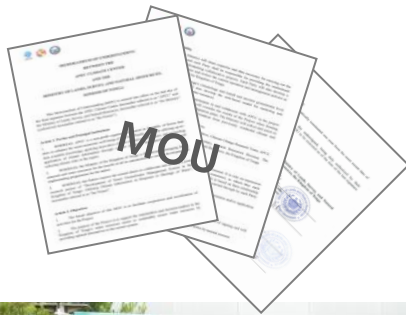
Background of Tonga Project

# History of Tonga Water Project and MOU



## 2016 ROK-Tonga Water Management Project

Development of smart groundwater management system in the Kingdom of Tonga



- Jun. '15: APCC-Tonga Delegation Meeting @ Busan
- Dec. '15: MOU Discussion and Field Survey – 1<sup>st</sup> Visit
- Feb. '16: Project MOU between APCC and Tonga
- Mar. '16: Start the Tonga Water Project
- Jul. '16: Installation of Sensors and Server – 2<sup>nd</sup> Visit
- Mar. '17: APCC-Tonga Joint Workshop and Agri-Water Project MOU @ TONGA – 3<sup>rd</sup> Visit
- Jul. '17: Installation of Sensors and Server – 4<sup>th</sup> Visit
- Jun. '18: Final Workshop @ Tonga -5<sup>th</sup> Visit

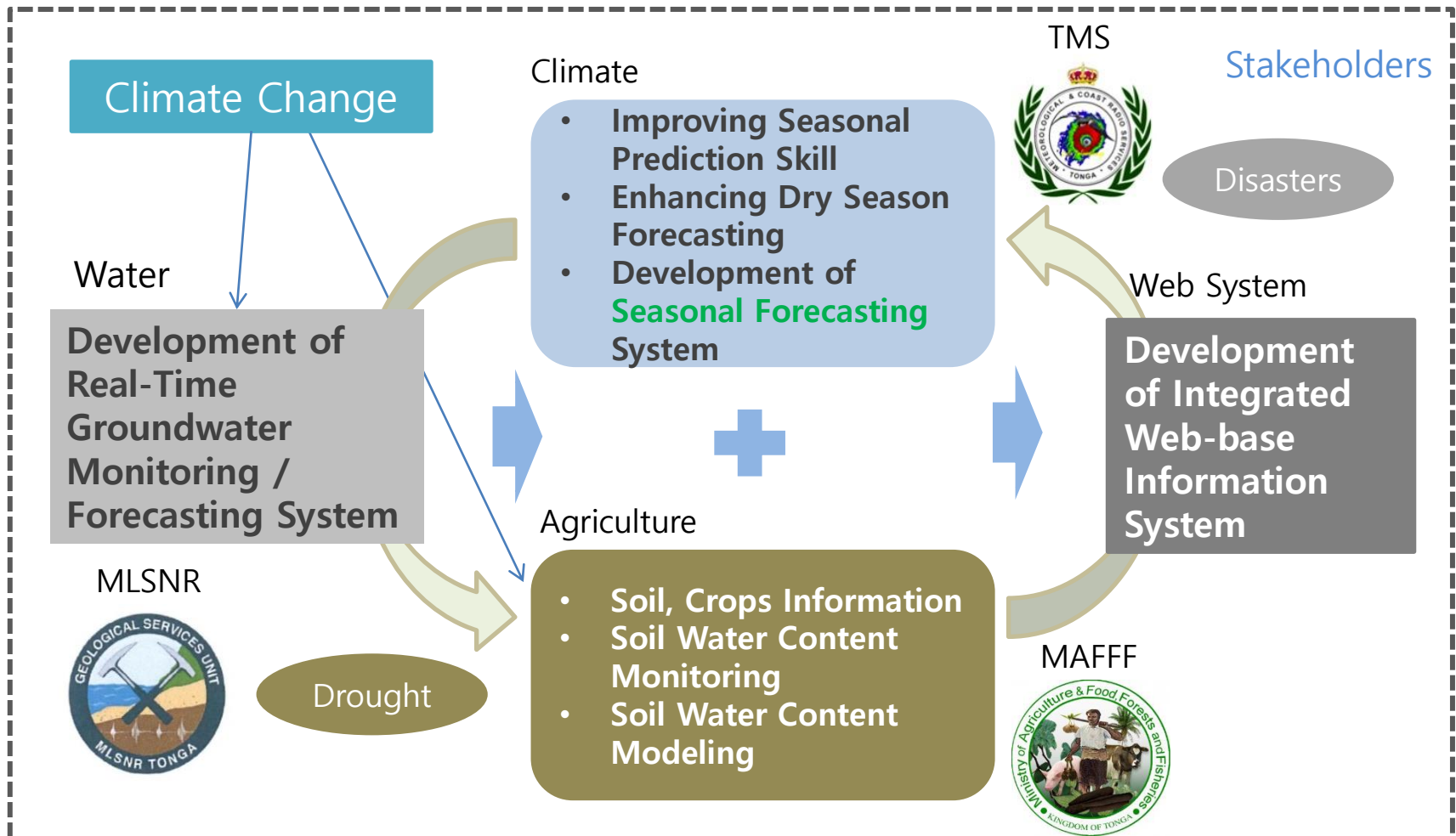


Delegation Meeting @ APCC



Tonga MLSNR office

## APCC-Tonga Agri-Water Project

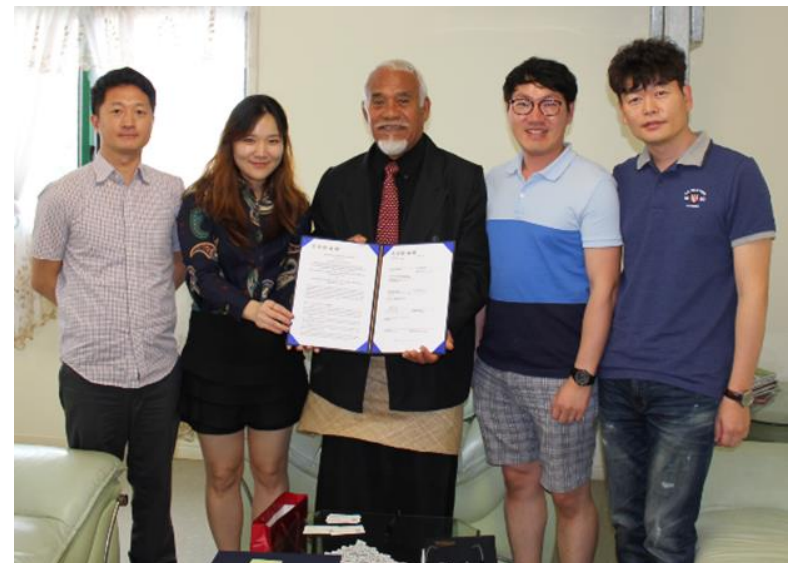


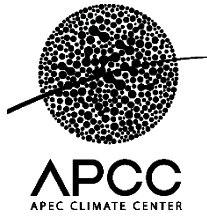
# Tonga Agri-Water Project MOU



Agro-Water Project MOU at TANOVA Hotel, Tonga

- MOU with APCC-MAFFF-MLSNR
- Periods: 2017~2018





Background of Tonga Project

# Tonga Agri-Water Project Joint Workshop



- ✓ Tonga Agro-Met Project (2014-2016): APCC-TMS-MAFF
- ✓ Tonga Groundwater Project (2016-2018): APCC-MLSNR
- ✓ Tonga Agri-Water Project (2017-2018): APCC-MAFF-MLSNR

# III Climate Change and Water

- Climate Change in Tonga
- Water Resources in Tonga
- ENSO and Drought in Tonga



# Status of Tonga and its Water Resources

Source: (<http://www.pacificwater.org/pages.cfm/country-information/tonga.html>)

## Tonga

Home > Country Information > [Tonga](#)



### Geography

Total Area	748 km <sup>2</sup>
Land	718 km <sup>2</sup>
Water	30 km <sup>2</sup>
Highest Elevation	1,033 m

### Land Use

Arable	20%
Perm. Crop	14.67%
Other	65.33% (2005)

### People

Population	116,921 (July 2007 est.)
Population Growth Rate	1.847% (July 2007 est.)

### Economy

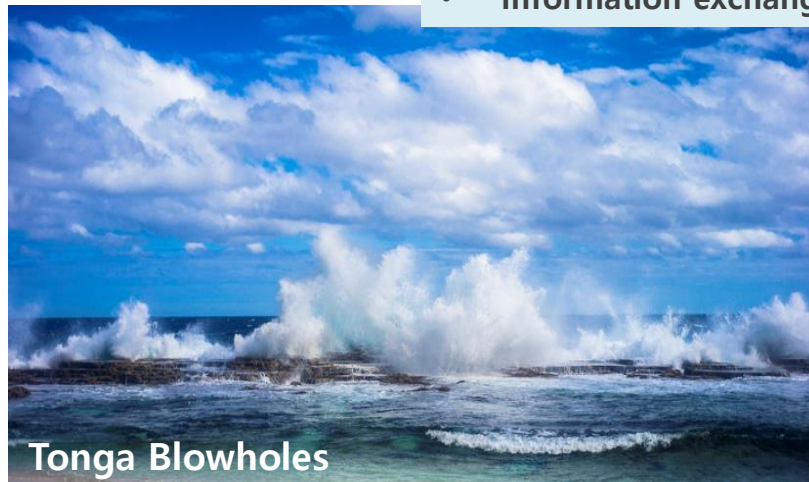
GDP per capita (PPP)	\$2,200 (2005 est.)
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### Water Statistics

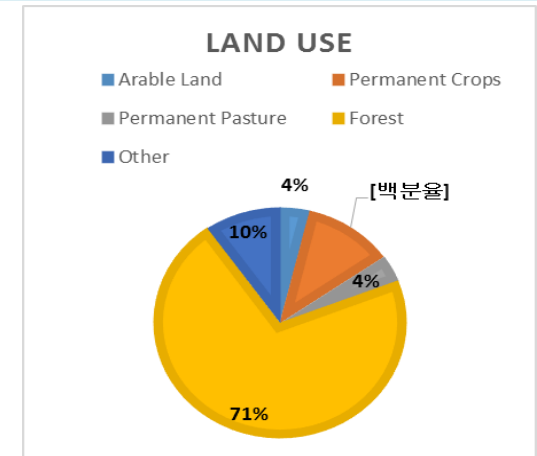
Avg Rainfall	Varies from north to south of Tonga with an estimated average of 2500 mm per annum
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## Problems with Water Resources

- Wastewater management and pollution control
- Information exchanges on water resources

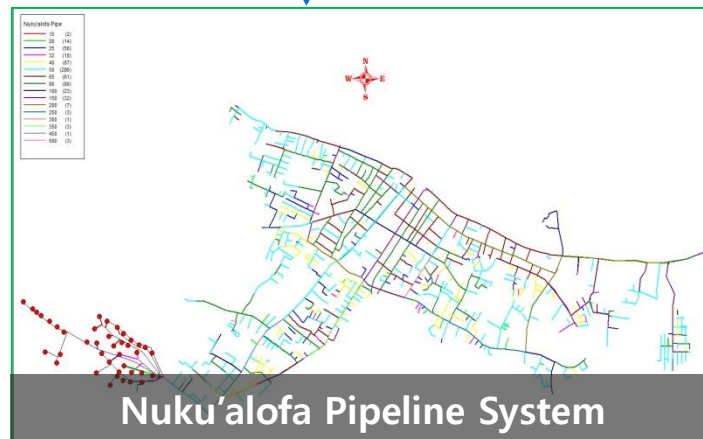
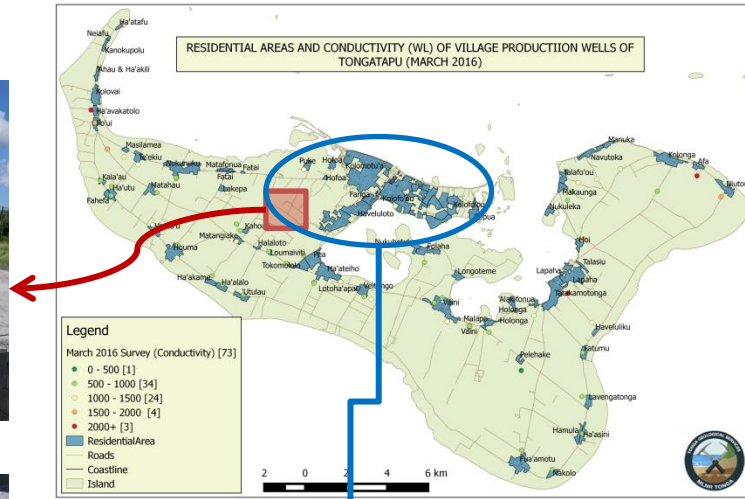


Tonga Blowholes



Source of Water	Drinking water coverage estimates					
	Urban (%)		Rural (%)		Total (%)	
	1990	2015	1990	2015	1990	2015
Piped onto premises	--	73	--	80	--	78
Other improved source	97	100	99	100	99	100
Other unimproved	3	0	1	0	1	0
Surface water	--	0	--	0	--	0

## Urban

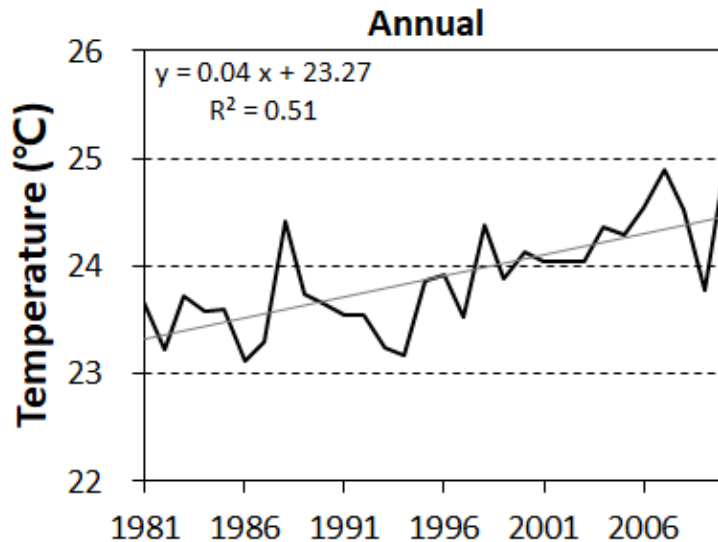


## Rural



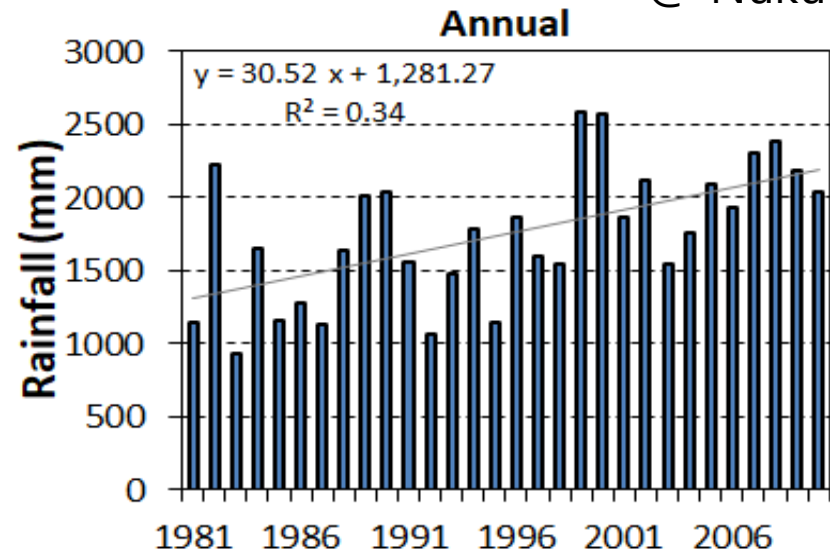
# Climate: Historical Observation Data

@ Nuku'alofa



- Annual Temperature: 23.9 °C
  - Max: Feb. 26.5 °C
  - Min.: Aug. 21.3 °C

Last 30-year: Temperature was increased about **1.2 °C**

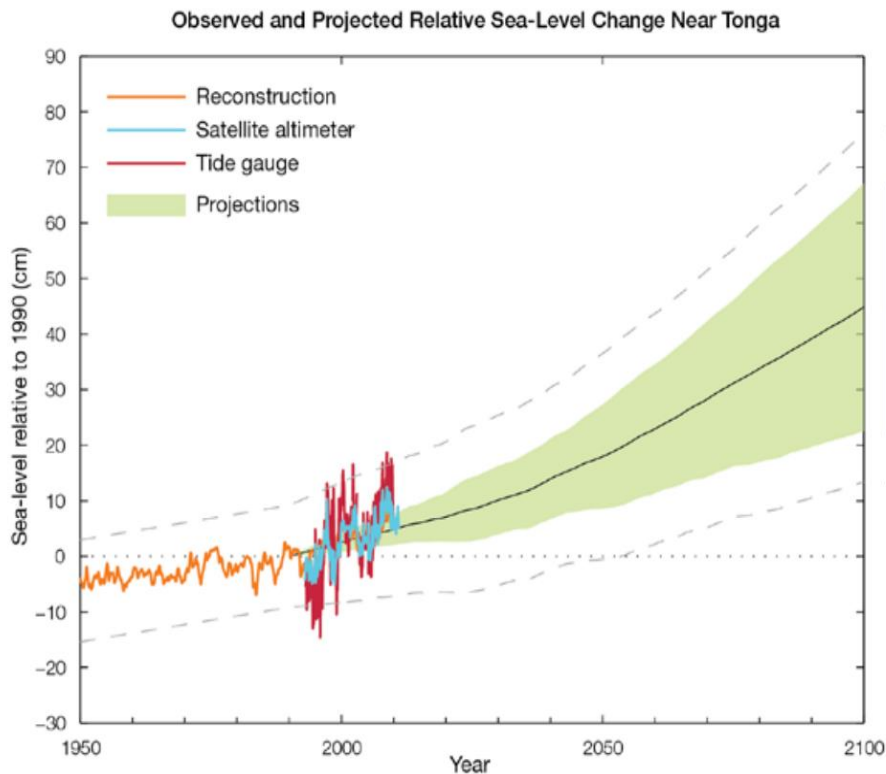


- Annual Precipitation: 1,754 mm
  - Wet Season: Nov. to Apr. 1,057 mm
  - Dry Season: May to Oct. 697 mm

