문서번호 APCC-출장-18-0689(2018-07-16)

결재	사원	부서장	부서장	
	07/13 전인자	07/16 문상원	07/16 유진호	
협조	팀장			
	07/13 윤선권			

TRAVEL REPORT FORM
출장보고서

I. **Travel Overview** 출장개요

1. Traveler(s) 출장자

Department 소속	Position 직위(직급)	Name 성명	Note 비고
융합기술팀	팀장	윤선권	통가 농업수자원 프로젝트 최종워크숍 (2018.6.25.-30, 통가 누쿠알로파)
예측기술팀	선임연구원	김광형	
대외협력실	사원	전인자	

2. Travel Period 출장기간

☐ 2018. 6. 25(월) - 30(토) <5박 6일>

3. Occasion and destination 행사 및 출장지

☐ 출장장소: 통가 누쿠알로파

☐ 행 사 명: 통가 농업수자원프로젝트 최종워크숍

II. **Major Activities** 주요업무 수행내용

1. Main Contents and Activities 주요내용 및 활동

☐ Final Workshop 추진 및 Handover Ceremony (2018.6.27.수)

☐ ToGWIS 시스템 사용자 교육 및 현업화 체계구축 (2018.6.28.목)

※ 세부사항 붙임의 '출장보고서' 및 관련문서 '최종워크숍 결과보고' 참조

2. Relevance to APEC Climate Center's Activities 결론 및 소감

3. Suggestions and Remarks 건의사항

III. References (Presented and Collected Materials) 주요 수집자료

(with attachment of any information or report in case of attendance of conferences, workshops and meetings) 학술대회, 워크숍, 회의 등 참석 시 관련 정보 및 문서 첨부

Tonga Agri-Water Project 출장보고서

[융합기술팀 윤선권 팀장, 예측기술팀 김광형 선임연구원, 대외협력실 전인자 사원]

□ 출장개요

❍ 과업 추진 배경 및 목적

- 과 업 명 : 통가 물부족 대응을 위한 기후정보 활용 스마트 지하수 관리 시스템 개발(*"Development of smart water management system using climate information in response to shortage of water in the Kingdom of Tonga"*)

- 추진배경

· '15년, APCC-통가 정부 관계자 미팅(6월), 수자원 프로젝트 발굴논의(12월)

· '16년, 프로젝트 MOU 체결, 수자원 사업수행 및 상호지원 합의(2월), 1차년도 사업수행, Technical 워크숍 진행(7월)

· '17년, 농업·수자원 통합 프로젝트 MOU 체결(3월), 2차년도 사업수행 및 실무자 교육워크숍(7월)

· '18년, 3차년도 사업수행 및 프로젝트 완료(6월)

- 추진목적

· 본 프로젝트의 최종성과물을 통가 정부에 공유하여 프로젝트 결과물의 지속가능성을 위한 Ownership 전달. 이를 위해 프로젝트 결과물(ToGWIS, http://202.134.25.68:2080)사용과 현업화를 위한 사용자 교육워크숍 실시

· 기후예측정보와 지하수 모델링, 지하수 실시간 모니터링을 통해 통가 국토부의 기후변화 대응을 위한 지하수관리 및 의사결정을 지원

· 통가 국토부, 농림부, 그 외 관계자들에게 APCC 프로젝트 성과물과 협력에 대한 인식도 제고

❍ 주요 활동

- Final Workshop 추진 및 Handover Ceremony

- ToGWIS 시스템 사용자 교육 및 현업화 체계구축

- 사업 성과물 활용 방안 마련 및 향후 계획 수립

❍ **출장기간 :** 2018. 06. 25. (월) ~ 06. 30. (토), 5박 6일

❍ **방문기관 :** Ministry of Lands and Natural Resources (MLNR), Ministry of Agriculture, Forestry, Food & Fisheries (MAFFF), Tonga

❍ **출 장 자 :** 융합기술팀 윤선권 팀장, 예측기술팀 김광형 선임연구원, 대외협력실 전인자 사원(3인)

□ 주요일정

❑ 워크숍 주요일정

날 짜	시 간	주 요 내 용
6. 27(수)	오전	**사용자 교육워크숍 I** - 태평양 도서국 수자원 현황 및 관리 - 기후정보활용 스마트 물관리 시스템 소개
	오후	**사용자 교육워크숍 II** - ToGWIS 변경사항 및 새로운 기능 소개 및 시연 - ToGWIS 실무 활용 실습 - 지하수 모델링 완성본 소개 및 시연 - 지하수 모델링 실무 활용 실습
6. 28(목)	오전	**통가 농업수자원 프로젝트 최종워크숍** - 프로젝트 연구결과 공유 - 통가 지하수 통합관리 시스템(ToGWIS) 시연 - ToGWIS 시스템 수여식(Handover Agreement Signing)
	오후	**통가 국토부 및 농림부 미팅** - 최종워크숍 관련 세부사항 논의 - 프로젝트 성과물 활용현황 파악 및 피드백 제공

❑ 최종워크숍 세부 일정표

Time	Item	Person
Day 1 [June 27, 2018]		
10:00 - 11:00	Introduction to ToGWIS	Dr. Sunkwon Yoon
11:00 - 12:00	Hands-on session for ToGWIS	Dr. Sunkwon Yoon / Ms. Inja Jeon
12:00 - 12:30	Q&A and Discussion	Dr. Sunkwon Yoon / Ms. Inja Jeon
12:30 - 14:00	Lunch	
14:00 - 15:00	Introduction to Groundwater Modeling	Dr. Sunkwon Yoon
15:00 - 16:00	Hands-on session for GM	Dr. Sunkwon Yoon
16:00 - 16:30	Q&A and Discussion	
16:30 - 18:00	Introduction to ToCSA	Dr. Kwanghyung Kim
Day 2 [June 28, 2018]		
10:00 - 10:05	Opening Prayer	Maka Matekitonga (PUMA,MLNR)
10:05 - 10:10	Welcome Message from the APEC Climate Center	Dr. Jinho Yoo (Repr. Dr. Sunkwon Yoon)
10:10 - 10:15	Welcome Address from the Ministry of Lands & Natural Resources	Ms. Rosamond Bing (CEO,MLNR)
10:15 - 10:25	Introduction video on APCC-Tonga Groundwater Management Project	Ms. Inja Jeon (Project Manager,APCC)
10:25 - 10:45	Brief research outcomes, focused on groundwater management	Dr. Sunkwon Yoon (Research Fellow, APCC)
10:45 - 10:55	Showcase of ToGWIS	Ms. Inja Jeon (Project Manager,APCC)
10:55 - 11:15	Brief research outcomes, focused on agriculture sector	Dr. Kwanghyung Kim (Research Fellow, APCC)
11:15 - 11:25	Q&A Session	
11:25 - 11:35	ToGWIS Handover Signing	
11:35 - 11:40	Closing Address	
11:40 - 11:45	Closing Prayer	
11:45 - 12:00	Group Photo	
12:00 - 14:00	Luncheon at Chef Zero Restaurant	

□ 주요 활동 내용

○ APCC-Tonga Agri-Water Project Final Workshop

[※세부내용은 최종워크숍 결과보고서 참고]

- APCC-통가 정부 Ministry of Lands, Survey and Natural Resources(MLSNR) 간 수행한 농업-수자원 사업에 대하여 Final Workshop을 TANOA International Hotel에서 2018년 6월 28일(오전 10시~12시) 추진함
- 통가 부총리를 포함하여 MLNR, MAFFF, TMS, Tonga Water Board 등의 정부관계자 30여명이 참석하였으며, 수자원사업(2.5년), 농업-수자원사업(1.5년)의 주요성과를 발표하고 논의하는 자리를 마련함
- 사업의 주요 성과는 이상기후/기후변화에 따른 물수요 예측, 실시간 지하수 모니터링 시스템 구축, 정상류/부정류 지하수 흐름 모델링 시스템 개발, Web기반 지하수정보 시스템 구축(ToGWIS)이며, 수행 완료된 사업 전반에 관한 사항 발표 및 토론
- 통가의 경우, 안정적인 수자원 확보를 위하여 지하수관리가 필수적이며, 원거리에 위치한 섬들의 실시간 지하수 정보 관리를 위해서는 본 사업의 원격통신 방식 관리방안에 장점이 있음
- 기후예측정보(APCC-MME: 3개월, 6개월 전망)를 활용한 지하수자원 관리는 엘니뇨/라니냐 등 이상기후에 따른 가뭄/홍수에 대비한 수자원 관리가 가능하여 조기경보 체계구축과 선제적 지하수 관리 가능할 것으로 사료됨
- 이번 프로젝트를 계기로 APCC-통가 정부 간 향후 지속적인 관계 발전을 도모하고 후속과제 발굴 등의 노력을 통한 지속 사업희망의 의지를 보임

※ 관련 기사 링크: APCC-Tonga Agri-Water Project Final Workshop

http://www.mic.gov.to/news-today/press-releases/7367-apcc-tonga-agri-water-project-final-workshop-development-of-smart-groundwater-management-system-in-the-kingdom-of-tonga-utilizing-climate-information-in-response-to-shortage-of-water

(b) Workshop 단체사진

(a) Handover

그림 1. Final Workshop에 참석한 정부관계자들과의 단체 사진 촬영 및 사업 성과물 Handover ceremony (with MLNR CEO)

○ **Technical Workshop 추진 및 ToGWIS 사용자 교육**

[※세부내용은 최종워크숍 결과보고서 참고]

- 국토부 Office에서 2018년 6월 27(수) 10:00~18:00까지 실시한 Technical workshop에는 통가 MLNR 물관리 담당 정부관계자 15명 정도가 참석하였음
- 첫 번째 주제 강의는 PIC (Pacific Island Country) 도서지역의 수자원 현황 및 관리와 관련한 내용으로, 통가 물관리 실무자의 수자원에 대한 이해와 역량강화 교육을 목표로 하였음
- 두 번째 주제 강의는 통가타푸 섬을 대상으로 실시한 기후정보 활용 스마트 물관리 시스템 개발과 관련한 내용으로, 이번 수자원 프로젝트를 통하여 개발한 실시간 지하수 모니터링 시스템, 지하수 흐름해석 모델, Web기반 지하수 관리 시스템에 대한 전반적인 설명과 이해를 도움
- 세 번째 시간에는 본 사업 최종성과물인 ToGWIS (Tonga Groundwater Information System) 시스템의 사용자 교육을 실시하였으며, Web상에 개발한 시스템과 사용자 매뉴얼을 통한 Hand-on Session 시간을 갖음
- 워크샵 진행 동안 다양한 질문과 의견들을 수렴하였으며, 향후 실무자 Feedback을 반영하여 개발 시스템을 개선/보완하고, 필요시 추가적인 사용자 교육/매뉴얼 개선 등을 실시할 계획임


그림 2. Technical Workshop 및 ToGWIS 사용자 교육 장면

○ **통가 GCF 사업 관련 논의**

- 통가는 수량·수질 등 복합적인 문제와 기후변화 환경오염 문제로 인한 지속적인 수자원 확보에 어려움을 겪고 있음
- 따라서 기후변화에 따른 수자원 취약성 문제를 극복하고, 도시지역 주민의 자연재난(주로 홍수)으로 부터 안정적인 삶을 유지하기 위하여 중·장기 마스터플랜 수립 등 대응책 마련이 필요함
- 통가 정부에서 호주 컨설턴트를 고용하여 2019년 3월 제출을 목표로 수자원관리 관련 GCF Funding Proposal ($50백만 규모)을 준비 중임
- GCF Proposal의 주요 내용 Inland Flooding과 Urban Drainage System 구축과 관련한 사항임
- 통가 정부에서는 APCC에서 수행한 '기후정보 활용 스마트 물관리 시스템 구축' 사업의 확장을 위해 본 내용을 기획중인 사업의 한 컴포넌트로 포함시킬 의사를 밝히며 APCC의 적극적인 사업 참여를 요청함
- 통가 GCF Proposal에 본 사업의 내용이 포함되기 위해서는 실시간 모니터링(지하수위, EC 등)이 중요하며, Costal 지역에서의 조위(Tidal)영향을 고려한 Inland flooding과의 연계성이 필요함
- 따라서, 통가 정부의 사업 확장의지와 APCC의 사업경험을 바탕으로 추후 관련 사항을 지속적으로 논의하고 프로포절 작성에 참여하기로 함 (필요시 APCC 내부회의 및 통가정부 관계자 논의)

그림 3 GCF Proposal에 계획 중인 Sopur Drainage System shcematic (Nuku'alofa, Tonga)

그림 4 GCF Proposal에 계획 중인 Vuna Road Drainage System shcematic (Nuku'alofa, Tonga)

○ **통가 농림부 업무 협의**

- ToGWIS에서 제공하는 토양수분모형 개발 과정에 대해 설명하고 해당 토양수분함량 결과를 실제 활용할 수 있는 방안 및 정부 차원에서의 의사결정 지원을 위해 추가적으로 개선/개발되어야 하는 기능에 대한 다양한 피드백 수렴
- 통가 농업기후정보서비스 시스템 (ToCSA)을 통한 농업데이터 수집 및 통계 분석, 활용 방안에 대해 논의함

□ 결론 및 소감

○ 사업 성과물 활용 극대화 방안

- 본 사업 지속적인 성과물활용을 위해서는 사업 유지관리가 필요하며, 향후 개발 ToGWIS 시스템의 안정화 작업을 실시하고, 매뉴얼정비 및 지속적인 사용자 교육 실시
- 실시간 지하수 모니터링 장비는 Solar System으로 자동 Recharge 되나 정기적으로 Data logger주변 수풀을 제거하여 정리하고, 가드라인을 설치하여 외부로부터 장비보호 실시
- Focal Point(사업 담장자) 배정을 통한 지속적인 사업 시스템 관리(관측시스템, 모델링 시스템, 통신 및 서버시스템, 웹시스템 관리 등) 실시
- 통가 정부의 실무담당자와의 지속적인 커뮤니케이션을 통한 사업 후속관리 및 역량강화 실시

○ 그 외 해외사업 발굴에 활용

- 기후변화 이슈와 더불어 수자원, 농업 등과 관련한 주제는 전 세계적으로 저개발 국가 및 개발도상국 등의 주요 사업 아이템이 되고 있음
- 단기적으로, 본 사업의 결과를 ASIA 및 PIC 국가 수자원관리자 교육 및 역량강화에 활용하고, 센터에서 기획 중에 있는 GCF 프로포잘에 기후정보를 활용한 지하수 관측망 설치 및 모델링, ToGWIS시스템 개발의

내용을 포함시킴

- 장기적으로, 본 사업을 통하여 얻게 된 해외사업 경험과 노하우를 바탕으로 GCF WB, ADB, KOICA 등 해외 사업 Funding Proposal에 활용하고, APCC의 Funding Source 다양화 및 국제기구로서의 역량강화에 활용

APCC-Tonga Agri-Water Project
Final Workshop

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

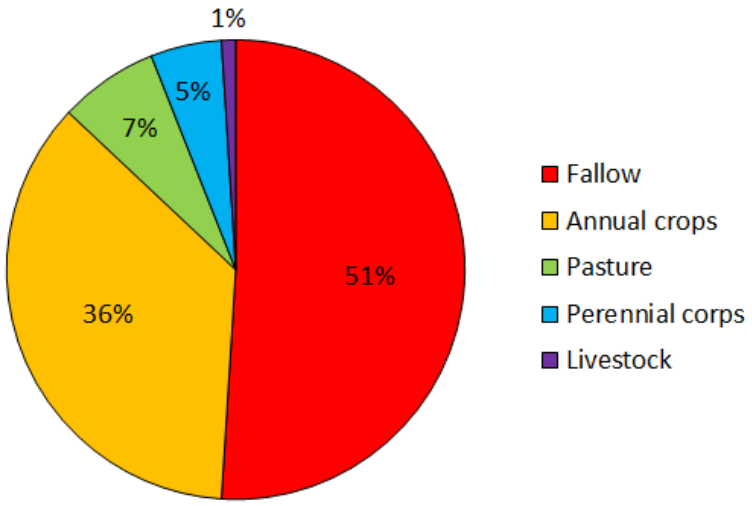
Dr. Yonghee Shin, Dr. Sunkwon Yoon, Dr. Kwanghyung Kim
Ms. Inja Jeon

APCC APEC CLIMATE CENTER

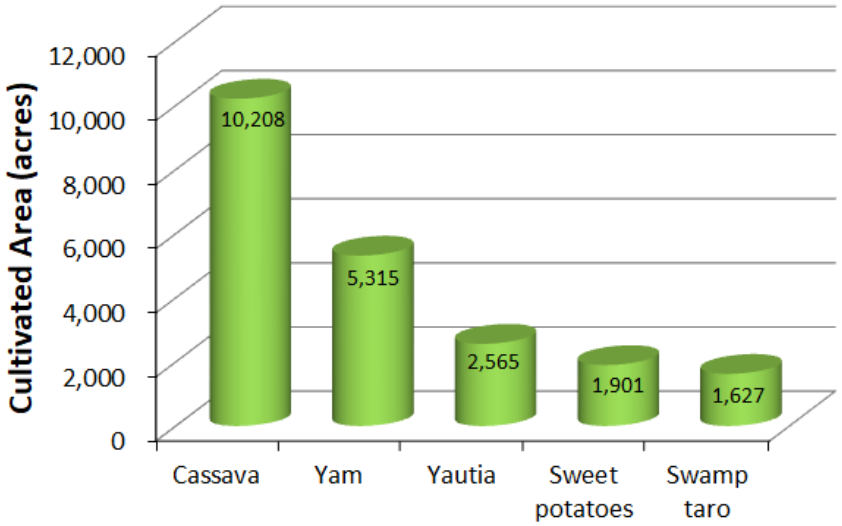
Smart Agricultural Water Management

Agriculture status in Tonga

Agricultural land use



Tonga major annual crop area



- Agriculture contributes about 19% of GDP in Tonga
- Rural households occupy 86% of all households
- Annual cropping area is 36% of all lands
- Major annual crops: Cassava, Yam, Tarua, Sweet potato, Swamp taro etc.

Smart Agricultural Water Management

Agriculture status in Tongatapu Island

Major annual crop plantation situation

Cassava

Yam

Tarua

Sweet potato

Swamp taro

Squash

Annual crop planting area in Tongatapu

Unit: Acres

Crops	Cassava	Yam	Tarua	Sweet potato	Swamp taro
Tongatapu	**8,160**	**4,248**	**1,956**	**1,408**	**1,216**
Kolomotu'a	844 (10%)	426 (10%)	222 (11%)	99 (7%)	215 (18%)
Kolofo'ou	890 (11%)	353 (9%)	181 (9%)	84 (6%)	183 (15%)
Vaini	1,809 (22%)	726 (17%)	356 (18%)	301 (21%)	301 (25%)
Lapaha	917 (11%)	1,023 (24%)	267 (14%)	235 (17%)	48 (4%)
Tatakamotonga	945 (12%)	699 (16%)	233 (12%)	222 (16%)	78 (6%)
Nukunuku	1,727 (22%)	673 (16%)	545 (28%)	264 (19%)	280 (23%)
Kolovai	1,028 (13%)	348 (8%)	153 (8%)	203 (14%)	111 (9%)

Source: Tonga national agricultural census (2015)

- In Tongatapu, cassava has the largest cultivation area followed by yam and taro, sweet potato
- Main cultivation area: Vaini, Nukunuku, Lapaha

Research Purpose (Agriculture)

- In this study, we aimed at strengthening the capacity of Tongan farmers to deal with drought through the development of Smart Agricultural Water Management technology.
- The Smart Agricultural Water Management technology includes soil moisture monitoring to come up with climate smart irrigation for selected crops.
- Collaborative activities between APCC and MAFFF were implemented:

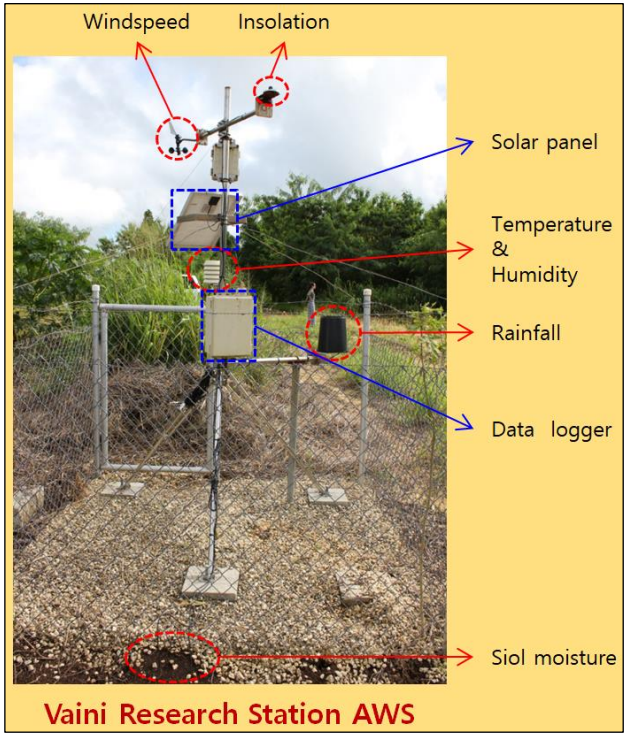
  Activity 1 : Installation of Soil Water Content and Soil Water Potential sensors / Monitoring of soil moisture condition