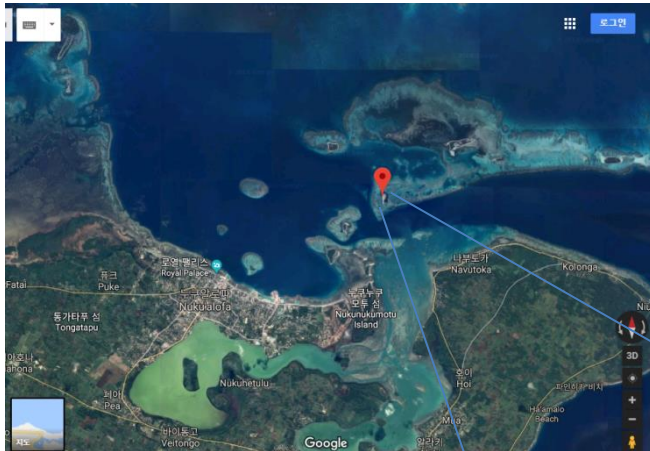
Last 30-year: Precipitation was increased about **900 mm**

## Observed and Projected relative sea level change

(PCCSP, 2014)



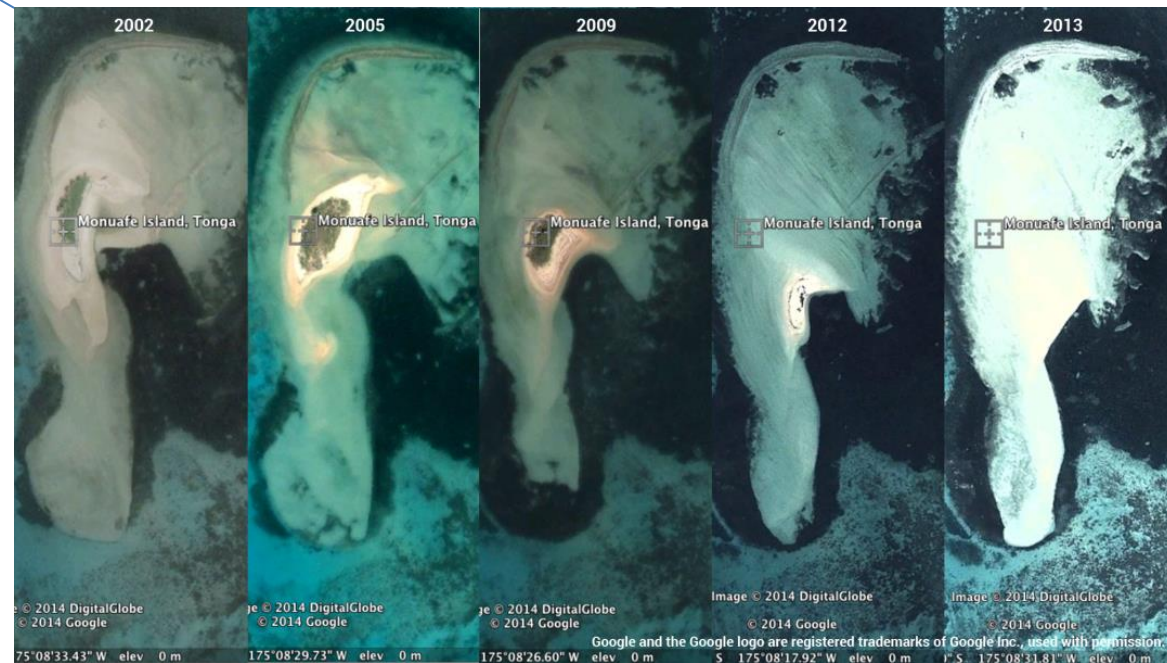
- Observation:  
Sea Level Change: **6.4 mm/year**  
(1993 to 2007)
- Climate Scenario Projection:  
2030-year: **5-15cm** increased  
2090-year: **20-60cm** increased



## Monuafe Island

25 years ago, Monuafe Island was a healthy island supporting diverse plants.

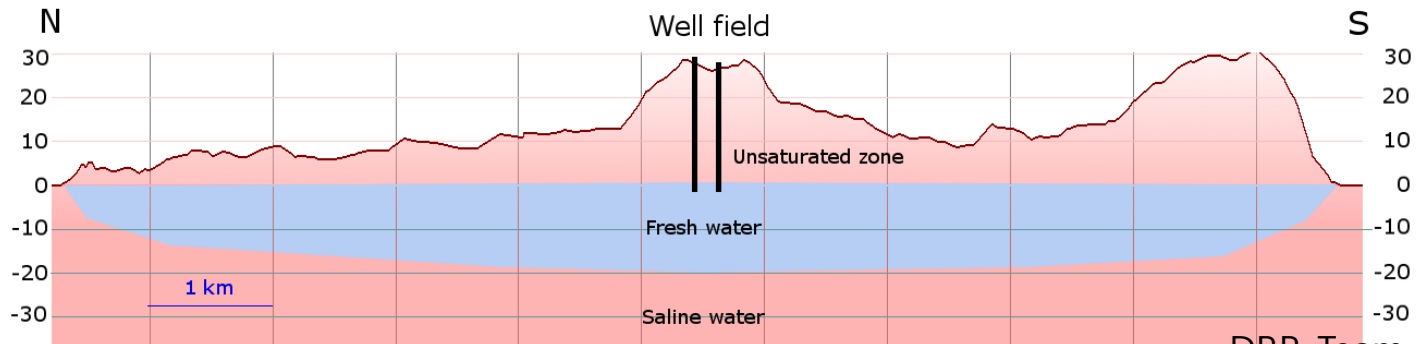
- 2012: Only a few plants are living in the Island
- 2014: Sea level rise and erosion progresses enough to show only sand at low tide





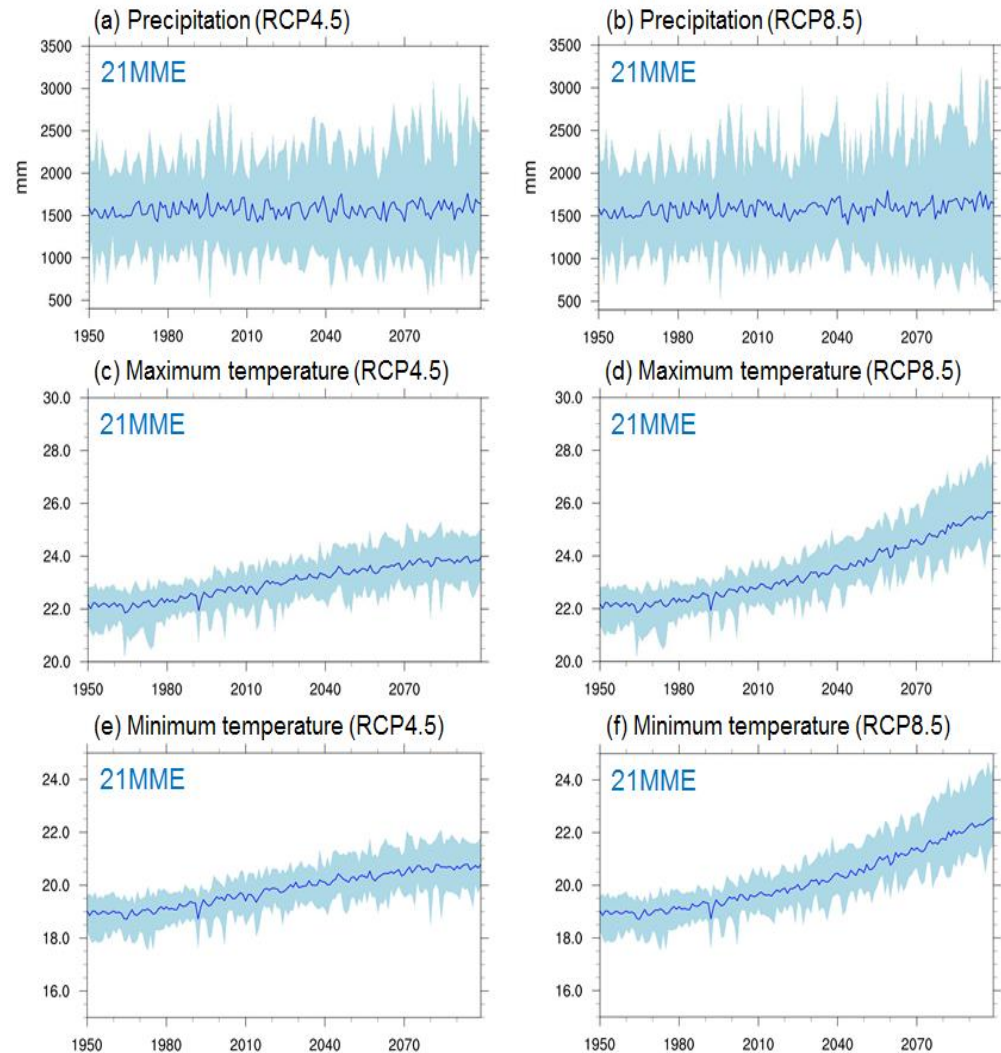


*Location of a North-South elevation profile through the Matakī'eua public water supply well field area*

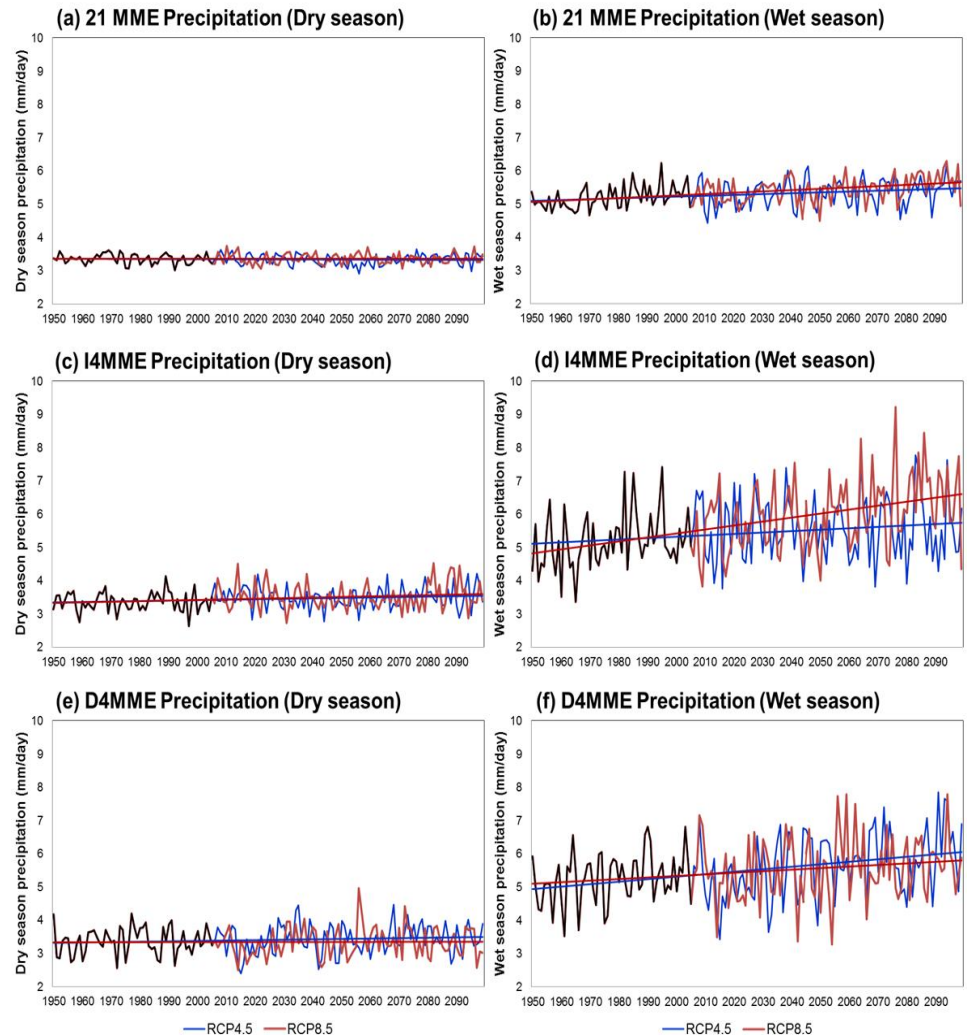


# Climate Change in Tongatapu

Time series of (a, b) precipitation, (c, d) maximum and (e, f) minimum temperature during historical and RCP 4.5 (left panels) and RCP 8.5 (right panels). Blue solid line is 21 MME(Multi-Model Ensemble) and shaded sky blue area is range from minimum to maximum among 21 models.