  Activity 2 : Development of soil water content model

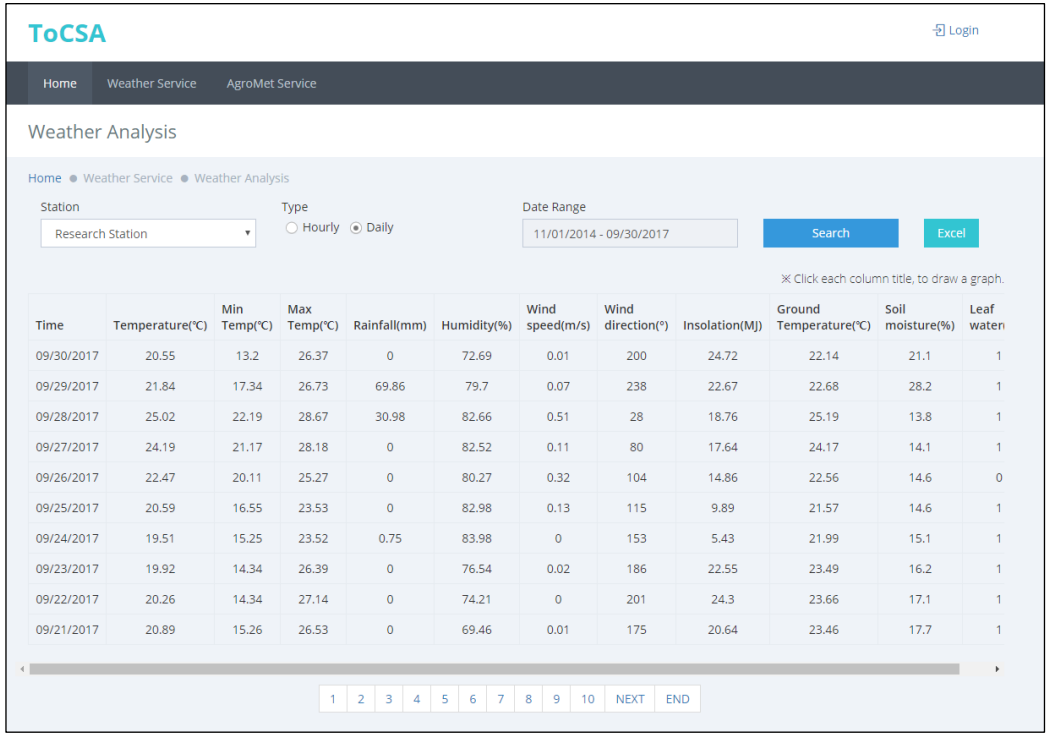
- The Smart Agricultural Water Management technology will be able to contribute to minimizing the damage by enhancing preventive capability against extreme weather events such as drought.

Research Materials – Meteorological Data

Vaini Weather Station



ToCSA (Tonga Climate Service for Agriculture)

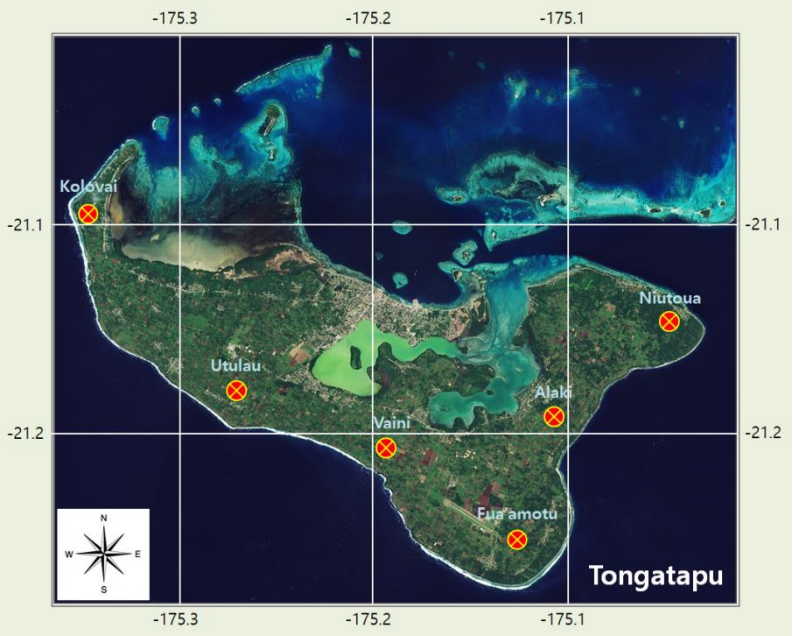


Time	Temperature(℃)	Min Temp(℃)	Max Temp(℃)	Rainfall(mm)	Humidity(%)	Wind speed(m/s)	Wind direction(°)	Insolation(MJ)	Ground Temperature(℃)	Soil moisture(%)	Leaf water
09/30/2017	20.55	13.2	26.37	0	72.69	0.01	200	24.72	22.14	21.1	1
09/29/2017	21.84	17.34	26.73	69.86	79.7	0.07	238	22.67	22.68	28.2	1
09/28/2017	25.02	22.19	28.67	30.98	82.66	0.51	28	18.76	25.19	13.8	1
09/27/2017	24.19	21.17	28.18	0	82.52	0.11	80	17.64	24.17	14.1	1
09/26/2017	22.47	20.11	25.27	0	80.27	0.32	104	14.86	22.56	14.6	0
09/25/2017	20.59	16.55	23.53	0	82.98	0.13	115	9.89	21.57	14.6	1
09/24/2017	19.51	15.25	23.52	0.75	83.98	0	153	5.43	21.99	15.1	1
09/23/2017	19.92	14.34	26.39	0	76.54	0.02	186	22.55	23.49	16.2	1
09/22/2017	20.26	14.34	27.14	0	74.21	0	201	24.3	23.66	17.1	1
09/21/2017	20.89	15.26	26.53	0	69.46	0.01	175	20.64	23.46	17.7	1

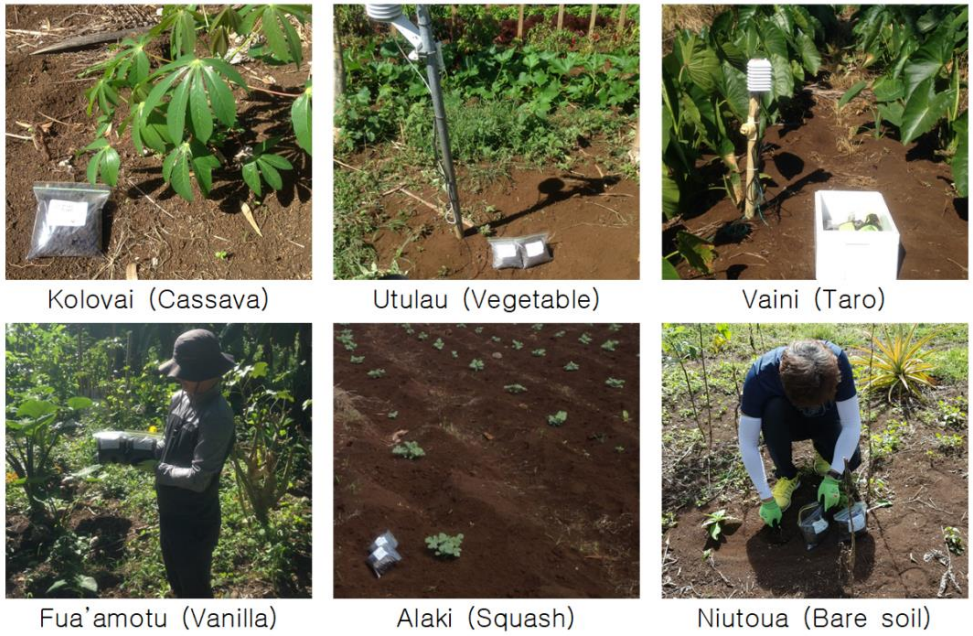
- Automated Weather Station in the Vaini Research Station
- Temperature(℃), Relative humidity(%), Rainfall(mm), Solar radiation(MJ/m^2), Wind speed(m/s), etc.
- Automatically transmitted to ToCSA through the regular communication via bluetooth transmission

Research Materials – Soil Data

Soil sampling in Tongatapu



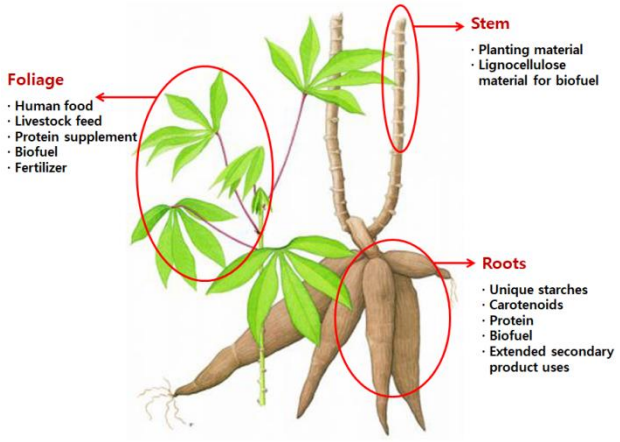
Cultivation status at soil sampling site



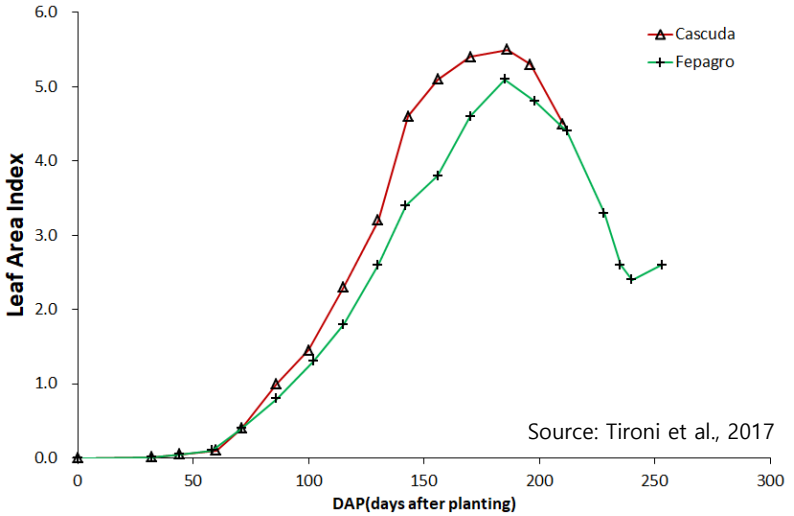
- In order to develop a soil water content model, the ratio of Sand, Silt, Clay contents (physical soil property) is required.
- Sampled the soil in current weather observation area (Fua'amotu, Vaini, Utulau) and future planned AWS installation area(Alaki, Niutoua, Kolobai)
- Referenced the physical characterization results of Vaini Clay and Lapaha Clay by Gibbs (1976)

Research Materials – Crop Data (Cassava)

Cassava



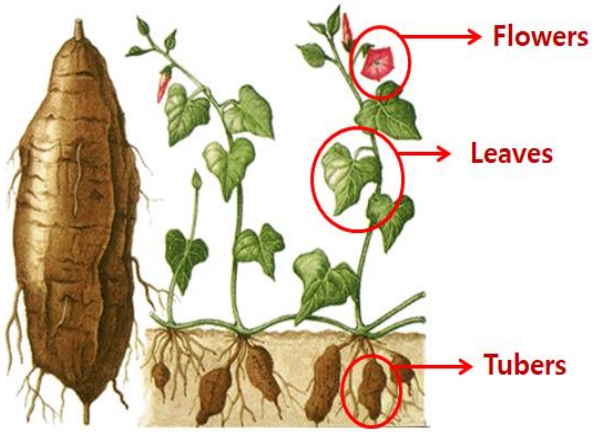
LAI variability during Cassava growth



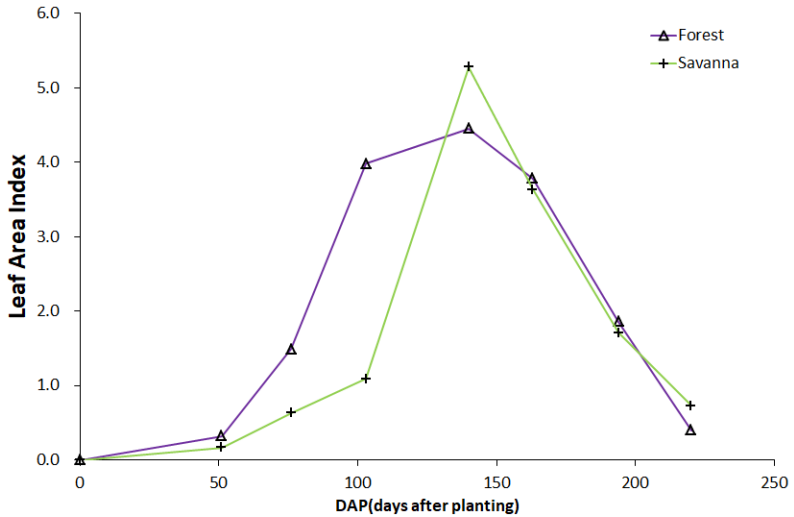
- **To estimate soil water content, length of crop cycle, LAI, crop height and root depth are required.**
- Cassava generally has a growth period of about 250 days
- LAI is highest around 180 days after sowing
  (Cascuda: 5.5, Fepagro: 5.1)

Research Materials – Crop Data (Yam)

Yam



LAI variability during Yam growth

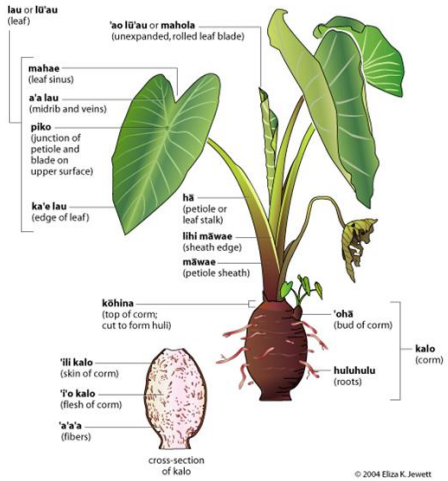


Source: Diby et al., 2011

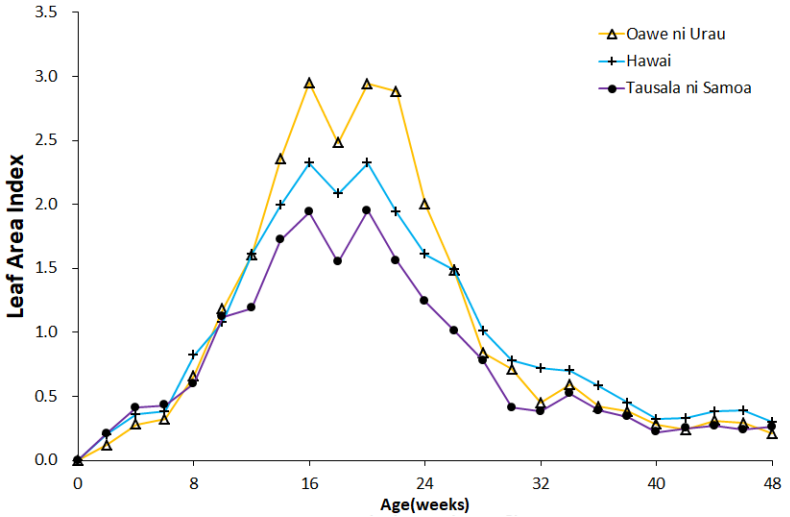
- Widely grown in the temperate and subtropical regions
- In Tonga, traditional mixed cultivation method is used
- Yam generally has a growth period about 220 days
- LAI is highest around 140 days after sowing
  (Forest: 4.45, Savanna: 5.28)

Research Materials – Crop Data (Swamp taro)

Swamp taro



LAI variability during Taro growth



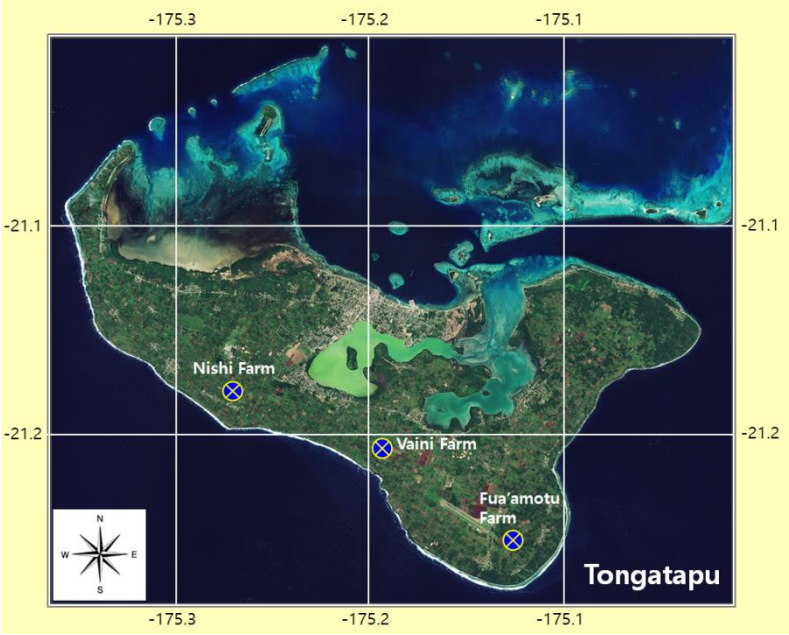
Source: Sivan, 1979

- Widely grown in the Midwest Africa, Northeast Asia, and South Pacific regions
- Growth period differs depending on varieties. Swamp taro has a growth period of about 336 days.
- LAI is highest around 112 days after sowing (Oawe ni Urau: 2.9, Hawai: 2.3, Tausala ni Samoa: 1.9)

Smart Agricultural Water Management

Installation of Soil Moisture Sensor

Soil Moisture Sensor installation site



- Installed in three sites (Vaini Farm, Fua'amotu Farm, Nishi Farm) with cooperation of MAFF
- Soil Water Content(SWC), Soil Water Potential(SWP)
- Automatically stored in data logger every one hour