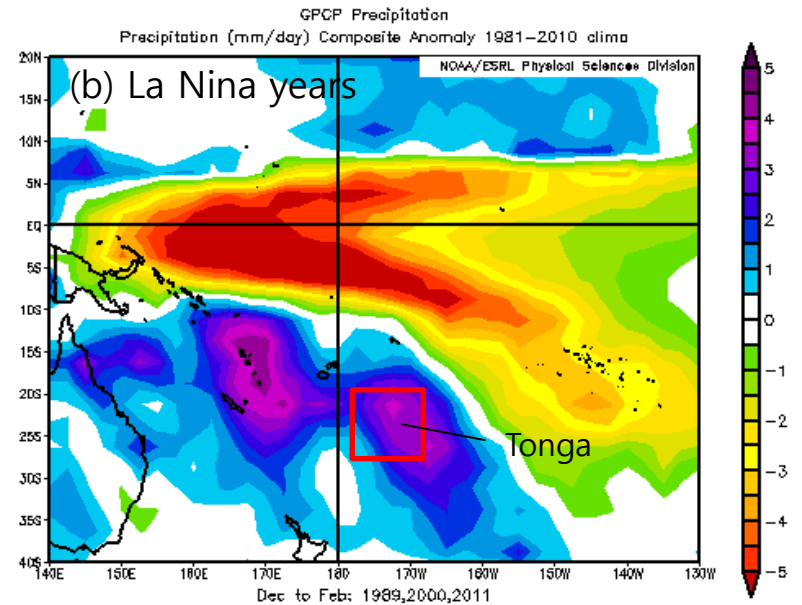
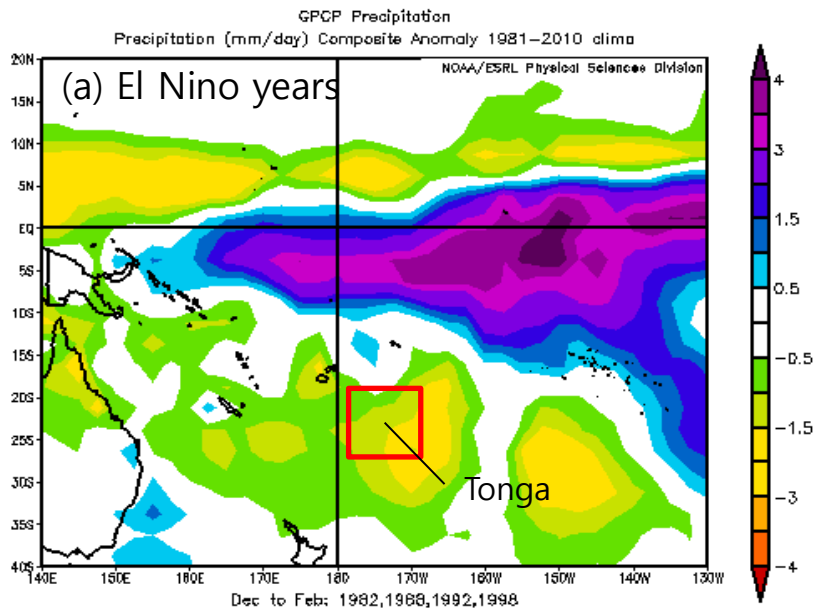


Time series of precipitation of historical and RCP scenarios averaged among (a),(b) 21MME, (c),(d) I4MME and (e),(f) D4MME, respectively. Black solid line is historical variation, blue and red lines are for RCP 4.5 and 8.5 scenario.



➤ ENSO teleconnection

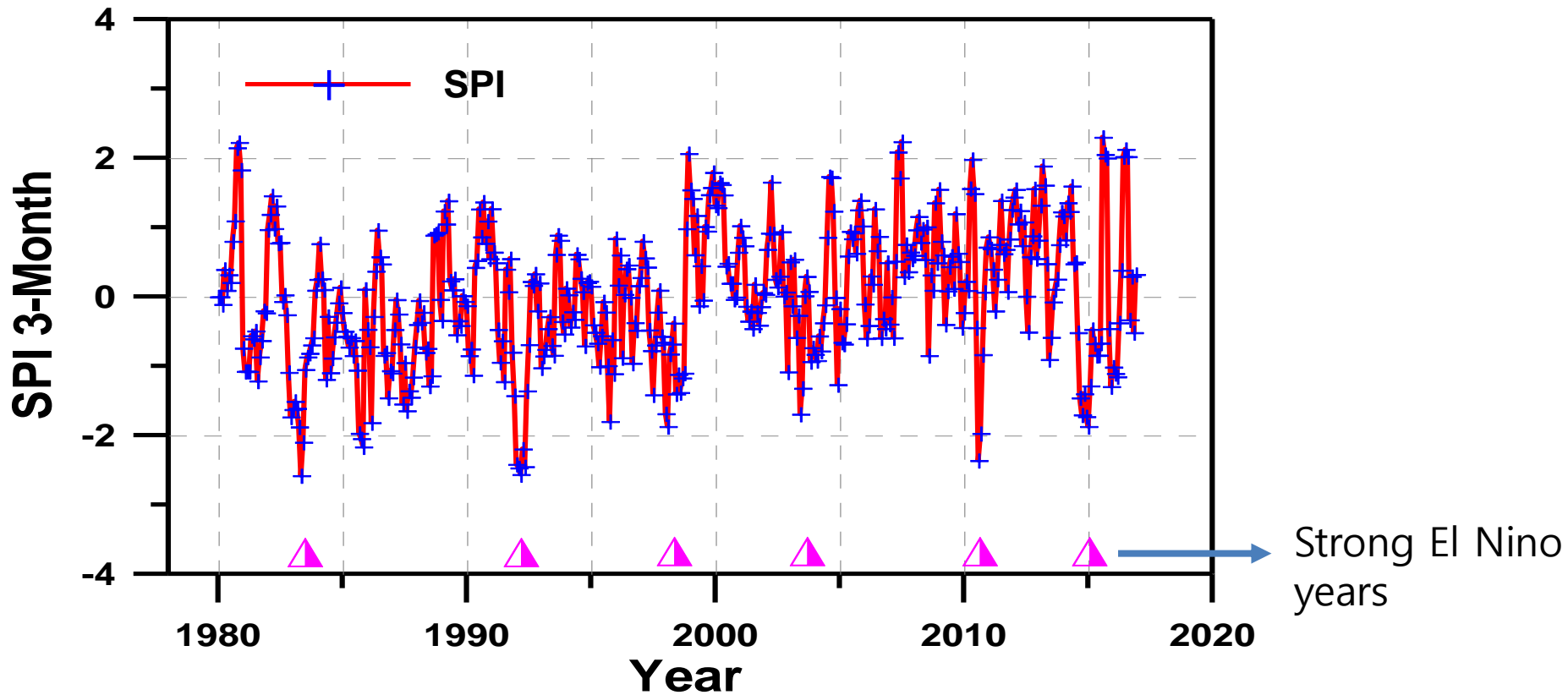
## Impacts of El Niño and La Niña Episodes on Rainfall



Wetter and Drier regions associated with El Niño and La Niña episodes

# SPI 3-month drought index and strong El Nino years

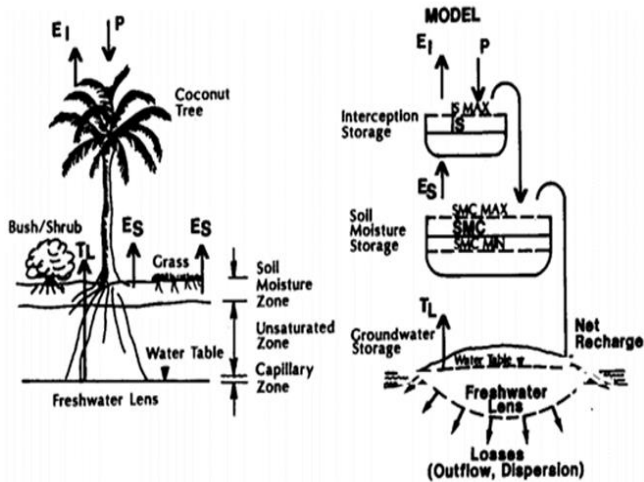
## Nuku'alofa (Station #3098), Tonga



# Groundwater Recharge Calculation using WATBAL model in Tongatapu

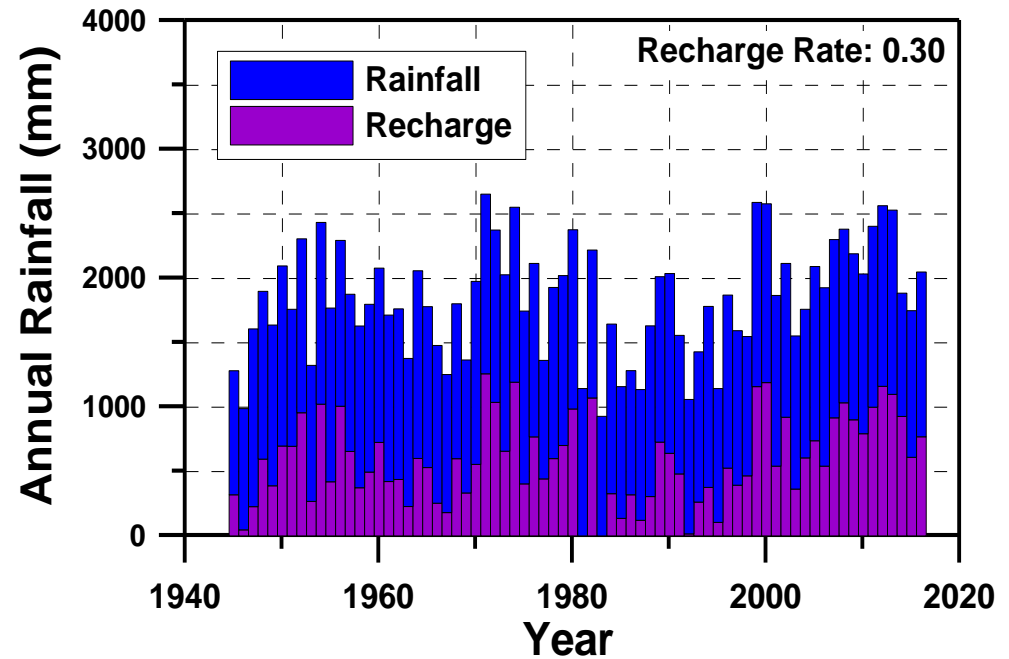
## ➤ WATBAL model

$$R = P - ET_a \pm \delta V$$



By Falkland and Woodroffe, 1997

## ➤ Groundwater Recharge

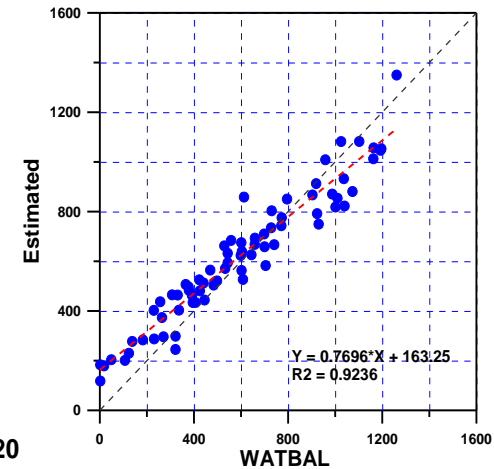
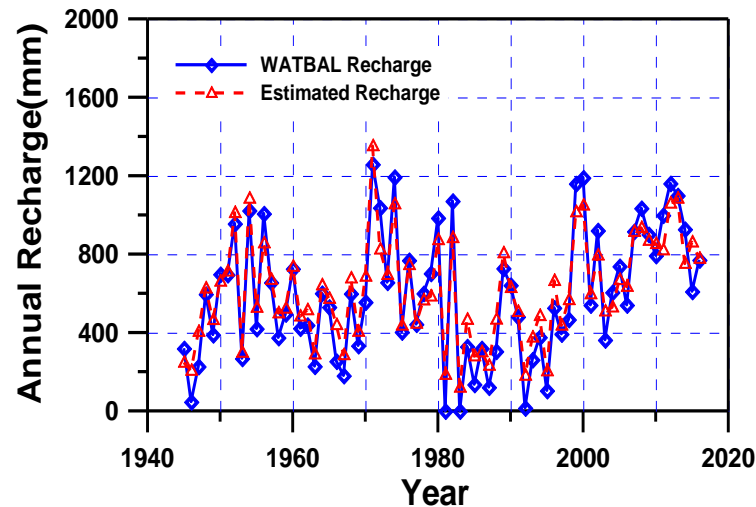
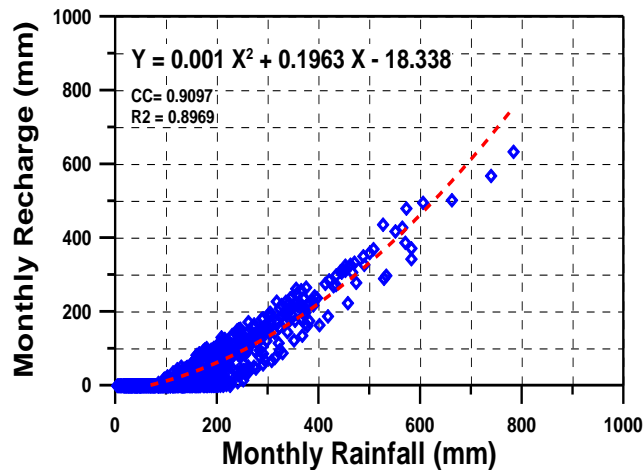


## ➤ Hamon(1963) Potential Evapotranspiration

$$PET = k \times 0.165 \times 216.7 \times N \times \left( \frac{e_s}{T + 273.3} \right), \quad e_s = 6.108e^{\left( \frac{17.27T}{T + 237.3} \right)}$$

# Annual rainfall and groundwater recharge model in Tongatapu

$$Y = 0.001X^2 + 0.1963X - 18.338 ; \quad (\text{if, } Y < 0, \text{ then } Y = 0)$$



# IV Project Main Outputs

- Tonga GW Monitoring System
- Tonga GW Flow Model
- Tonga GW Information System (ToGWIS)



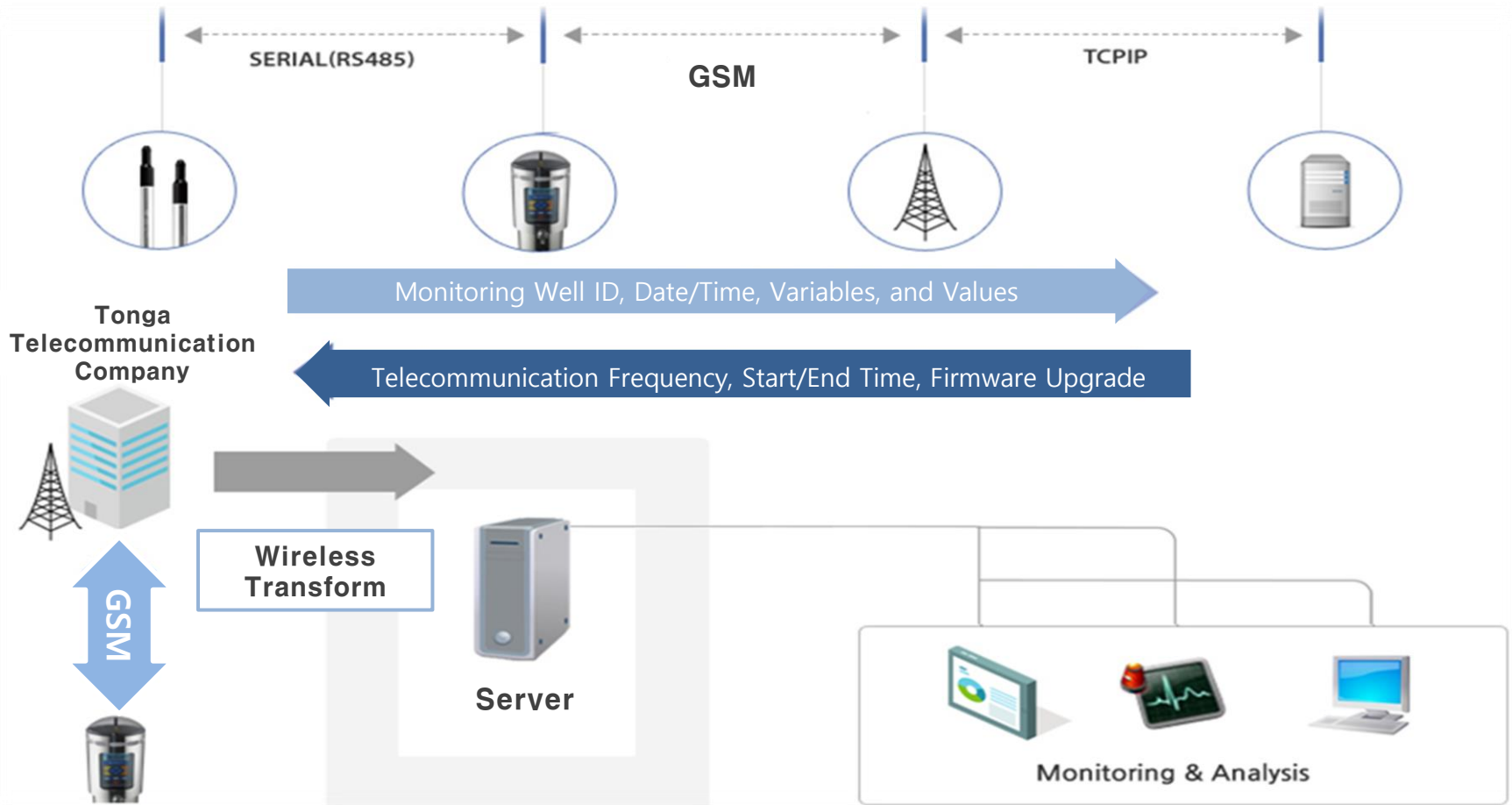


Tonga GW Monitoring System (ToGWMS)