Observation sensors and installation situation


Vaini Farm

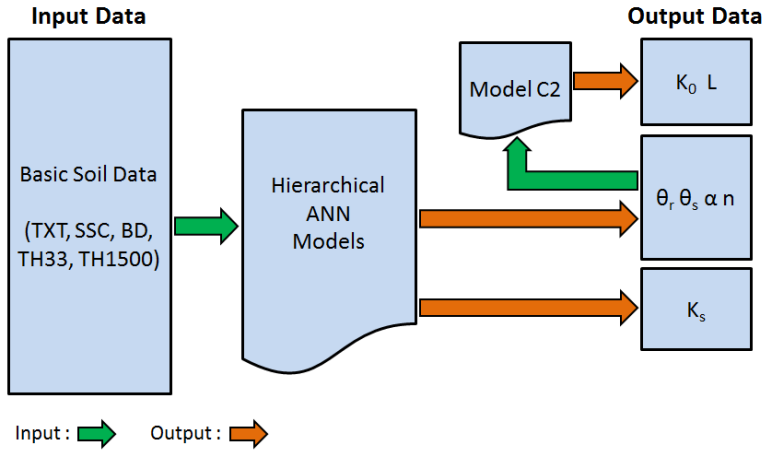

Fua'amotu Farm

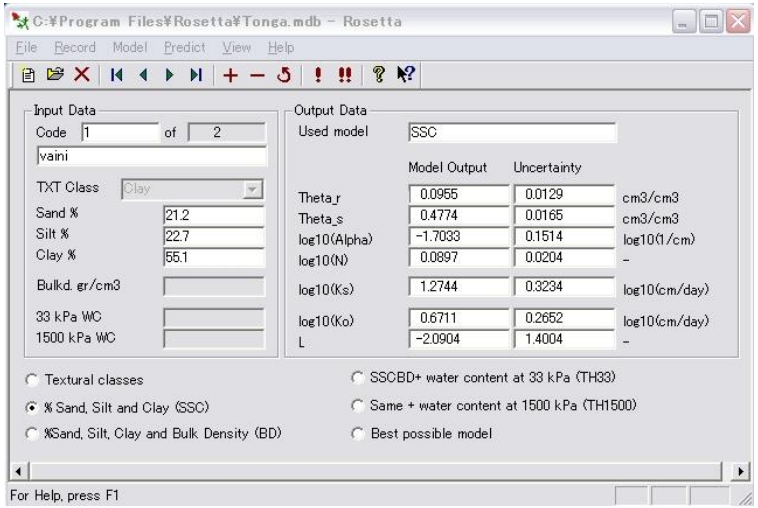

Nishi Farm

Smart Agricultural Water Management

ROSETTA Model

ROSETTA model flow chart and execution





Input and Output data of ROSETTA model

ROSETTA input data

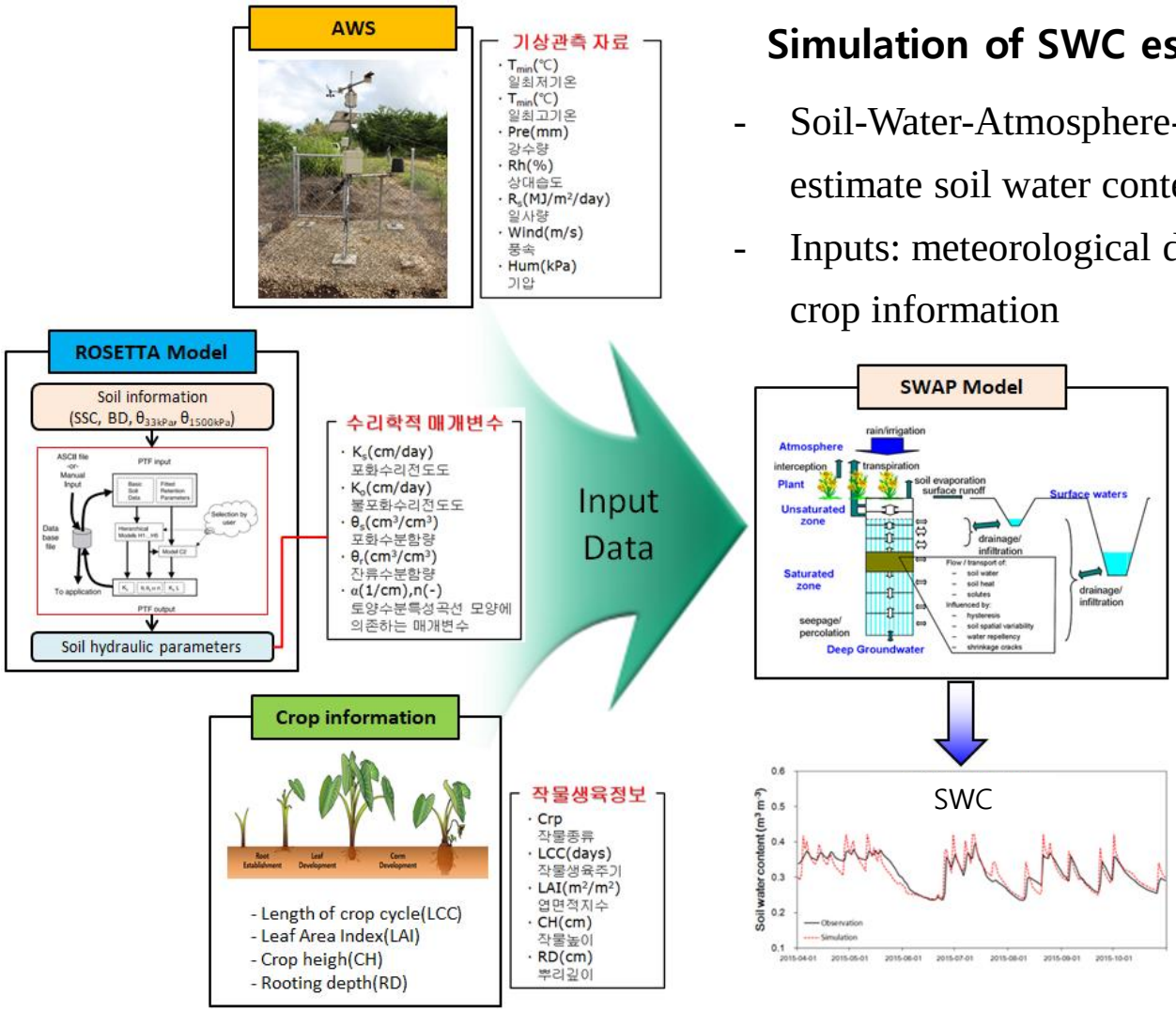
Item	Explanation	Unit
TXT	Soil textural class (12 soil class)	-
SSC	Sand, Silt and Clay percentages	%
BD	Bulk density	g/cm3
TH33	Water contents at 33 kPa	cm3/cm3
TH1500	Water contents at 1500 kPa	cm3/cm3

ROSETTA output data

Item	Explanation	Unit
θ_r	Residual water content	cm3/cm3
θ_s	Saturated water content	cm3/cm3
α	Curve shape parameter	1/cm
n	Curve shape parameter	-
K_s	Saturated hydraulic conductivity	cm/day

Source:https://www.ars.usda.gov/pacific-west-area/riverside-ca/us-salinity-salinity-laboratory/docs/ROSETTA-model/

SWAP Model



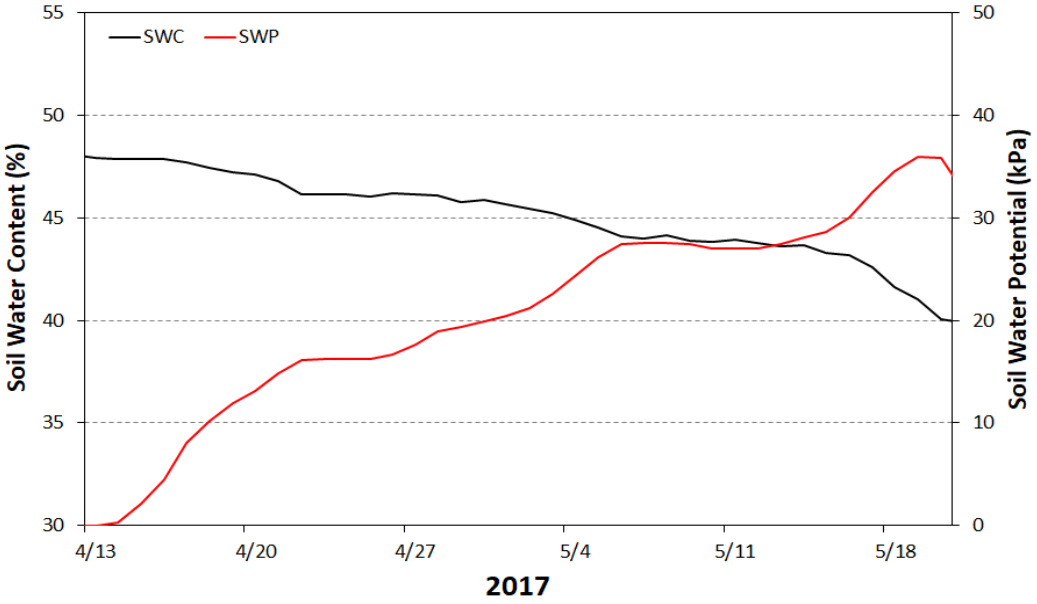
Simulation of SWC estimation of SWAP model

- Soil-Water-Atmosphere-Plant(SWAP) model is used to estimate soil water content in each site
- Inputs: meteorological data, soil characteristics, and crop information

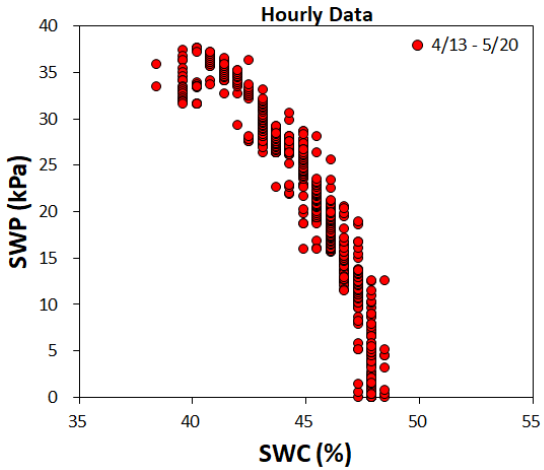
Smart Agricultural Water Management

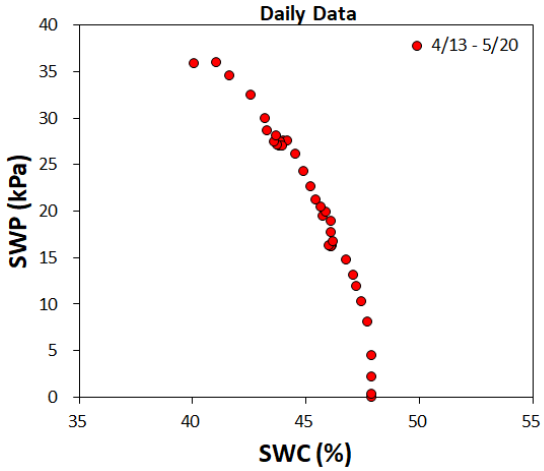
Observation Results (Vaini Farm)

Soil Water Content(SWC) observation in Vaini Farm



Relationship between SWC and SWP

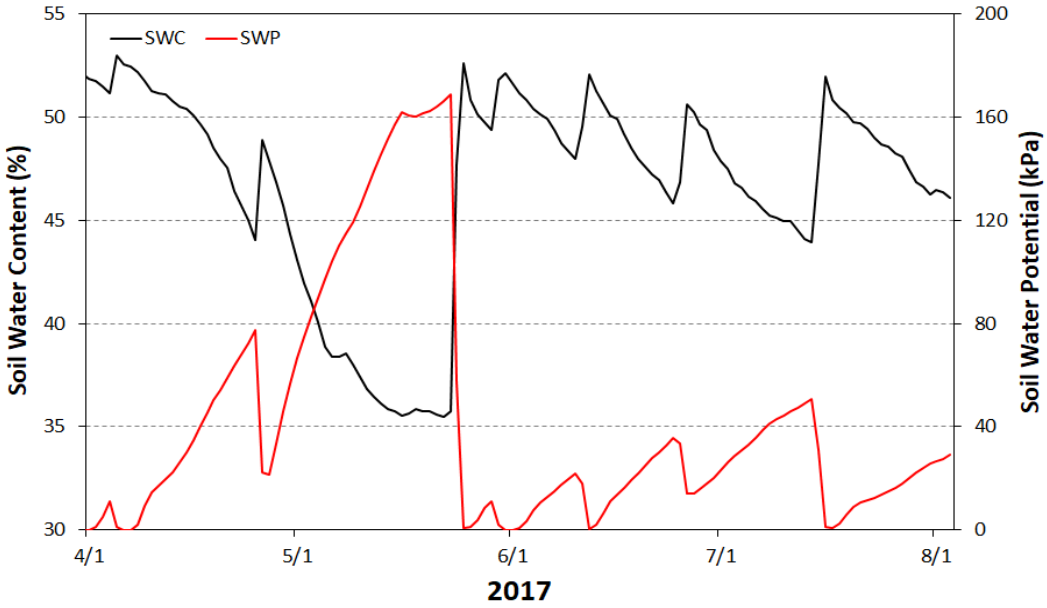




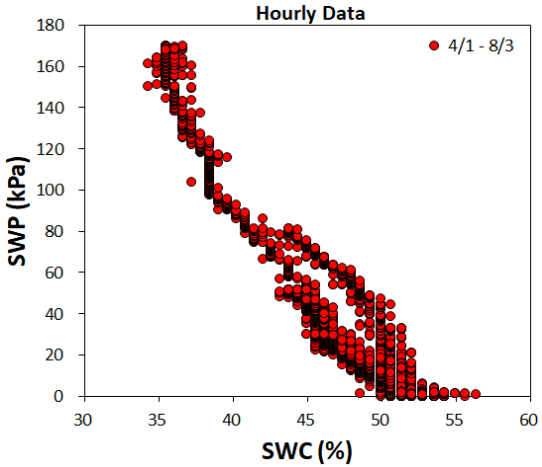
- The SWP sensor begins to react from April 13
- Sensors deviate from data logger due to heavy rain of 92 mm on May 23
- Correlation between SWC and SWP from April 13 to May 20 is $R^2 = 0.91$

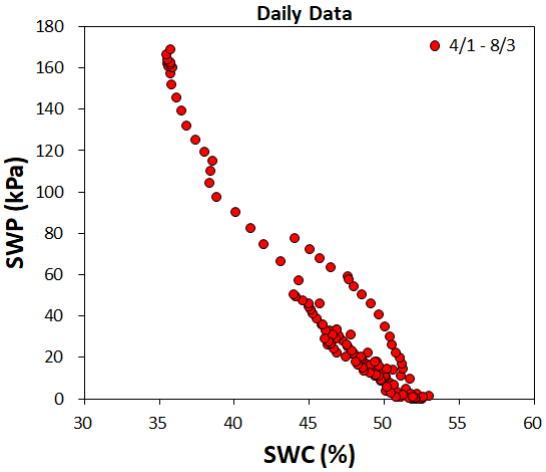
Observation Results (Fua'amotu Farm)

SWC observation in Fua'amotu Farm



Relationship between SWC and SWP





- When SWC is greater than 51%, SWP is close to 0 kPa
- When SWC is less than 36%, SWP is close to 160 kPa
- Correlation between SWC and SWP from April 1 to August 3 is $R^2 = 0.93$
- Irrigation is recommended in the 60-100 kPa range for high-density clay soils

Smart Agricultural Water Management

Soil Physical Property Analysis Result (in Tonga)

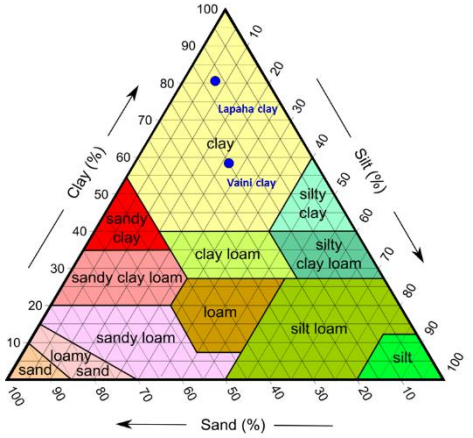
Analysis of soil physical properties



Performing particle size analysis test in Tonga

Soil characteristics of Tonga soil

Region	Soil depth (cm)	Soil Texture (%)		
		Sand	Silt	Clay
Vaini clay	13-28	20.0	21.7	58.3
Lapaha clay	13-30	12.0	7.4	80.6



Region	Soil hydraulic parameters						
	θ_r (cm^3/cm^3)	θ_s (cm^3/cm^3)	α (1/cm)	n	K_s (cm/day)	K_r (cm/day)	L
Vani clay	0.097	0.484	0.020	1.216	18.652	4.789	-2.353
Lapaha clay	0.102	0.497	0.020	1.150	16.665	3.734	-4.488

Smart Agricultural Water Management

Soil Physical Property Analysis Result (in Korea)

Vaini Farm

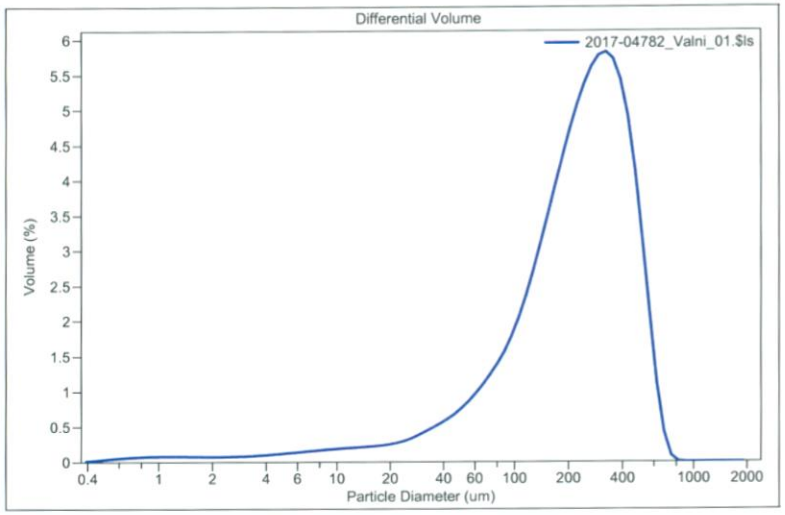
BECKMAN COULTER

LS Particle Size Analyzer

Beckman Coulter LS 13 320

7 Nov 2017 17:55

File name:	C:\LS13320\데이터\2017-04782_Valni_01.$ls 2017-04782_Valni_01.$ls		
File ID:	2017-04782		
Sample ID:	Valni		
Run number:	5		
Optical model:	Fraunhofer.rf780f		
Residual:	0.58%		
LS 13 320	Dry Powder System		
Start time:	17:54 7 Nov 2017	Run length:	28 seconds
Average Vacuum:	25.1" H2O		
Obscuration:	5%		
Software:	5.01	Firmware:	2.02



Volume Statistics (Arithmetic) 2017-04782_Valni_01.$ls

Calculations from 0.375 um to 2000 um

Volume:	100%		
Mean:	248.4 um	S.D.:	151.7 um
Median:	233.0 um	C.V.:	61.1%
Mode:	324.4 um	Skewness:	0.447 Right skewed
		Kurtosis:	-0.384 Platykurtic

d_{10}: 55.38 um d_{50}: 233.0 um d_{90}: 461.4 um

<10%	<25%	<50%	<75%	<90%
55.38 um	131.1 um	233.0 um	352.5 um	461.4 um

Fuaamotu Farm

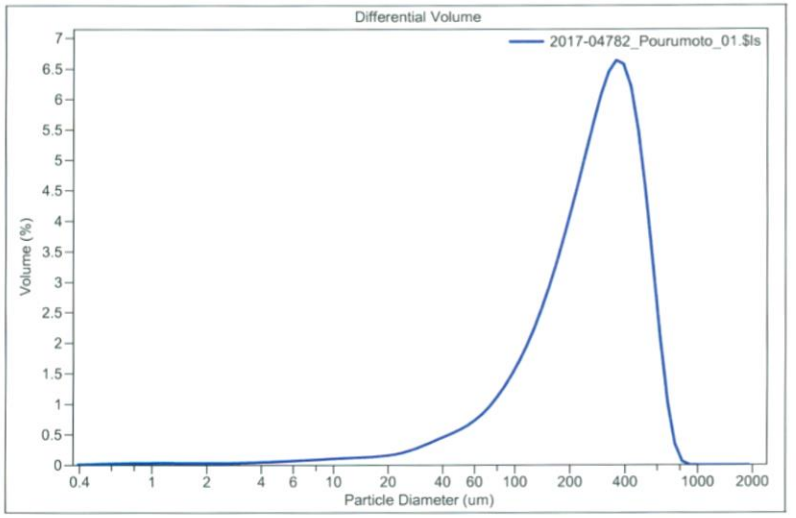
BECKMAN COULTER

LS Particle Size Analyzer

Beckman Coulter LS 13 320

8 Nov 2017 10:15

File name:	C:\LS13320\데이터\2017-04782_Pourumoto_01.$ls 2017-04782_Pourumoto_01.$ls		
File ID:	2017-04782		
Sample ID:	Pourumoto		
Run number:	3		
Optical model:	Fraunhofer.rf780f		
Residual:	0.66%		
LS 13 320	Dry Powder System		
Start time:	10:15 8 Nov 2017	Run length:	23 seconds
Average Vacuum:	25.1" H2O		
Obscuration:	3%		
Software:	5.01	Firmware:	2.02