# Real-Time Groundwater Monitoring System



## Wireless Telecommunication System for Real-Time Groundwater Monitor



## Sensor



Water Level (depth),  
Temperature, Electrical  
Conductivity (EC), Flash  
Memory (4Mbyte),  
Internal Lithium Battery

## Data Logger



High performance, Low  
Power Consumption, LCD  
Monitoring System, and  
Inner Battery (14.4V Lithium  
19Ah)

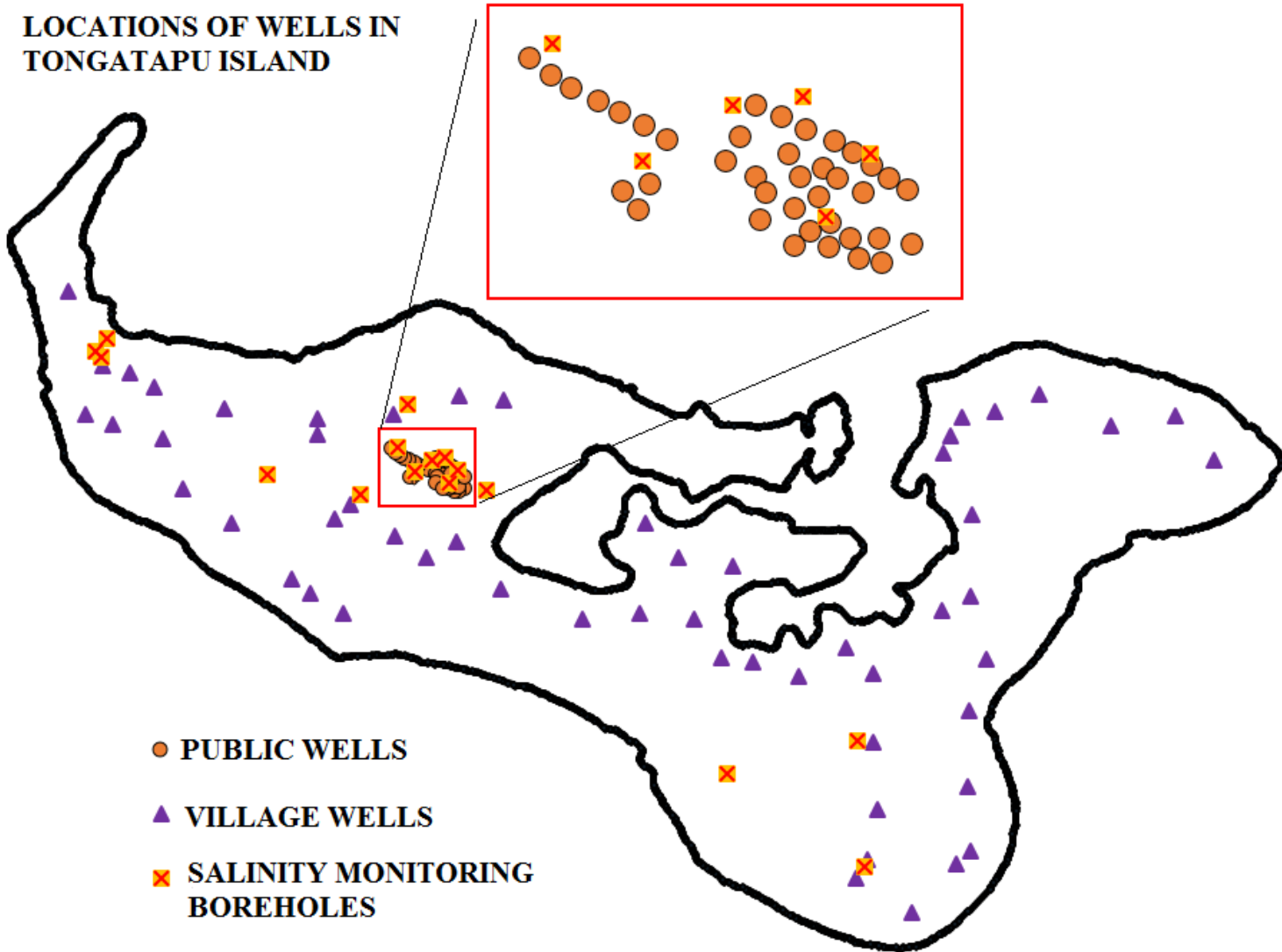
## STU-CAP



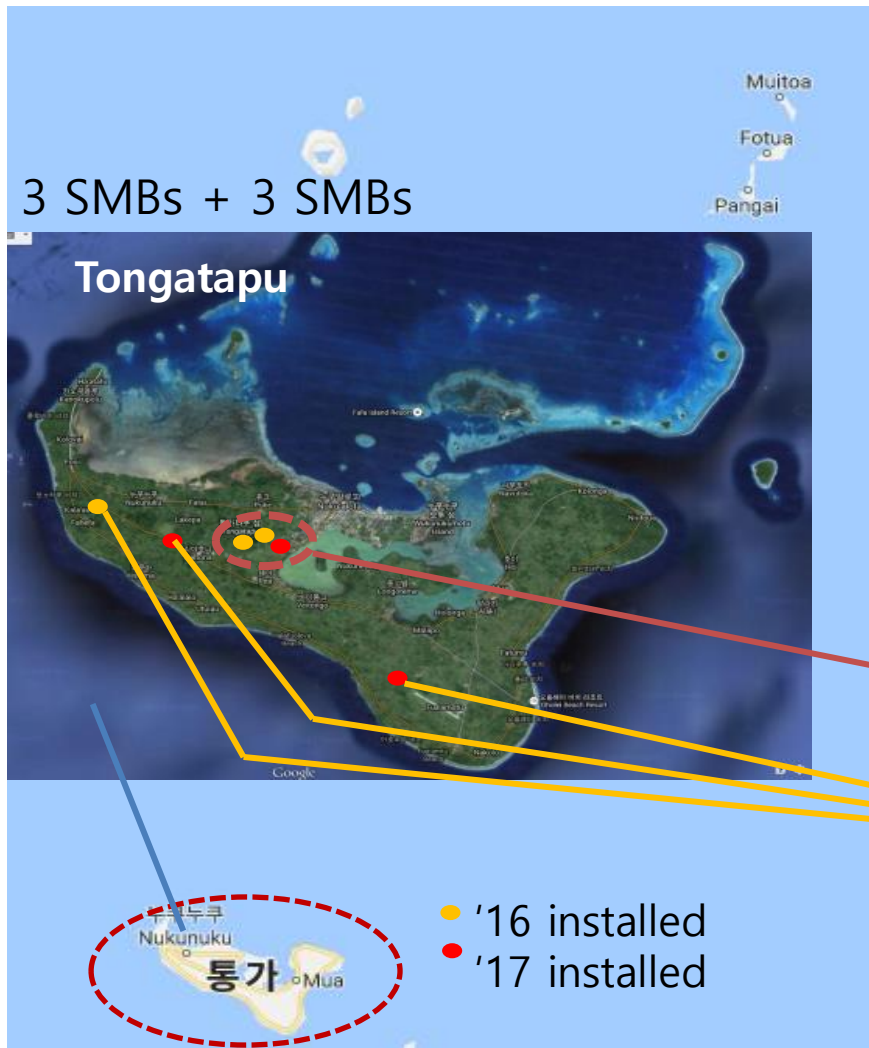
Solar Charging Device,  
Wireless Communication,  
Saving Space, and  
Comport Install and  
Maintain System

# Tongatapu Well Locations

LOCATIONS OF WELLS IN  
TONGATAPU ISLAND



# Locations of the data loggers and sensors



## TOTAL

- 6 SMBs
- 6 Data Loggers
- 9 Sensors

Multi-Sensors

Single Sensors



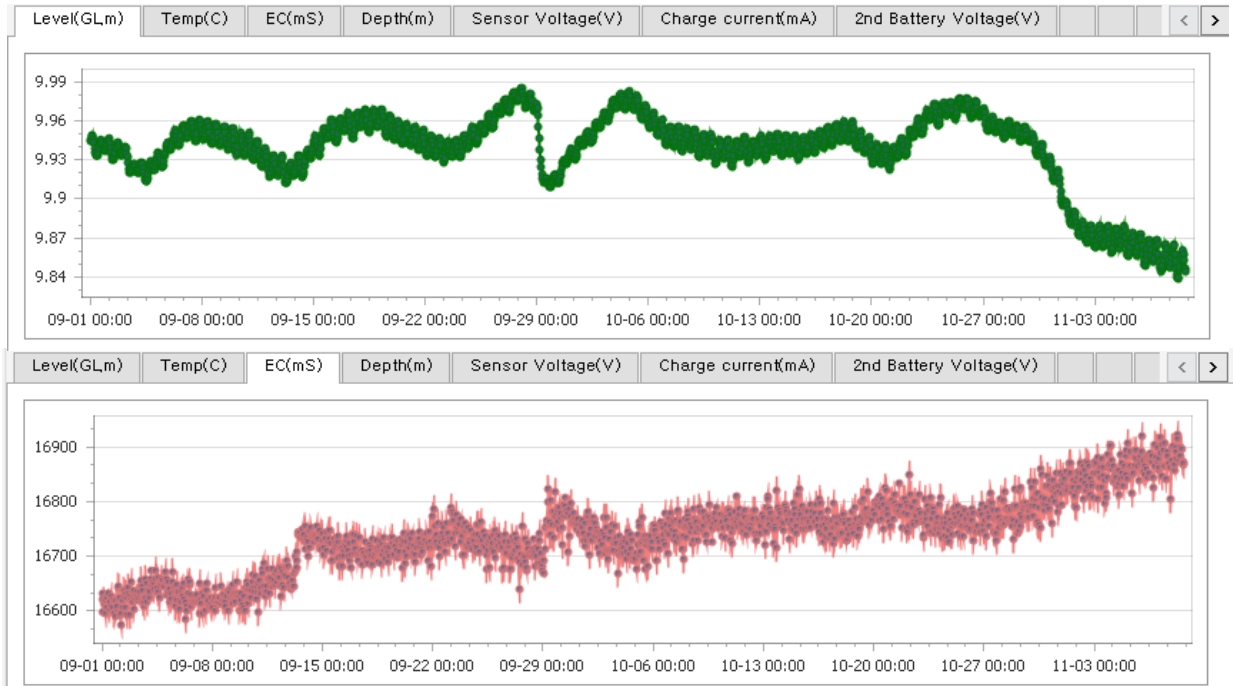


Tonga GW Monitoring System (ToGWMS)




# Real-Time Groundwater Monitoring System



Mataki 'Eua Well Field



The sensors and data Loggers are installed in 2016

SMBs	SMB 02	SMB 13	SMB 15
Address	Beside pump station 105, Mataki'eua	Next to pump station 313, Mataki'eua-Tongami	Middle of Hihifo well field
Lat./Long.	S: - 21.153897 W: - 175.241717	S: - 21.154274 W: - 175.253035	S: - 21.139717 W: - 175.316732
Photo			
Tube	No. 3 / N. 4	No. 3 / N. 4	No. 2
Cable Length (DSP)	<ul style="list-style-type: none"> <li>• Tube #3: 16.50m</li> <li>• Tube #4: 22.50m</li> </ul>	<ul style="list-style-type: none"> <li>• Tube #3: 30.00m</li> <li>• Tube #4: 26.82m</li> </ul>	<ul style="list-style-type: none"> <li>• Tube #2: 17.00m</li> </ul>
Tel.	+676-841-5229	+676-841-5231	+676-841-5230

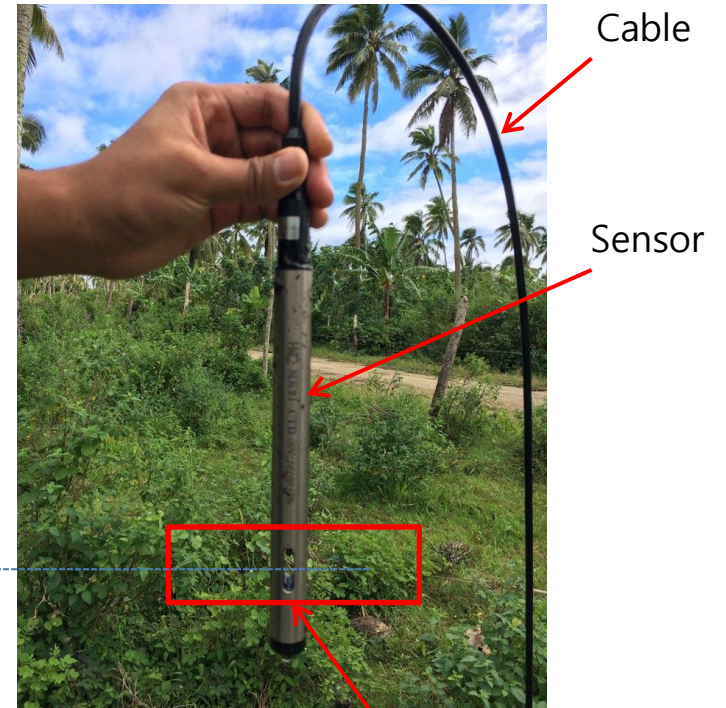
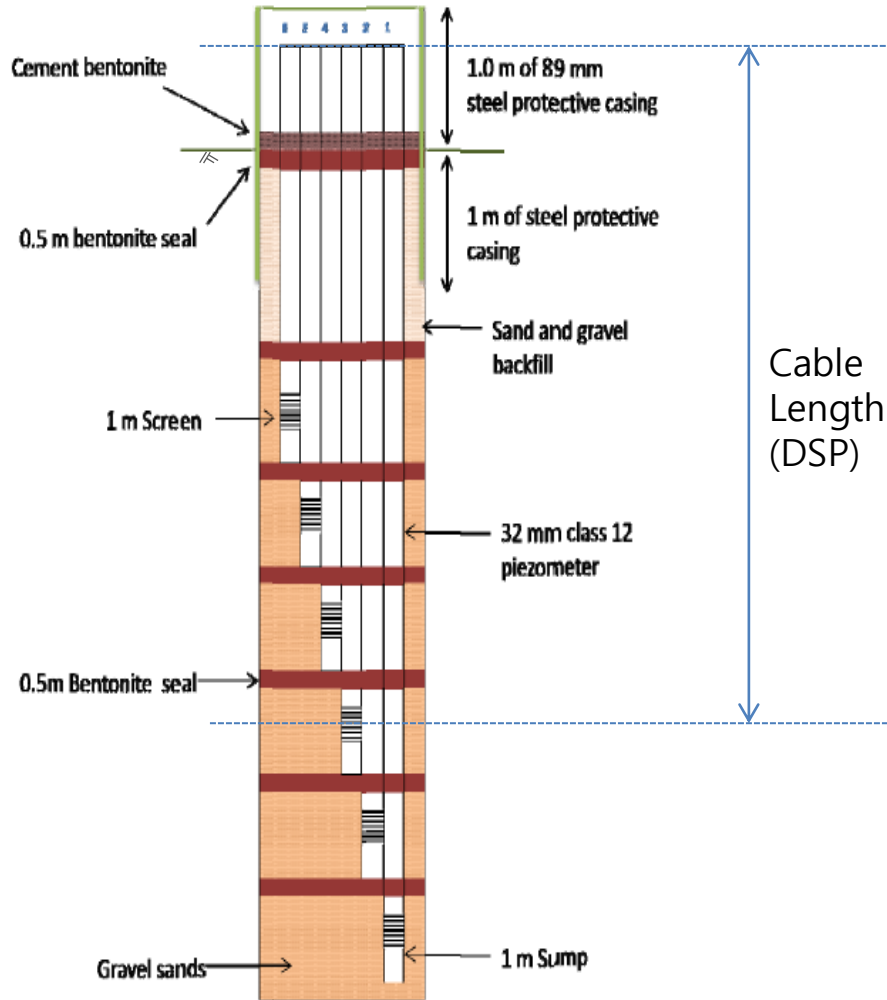
- The sensors are located in the middle of screen slot in each tube.
- The cable length indicates Depth of Sensing from the top edge of Piezometer (DSP).

The sensors and data Loggers are installed in 2017

SMBs	SMB 01	SMB 08	SMB 09
Address	South side of track between Matakī'eua and Fanga'uta Lagoon	Houma, Hala Vaea Road	Toloa-End of Airport Runway, Fua'amotu
Lat./Long.	S: - 21.158825 W: - 175.234643	S: - 21.154315 W: - 175.291506	S: - 21.229317 W: - 175.171285
Photo			
Tube	No. 2 / N. 3	No. 5	No. 4
Cable Length (DSP)	<ul style="list-style-type: none"> <li>• Tube #2: 19.79m</li> <li>• Tube #3: 14.70m</li> </ul>	<ul style="list-style-type: none"> <li>• Tube #5: 19.00m</li> </ul>	<ul style="list-style-type: none"> <li>• Tube #4: 38.00m</li> </ul>
Tel.	+676-884-8617	+676-884-8618	+676-884-8619

- The sensors are located in the middle of screen slot in each tube.
- The cable length indicates Depth of Sensing from the top edge of Piezometer (DSP).

# Schematic View of the Multi-Nested Piezometer Design (Not to scale)

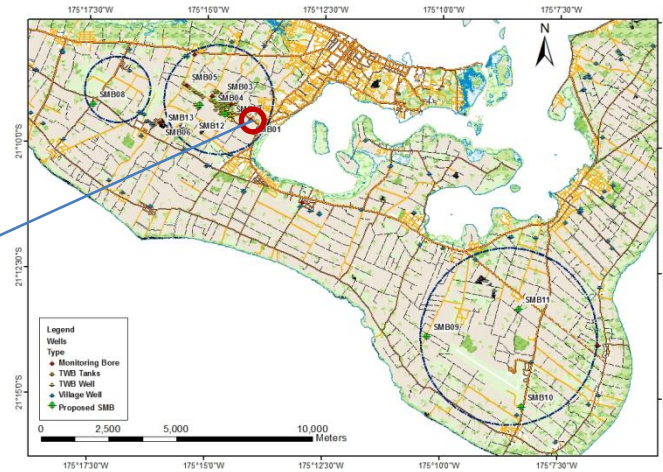


Location of sensing

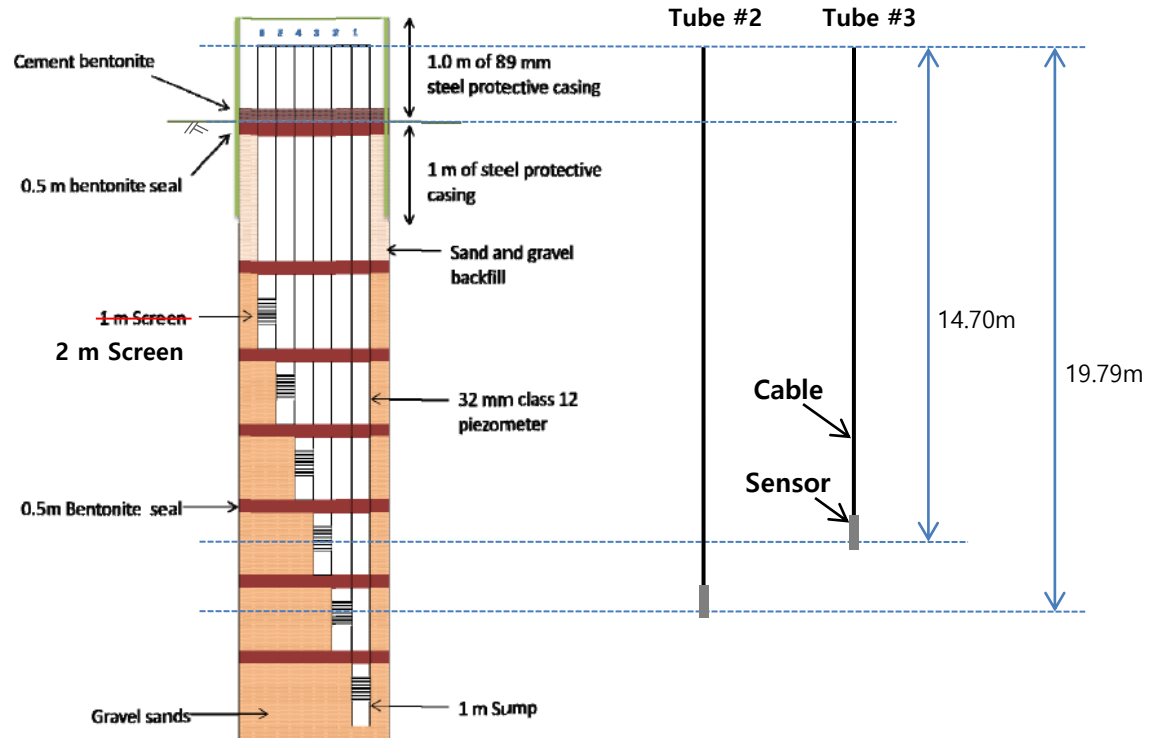
# SMB01

Multi-Sensor  
Tube #2, Tube #3

**Location:** South side of track between Matakī'eua and Fanga'uta Lagoon  
(S: - 21.158825 W: - 175.234643)



## Location of sensors

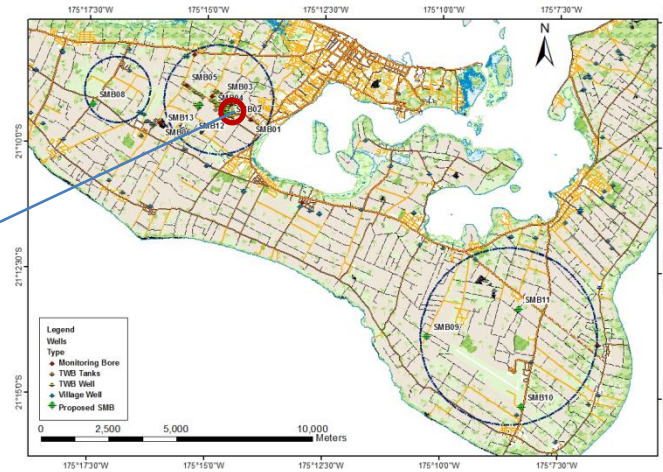


SMB01 to SMB07 and SMB14 to SMB16:  
Leave 1 meter sump at base of screen and slot 2 meters

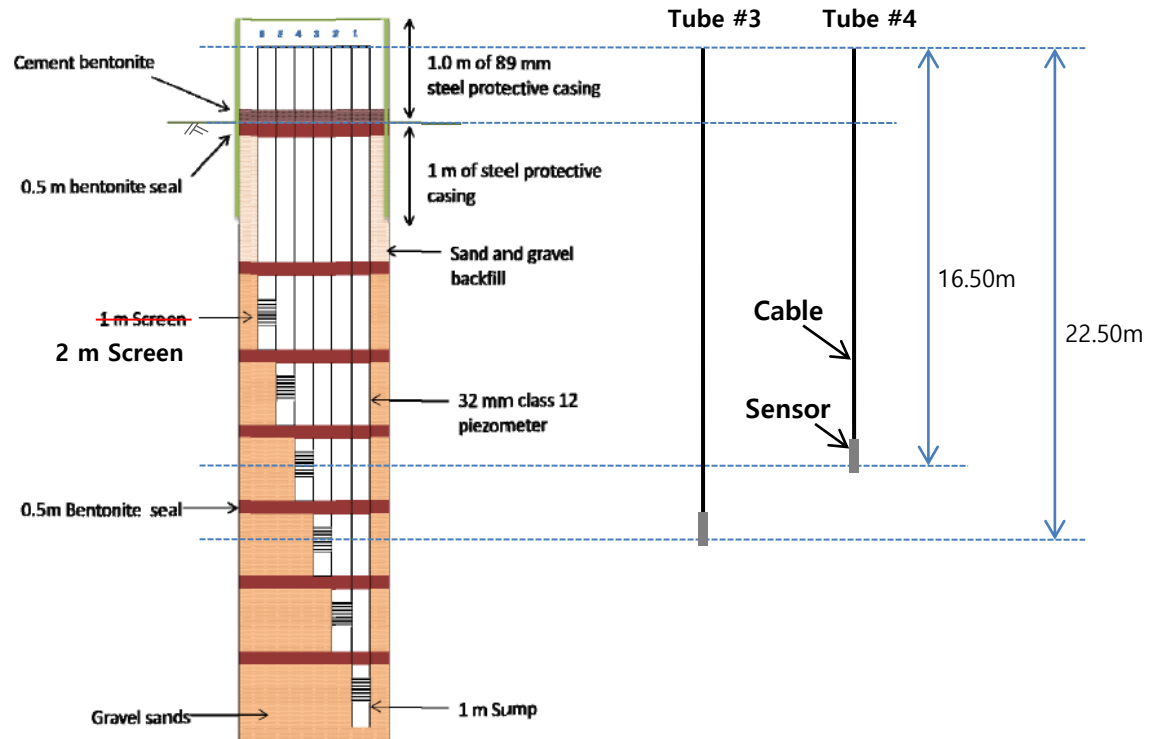
# SMB02

Multi-Sensor  
Tube #3, Tube #4

**Location:** Beside pump station 105, Matakī'eua  
(S: - 21.153897 W: - 175.241717)



## Location of sensors

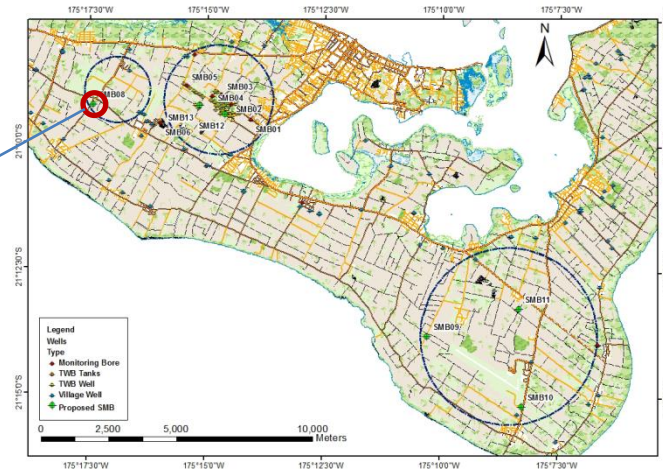


SMB01 to SMB07 and SMB14 to SMB16:  
Leave 1 meter sump at base of screen and slot 2 meters

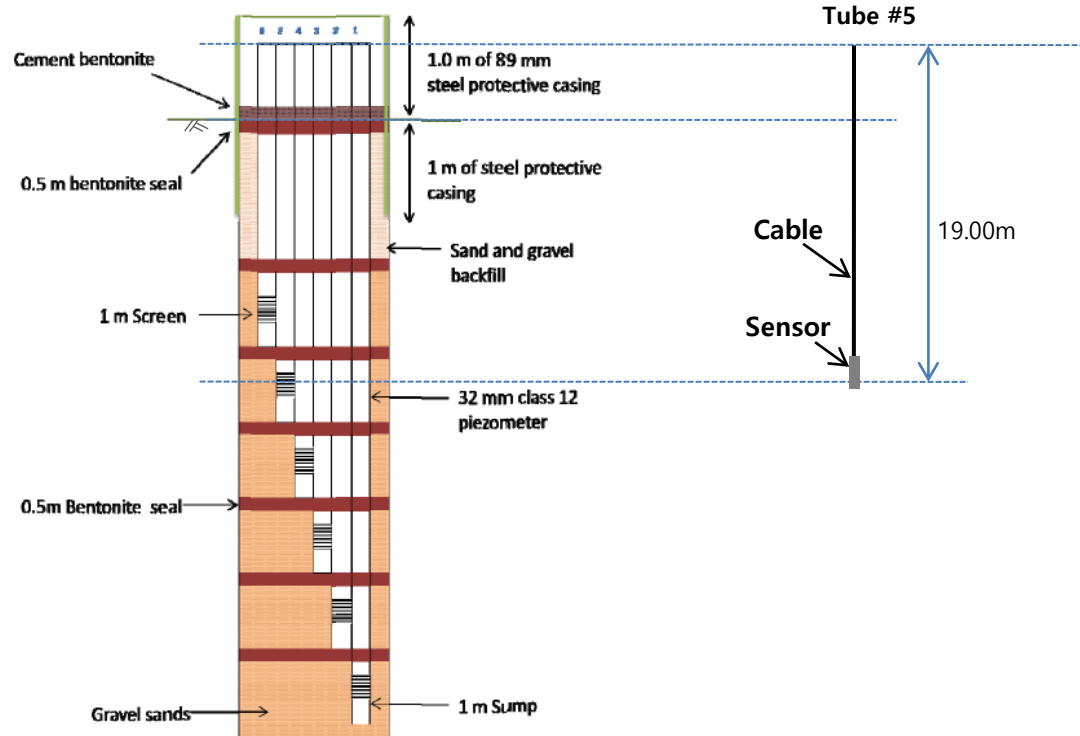
# SMB08

Single Sensor  
Tube #5

Location: Houma, Hala Vaea Road  
(S: - 21.154315 W: - 175.291506)