Volume Statistics (Arithmetic) 2017-04782_Pourumoto_01.$ls

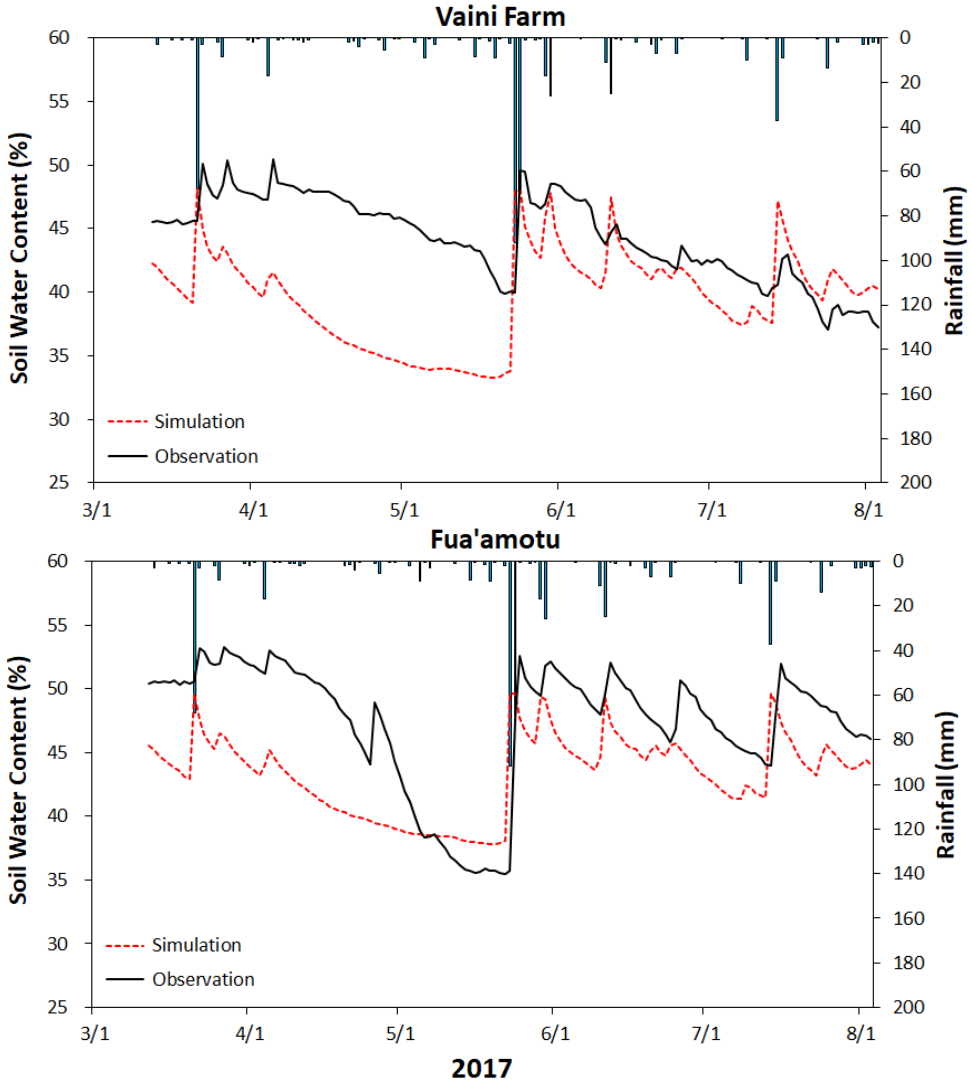
Calculations from 0.375 um to 2000 um

Volume:	100%		
Mean:	287.2 um	S.D.:	160.0 um
Median:	276.4 um	C.V.:	55.7%
Mode:	356.1 um	Skewness:	0.354 Right skewed
		Kurtosis:	-0.438 Platykurtic

d_{10}: 81.43 um d_{50}: 276.4 um d_{90}: 507.7 um

<10%	<25%	<50%	<75%	<90%
81.43 um	163.2 um	276.4 um	398.5 um	507.7 um

Soil Water Content Estimation Results (Crop Cultivation Area in Tongatapu)



SWC estimation for Vaini Farm soil

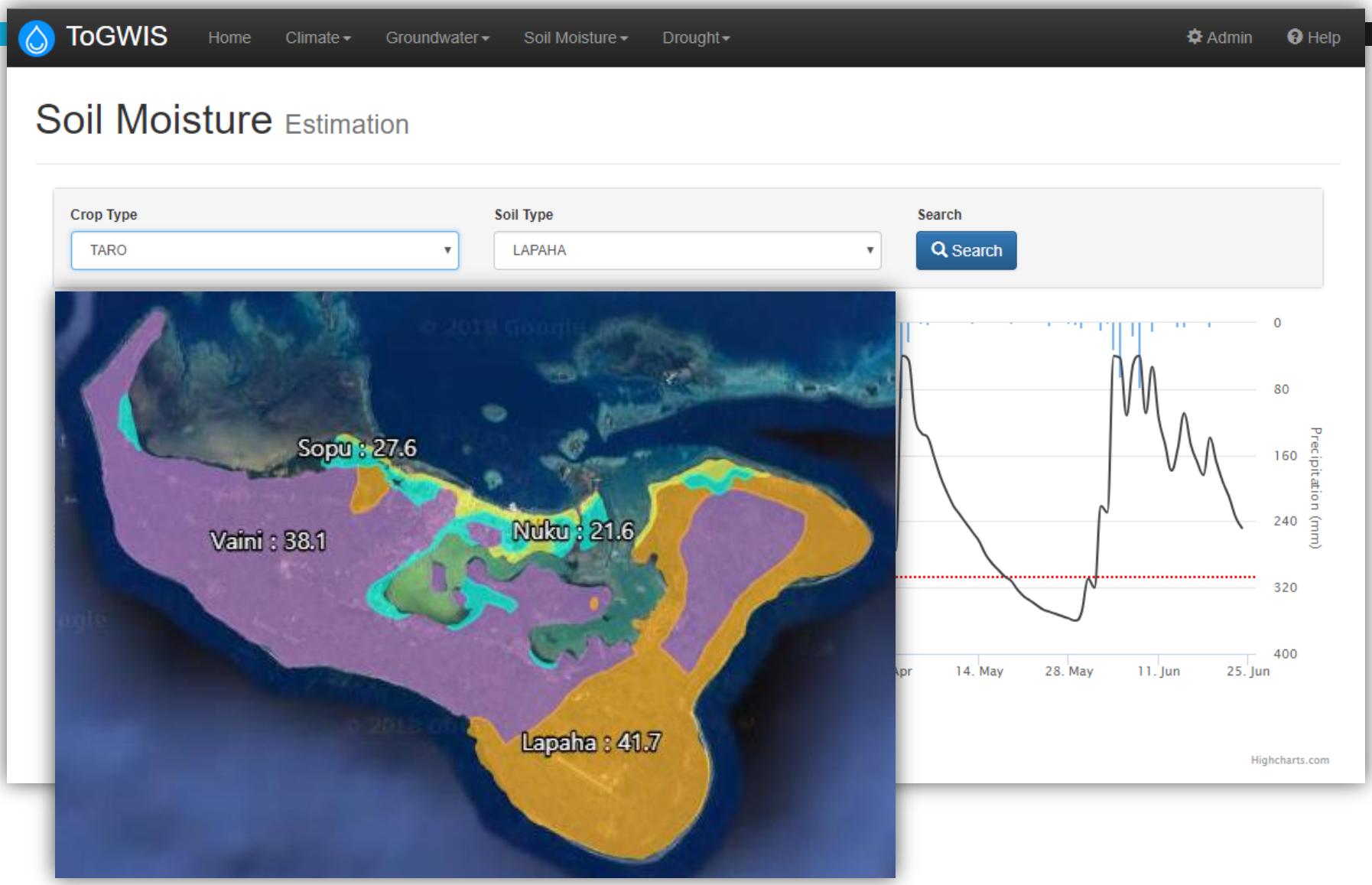
- Comparison of soil water content and simulation results for Taro cultivation area of Vaini Farm
- Use physical information of Vaini clay, not actual soil information, in the model

SWC estimation for Fua'amotu Farm soil

- Comparison of SWC observation data and simulation results on Vanilla cultivation area of Fua'amotu Farm
- The simulation results are generally lower than the observed values
- Significantly similar patterns since the large rainfall on May 23 and 24.

Smart Agricultural Water Management

ToGWIS



Thank you for your attention!