## Location of sensor

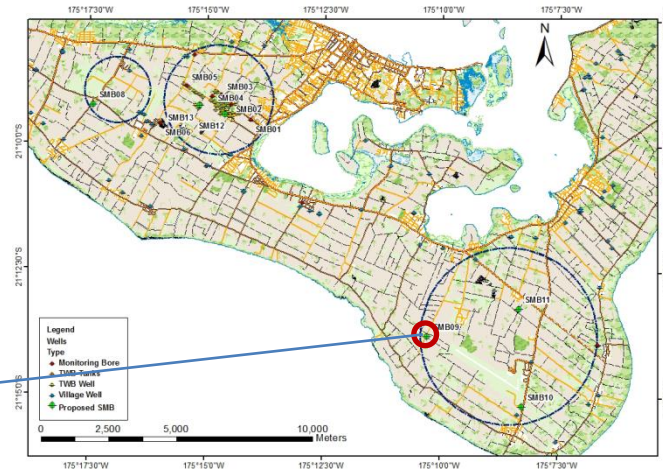


SMB08 to SM13:  
Leave 1 meter sump at base of screen and slot 1 meters

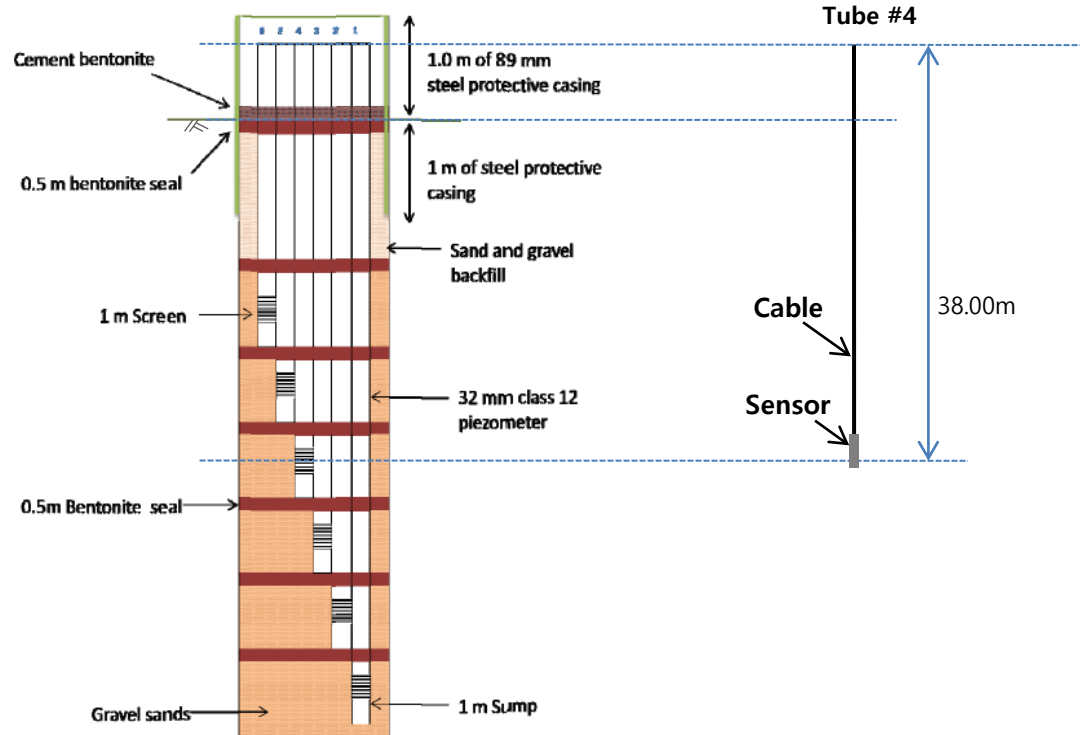
# SMB09

Single Sensor  
Tube #4

**Location:** Toloa-End of Airport Runway, Fua'amotu  
(S: - 21.158825 W: - 175.234643)



## Location of sensor

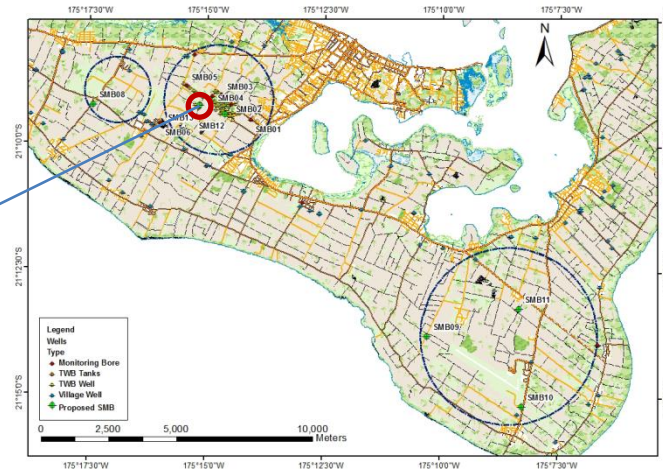


SMB08 to SM13:  
Leave 1 meter sump at base of screen and slot 1 meters

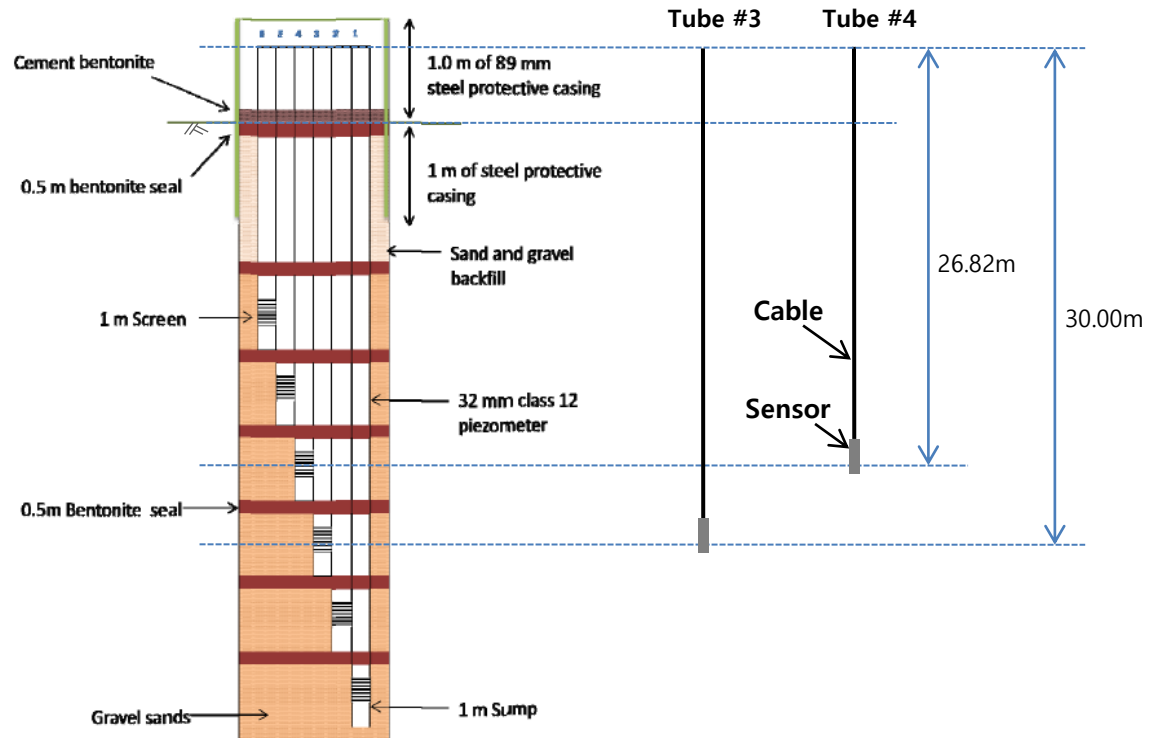
# SMB13

Multi-Sensor  
Tube #3, Tube #4

**Location:** Next to pump station 313, Matakī'eua-Tongami  
(S: - 21.154274 W: - 175.253035)



## Location of sensors

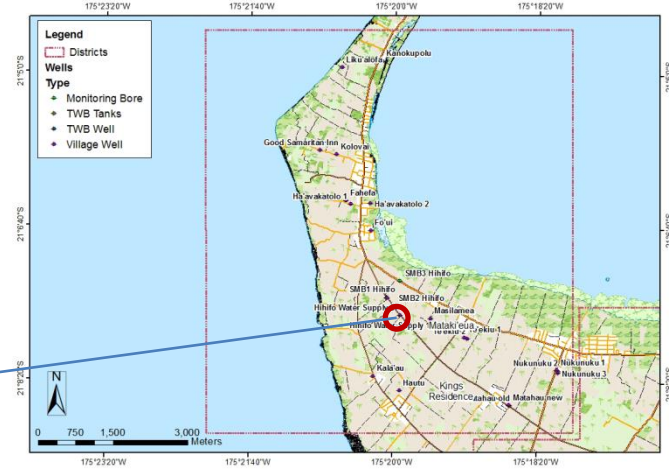


SMB08 to SM13:  
Leave 1 meter sump at base of screen and slot 1 meters

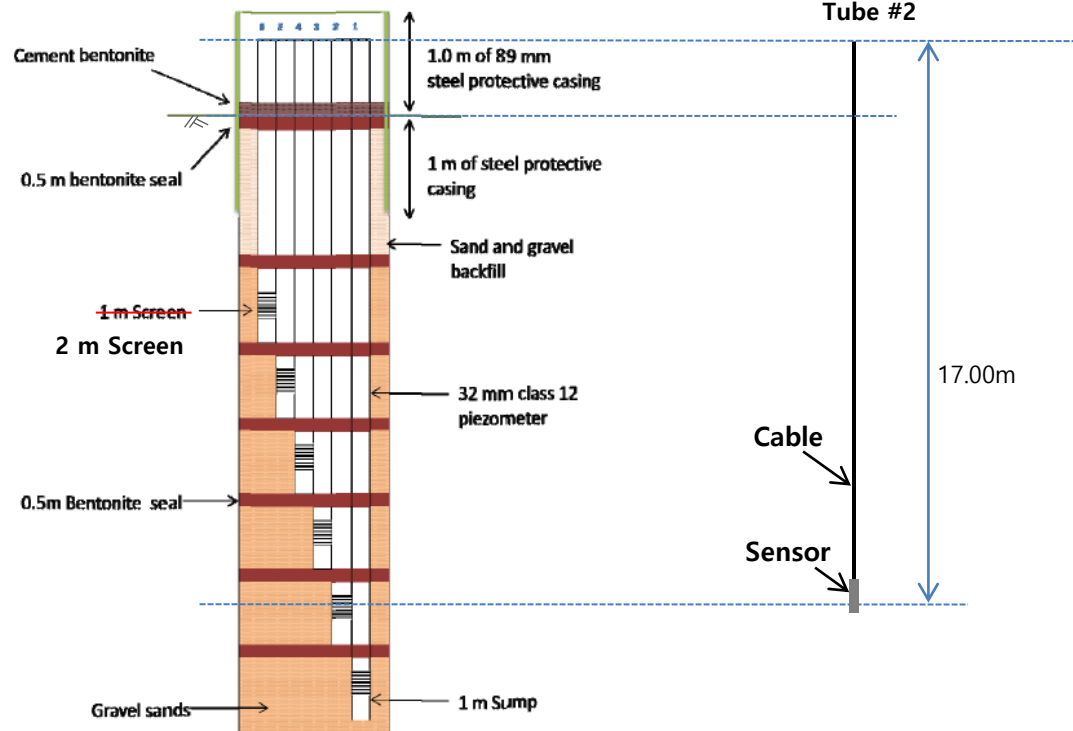
# SMB15

Single Sensor  
Tube #2

Location: Middle of Hihifo well field  
(S: - 21.139717 W: - 175.316732)



## Location of sensor



SMB01 to SMB07 and SMB14 to SMB16:  
Leave 1 meter sump at base of screen and slot 2 meters

## Model Characteristics

- Objective:  
Simulation of Groundwater Flow
- DUSWIM
- Two Phase
- Quasi Three dimensional
- Sharp Interface FEM
- Steady state and unsteady

## Model Geometry

- Original Geometry
- Coordinate Rotation and Translation are needed
- Non uniform mesh 100 m X 100 m;  
25 m X 25 m in well field
- Elements: 89200 and Nodes:89824
- Coastal Boundary

## Governing Equations

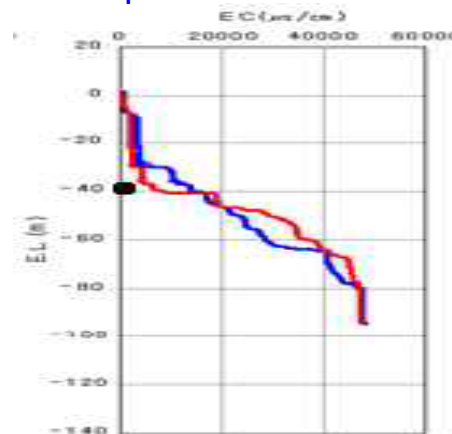
$$\frac{\partial}{\partial x_i} \left[ K_{ij}^f b^f \frac{\partial h^f}{\partial x_j} \right] + \alpha_T^f \lambda^f h^f + \alpha_B^f \lambda^f h^f$$

$$= b^f S_z^f \frac{\partial h^f}{\partial t} - \theta \frac{\partial \xi}{\partial t} - Q^f \quad (i, j=1, 2) \quad (1)$$

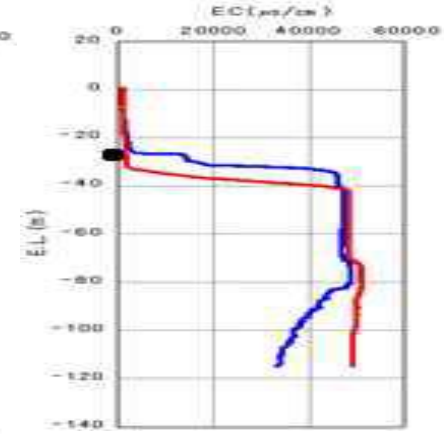
$$\frac{\partial}{\partial x_i} \left[ K_{ij}^s b^s \frac{\partial h^s}{\partial x_j} \right] + \alpha_T^s \lambda^s h^s + \alpha_B^s \lambda^s h^s$$

$$= b^s S_z^s \frac{\partial h^s}{\partial t} + \theta \frac{\partial \xi}{\partial t} - Q^s \quad (i, j=1, 2) \quad (2)$$

## Dispersion



## Advection

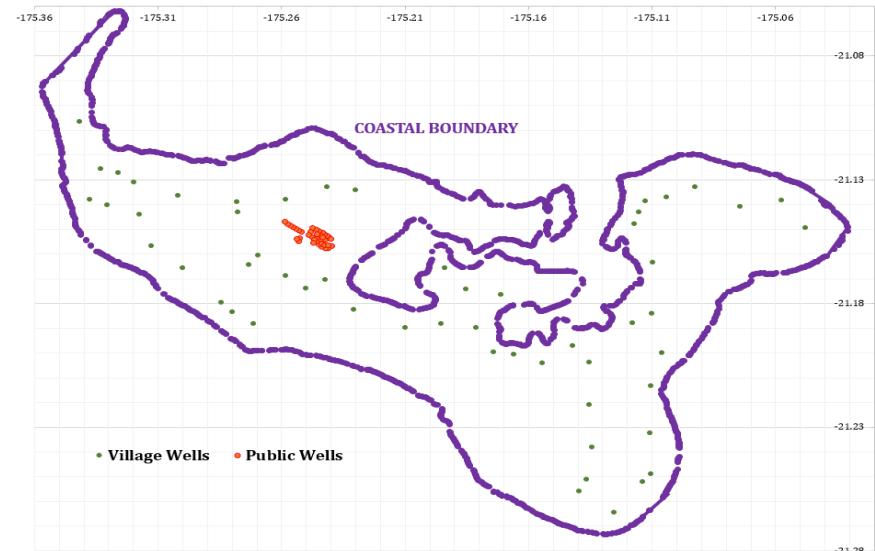


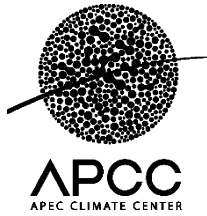
## Assumptions

- Darcy's law
- Constant densities & dynamic viscosities
- Flow in areal plane
- Single porous continuum.
- Unconfined Homogeneous and Isotropic Aquifer
- Porosity 0.3; Thickness 40 m
- Steady & uniform recharge rates
- Steady pumping
- No Tidal Effects
- Fangauta Lagoon : coastal boundary
- Annual average recharge : 570 mm

## Groundwater Withdrawal

- Estimated steady pumping
- 39 Public wells: 250 m<sup>3</sup>/day per Well
- 56 Village wells :125 m<sup>3</sup>/day per Well





# Tonga Groundwater Flow Model (ToGFlow)

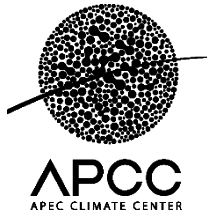


## Limitations

- Assumptions – lack of data
- Seasonal effects - not considered
- Tidal effects - not considered

## Range Input values

Item	Description	Range of Values	Default Value
1	Hydraulic Conductivity	1500-5000 m/day	3600 m/day
2	Recharge Rate	100-1000 mm/year	570 mm/year
3	Sea Level Rise	0-1 m	0 m
4	Number of wells	upto 450	95
5	Well Screen bottom elevation	upto -10 m	-5.0 m
6	Well screen length	upto 10 m	3.0 m
7	Pumping Rates-Public Wells	50-450 m <sup>3</sup> /day	250 m <sup>3</sup> /day
8	Pumping Rates-Village Wells	50-450 m <sup>3</sup> /day	125 m <sup>3</sup> /day
9	Monitoring Wells		16

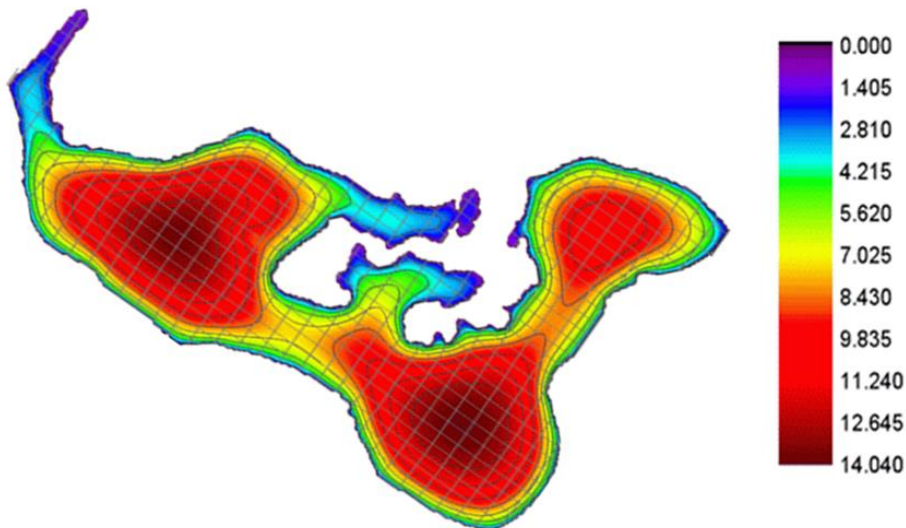


# Tonga Groundwater Flow Model (ToGFlow)

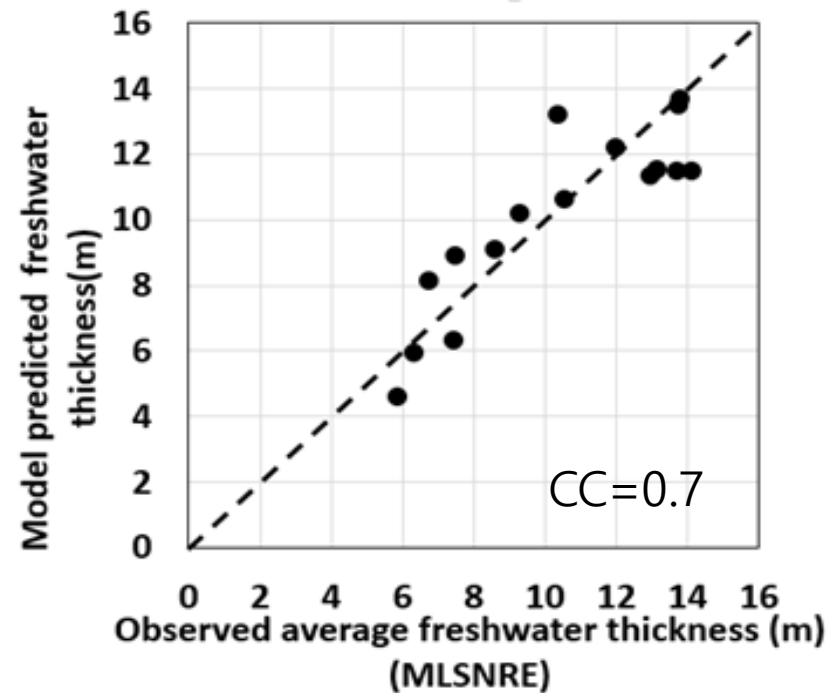


## Steady state analysis results

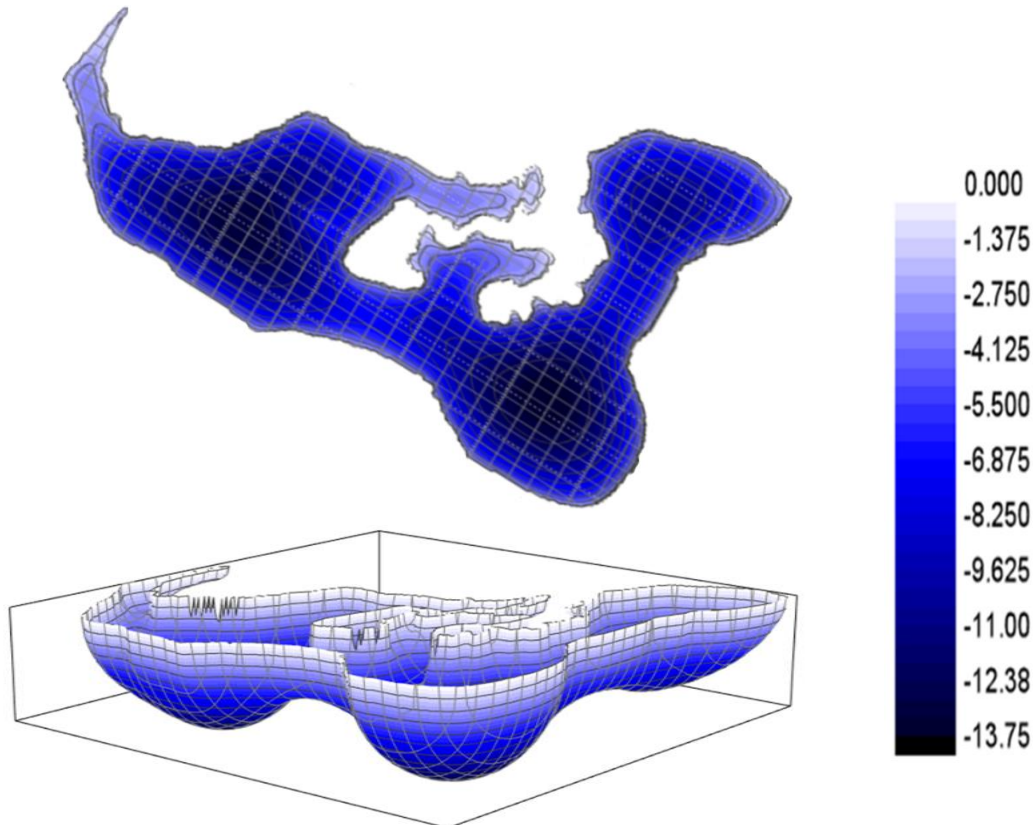
### ➤ Freshwater Thickness (m)



### Validation of steady state model



## Freshwater –Saltwater Interface Elevations



## Present Freshwater Resources in Tongatapu Island

**Average FW Thickness (m)**

**8.42**

**Maximum FW Thickness (m)**

**14.04**

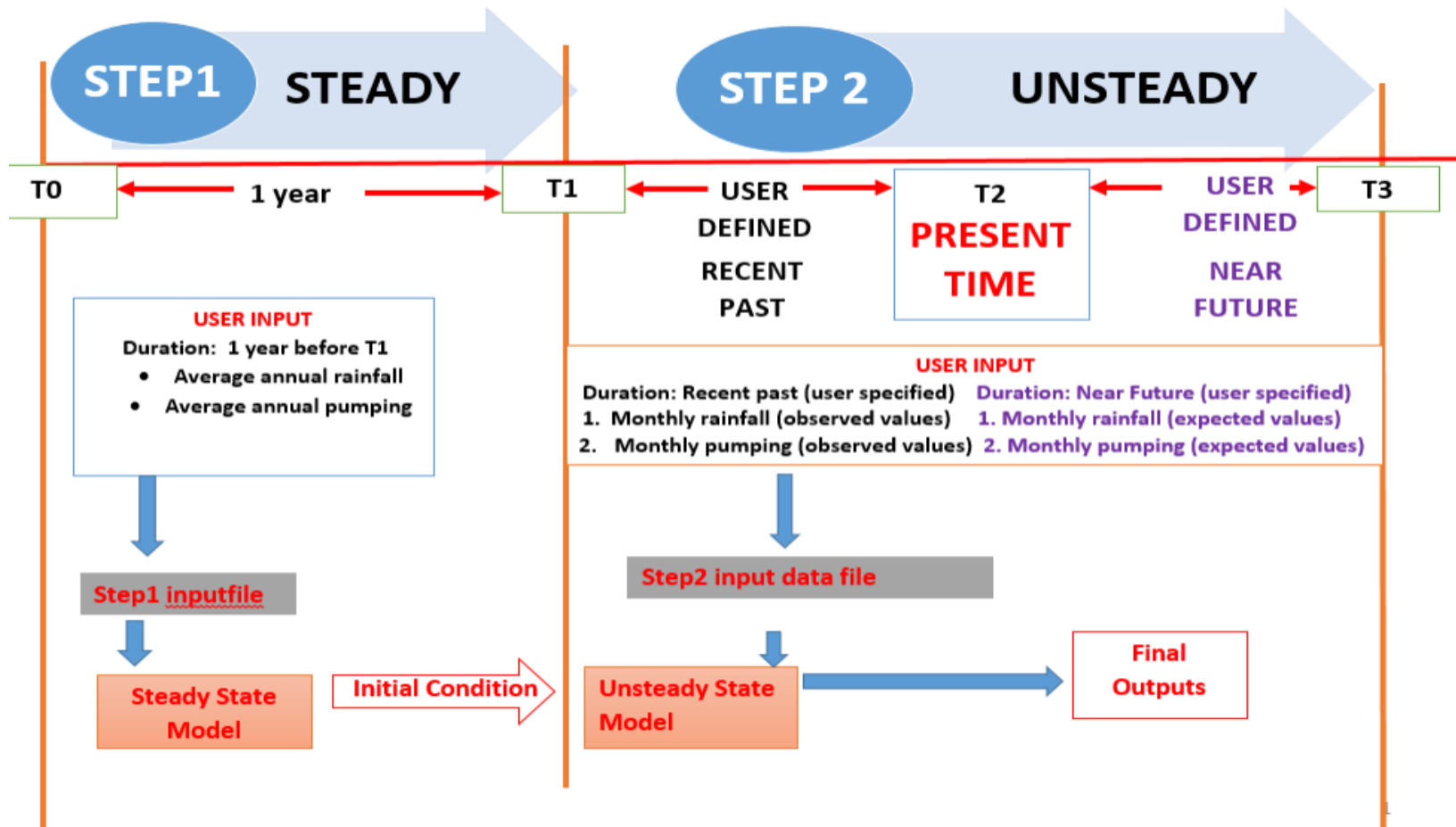
**Total Volume of Usable FW (m<sup>3</sup>)**

**193,800,000**

**Total Volume of FW (m<sup>3</sup>)**

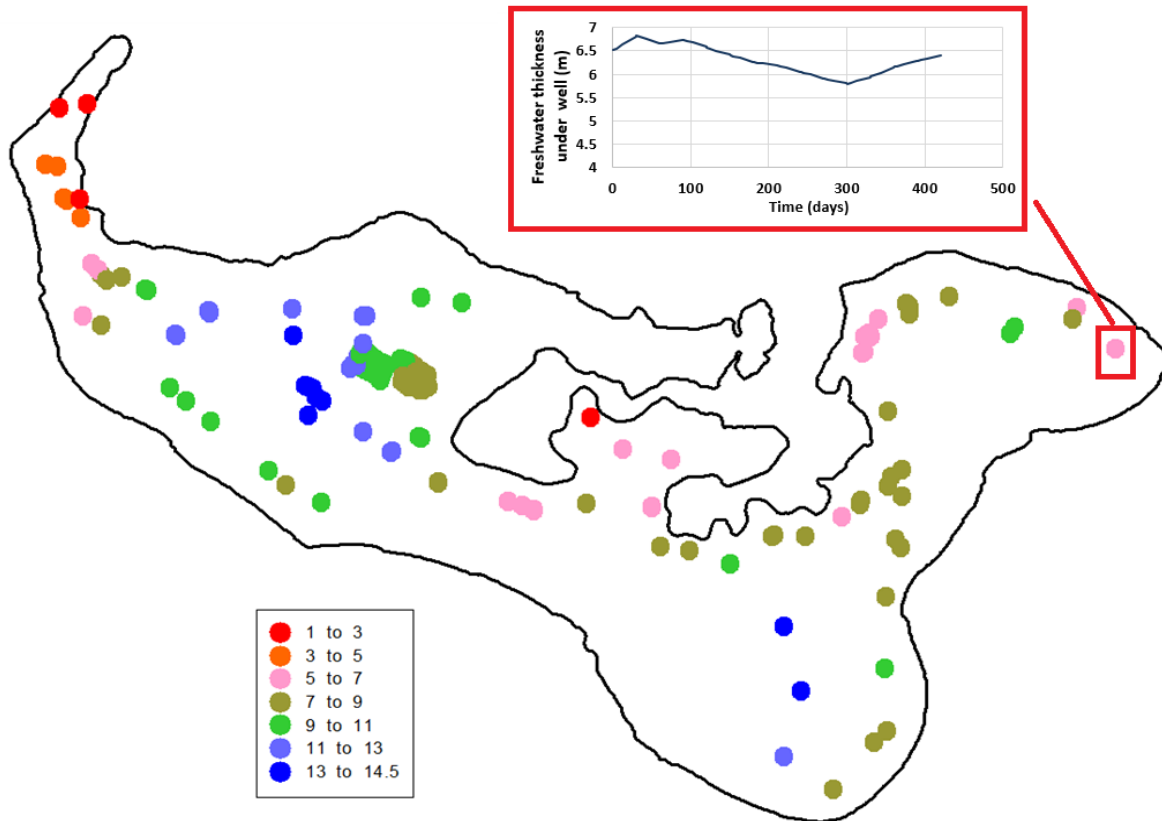
**2,123,000,000**

## Near future modeling (Unsteady)



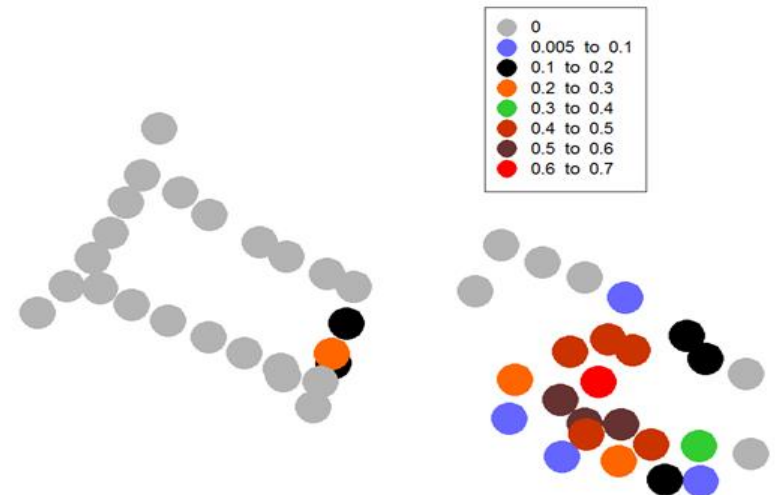
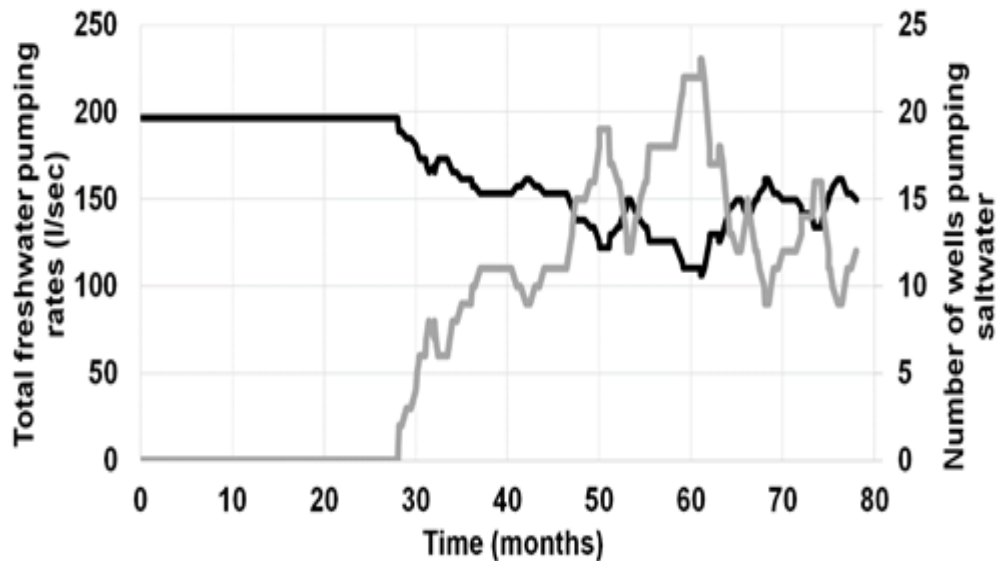
# Tonga Groundwater Flow Model (ToGFlow)

Average freshwater thickness (m) under the pumping wells (inset shows the temporal variation) during the 3/2017 to 4/2018



# Tonga Groundwater Flow Model (ToGFlow)

- Number of saltwater intruded wells (grey lines) and rate of freshwater pumping (black lines) for constant pumping rates
- Locations and ratios of saltwater intruded pumping wells at Matakī'eua and Tongamai



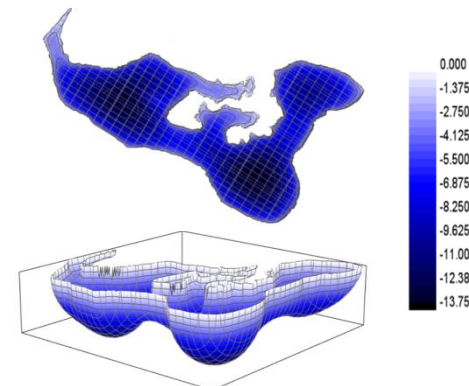


Web Based Groundwater Information System

# Groundwater Information System (ToGWIS)



01 MONITORING

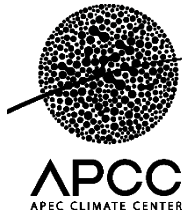


02 MODELING

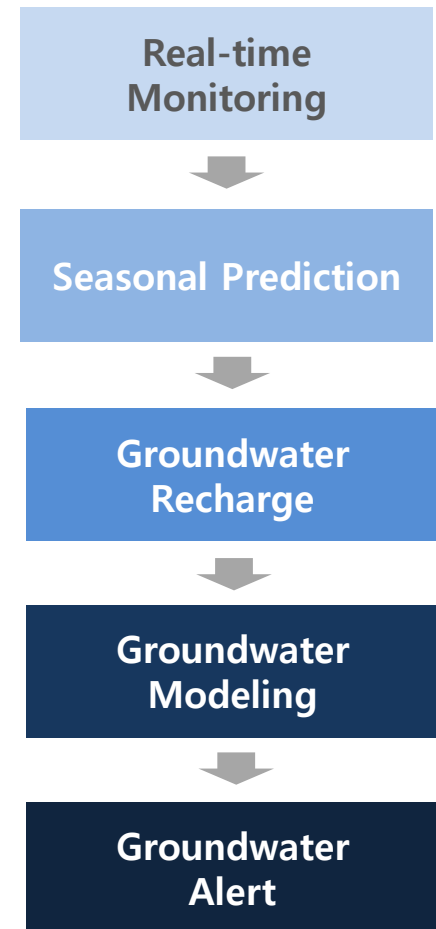
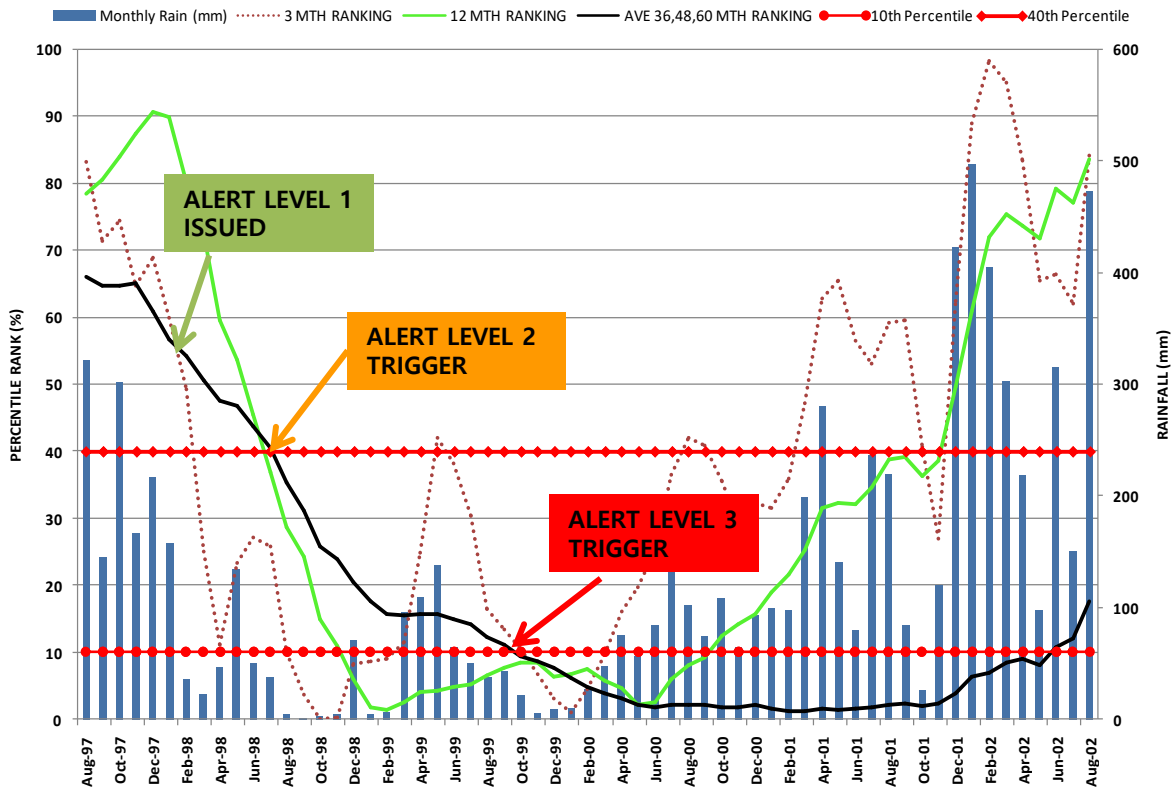


03 MANAGEMENT

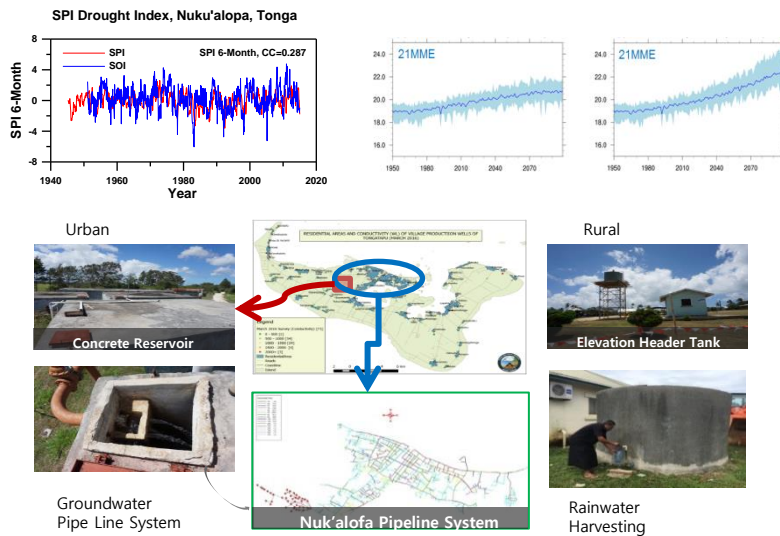
**ONE STOP SOLUTION FOR GROUNDWATER MANAGEMENT**



## Example: 1998-2001 Drought



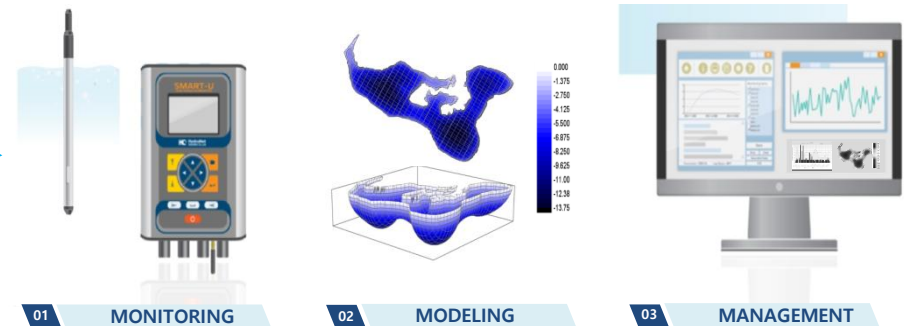
## ❖ Climate Information for Management of the Urban and Rural Water distribution system



## ❖ Real-Time groundwater monitoring system

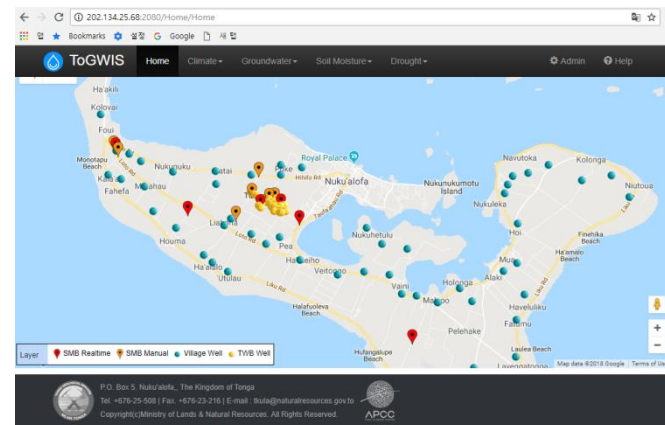


## ❖ Smart-Groundwater Management System



**ONE STOP SOLUTION FOR GROUNDWATER MANAGEMENT**

## ❖ Service: Tonga GroundWater Information system (ToGWIS)



V

# Concluding remarks



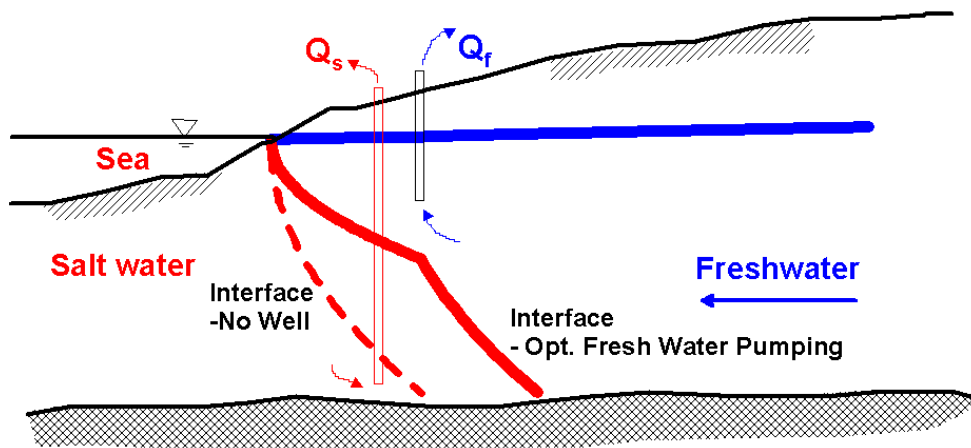
## ❑ Short-Term Measures

1. Optimal allocation of pumping rates
2. Proactive adjustment of groundwater
3. Mitigation of seawater upconing
4. Artificial recharge

## ❑ Long-Term Measures

1. Monitoring wells
2. Management of the Fangaua Lagoon
3. Leak detection and reduction of water distribution pipe network
4. Water quality

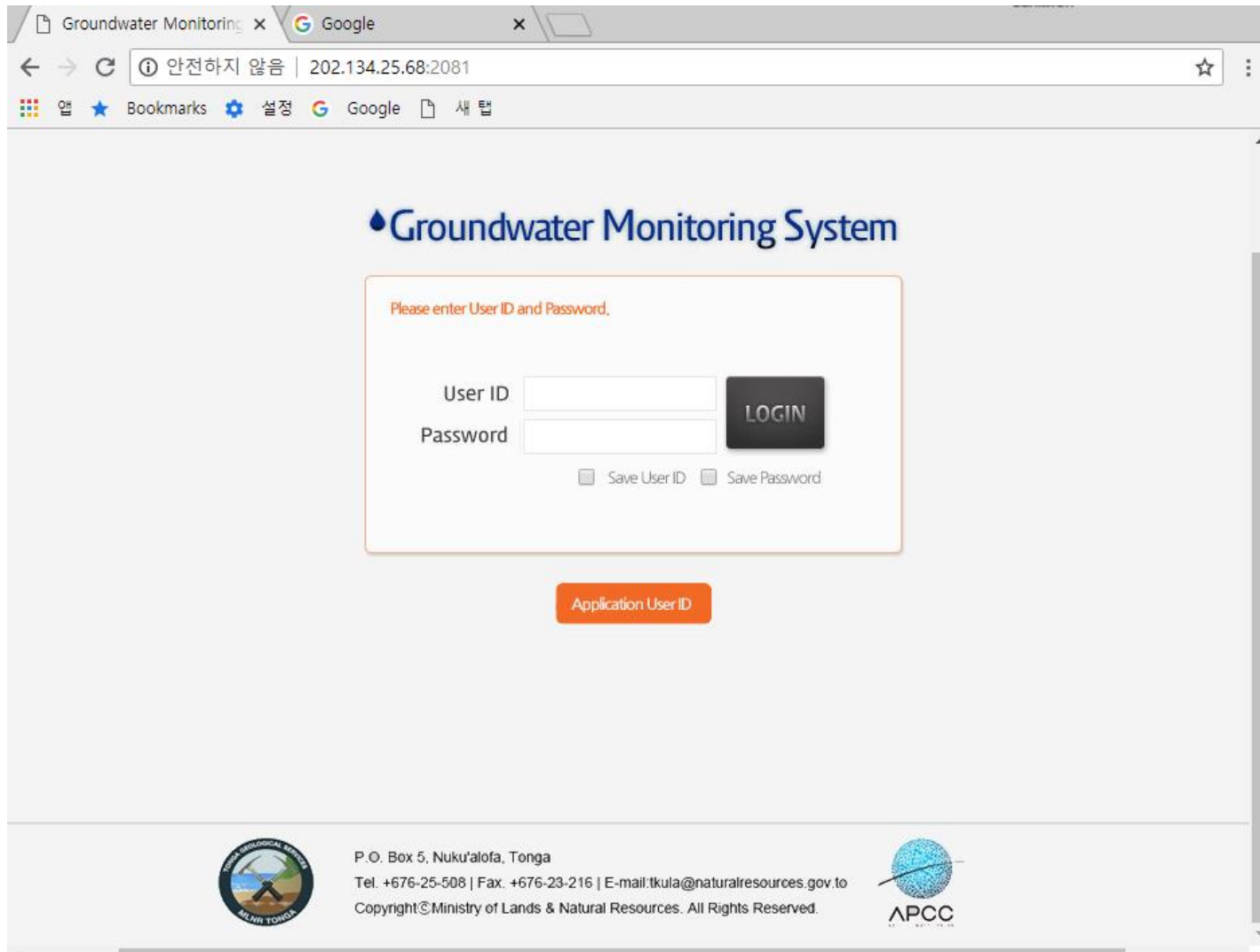
### Protection of Coastal Aquifers Optimum Pumping - Fresh & Salt Water



## ❑ Policy Recommendations

1. Inventory for and meter installations of pumping wells and water users
2. QA/QC - field observed data
3. Groundwater governance

<http://202.134.25.68:2081/>



The screenshot shows a web browser window with the URL <http://202.134.25.68:2081/>. The page title is "Groundwater Monitoring System". The main content area features a login form with the following elements:

- A heading: "Groundwater Monitoring System" with a blue water drop icon.
- A message: "Please enter User ID and Password."
- Input fields for "User ID" and "Password".
- A "LOGIN" button.
- Checkboxes for "Save User ID" and "Save Password".
- An orange button labeled "Application User ID" below the login form.

The footer contains the following information:

- MLNR Tonga logo on the left.
- Contact information: "P.O. Box 5, Nuku'alofa, Tonga", "Tel. +676-25-508 | Fax. +676-23-216 | E-mail:tkula@naturalresources.gov.to", and "Copyright © Ministry of Lands & Natural Resources. All Rights Reserved."
- APCC logo on the right.



# Tonga GW Information System (ToGWIS)



<http://202.134.25.68:2080>

**ToGWIS** Home Climate Groundwater Soil Moisture Drought Admin Help

Map Satellite

Layer ● SMB Realtime ● SMB Manual ● Village Well ● TWB Well

P.O. Box 5, Nuku'alofa, The Kingdom of Tonga  
 Tel. +676-25-508 | Fax. +676-23-216 | E-mail : tkula@naturalresources.gov.to  
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APCC APEC CLIMATE CENTER

# Video Clip

## The development of smart groundwater management system in the Kingdom of Tonga



<https://www.youtube.com/watch?v=zjvk95TtJlk>



**Thank you for your attention!**



**Malo!!**

*Bridging the Gap Between Climate Science and Applications  
for Smart water use in the Kingdom of Tonga*