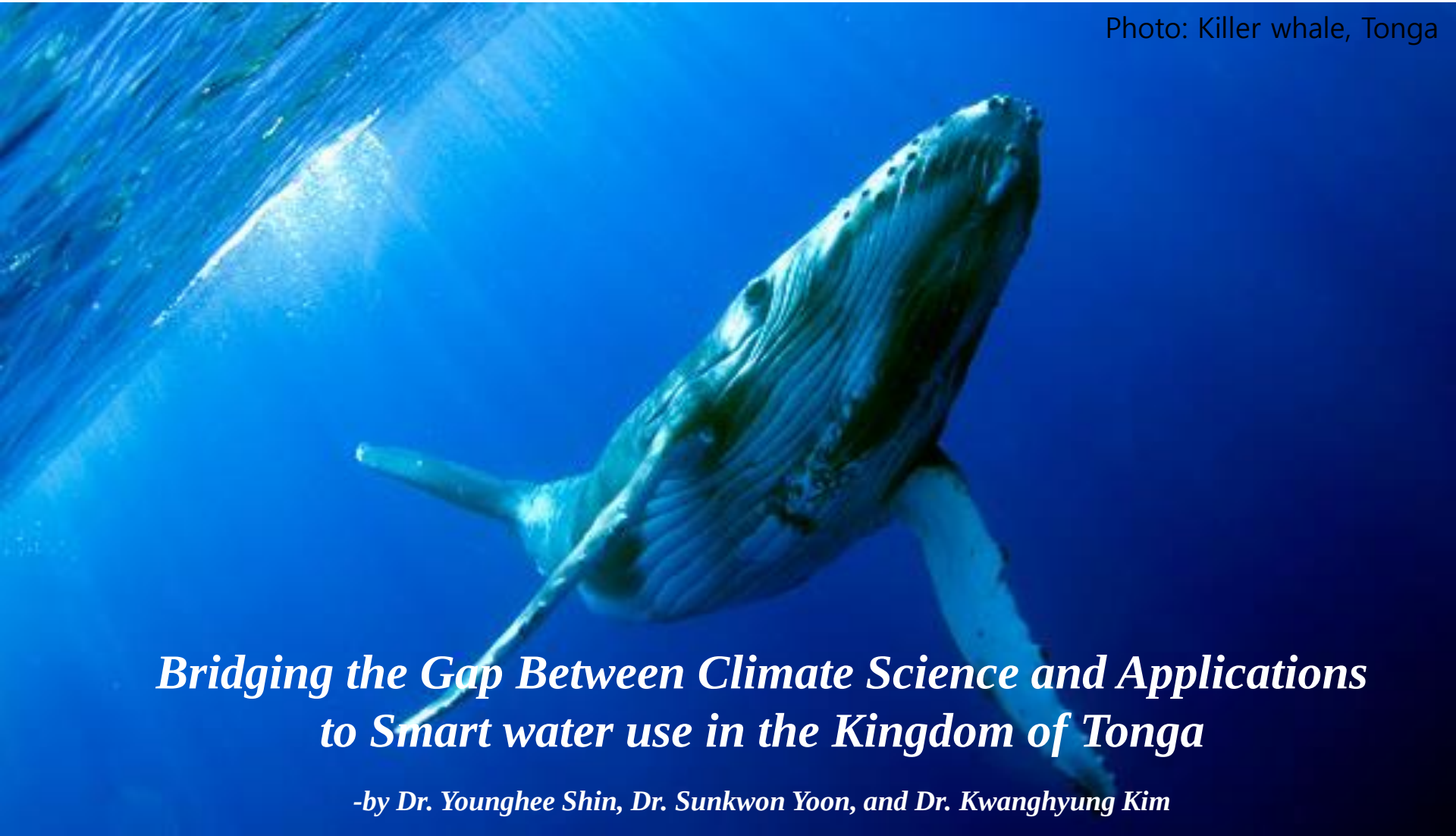


Photo: Killer whale, Tonga

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

-by Dr. Younghee Shin, Dr. Sunkwon Yoon, and Dr. Kwanghyung Kim

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

28 June, 2018

Sunkwon Yoon, Ph.D.

APCC APEC CLIMATE CENTER

Contents

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

I Project Overview

APCC
APEC CLIMATE CENTER

Background

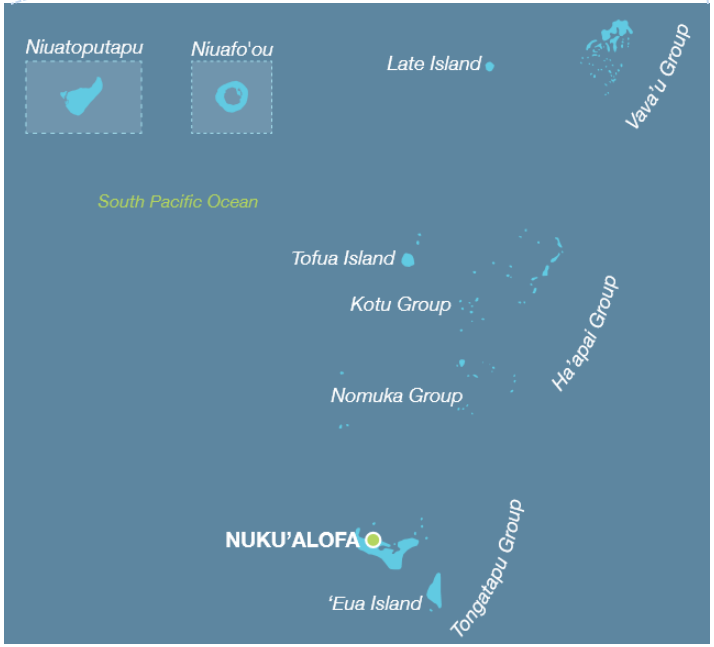
- The Kingdom of Tonga face diverse and difficult water challenges
- For example, the supply and demand of water resource in Tonga is regionally biased and the quantity and quality of it are at high risk due to the pollution and depletion of surface water as well as seawater intrusion
- These facts affect 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)

1st (2016-year)

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

2nd (2017-year)

Extending Web-based System and Developing GW Seasonal Forecasting System

3rd (2018-year)

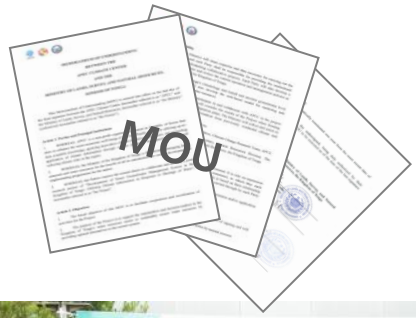
Development of Smart Tonga Water Information System & Funding from KOICA

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 – 1st Visit
- Feb. '16: Project MOU between APCC and Tonga
- Mar. '16: Start the Tonga Water Project
- Jul. '16: Installation of Sensors and Server – 2nd Visit
- Mar. '17: APCC-Tonga Joint Workshop and Agri-Water Project MOU @ TONGA – 3rd Visit
- Jul. '17: Installation of Sensors and Server – 4th Visit
- Jun. '18: Final Workshop @ Tonga -5th Visit

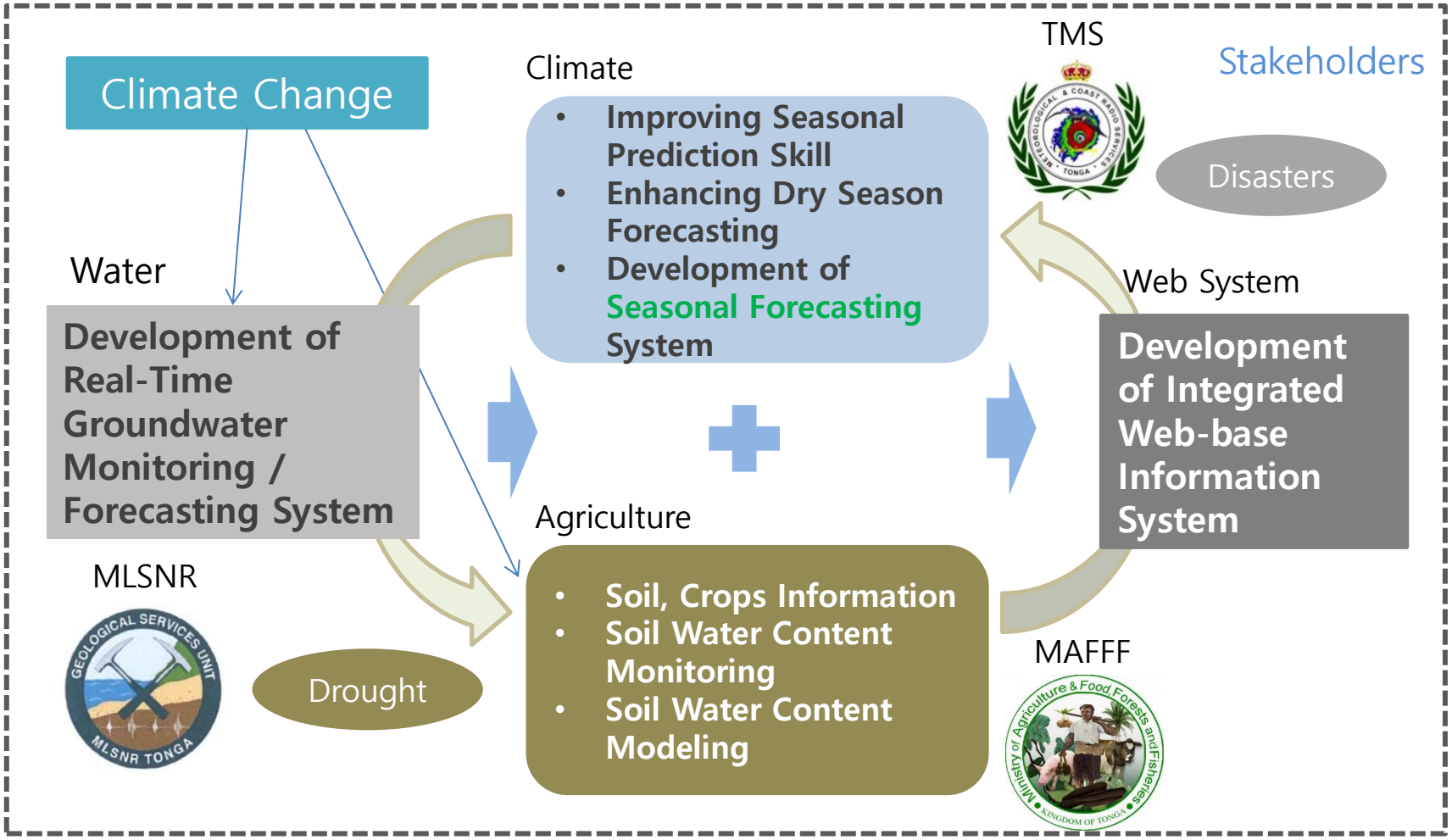
Delegation Meeting @ APCC

Tonga MLSNR office

Background of Tonga Project

Tonga Agri-Water Project Design

APCC-Tonga Agri-Water Project



Background of Tonga Project

Tonga Agri-Water Project MOU

Agro-Water Project MOU at TANOA 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-MAFFF-MLSNR

II Climate Change and Water

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

APCC
APEC CLIMATE CENTER

Background

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^2
Land	718 km^2
Water	30 km^2
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

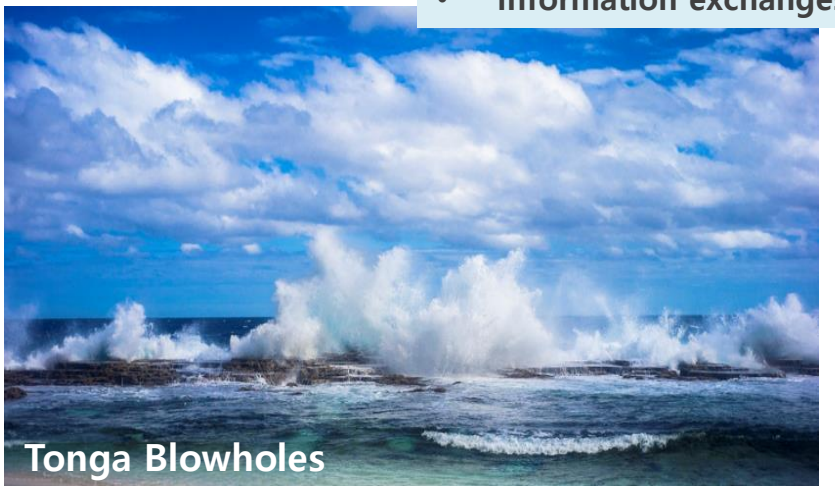
GDP per capita (PPP)	$2,200 (2005 est.)

Water Statistics

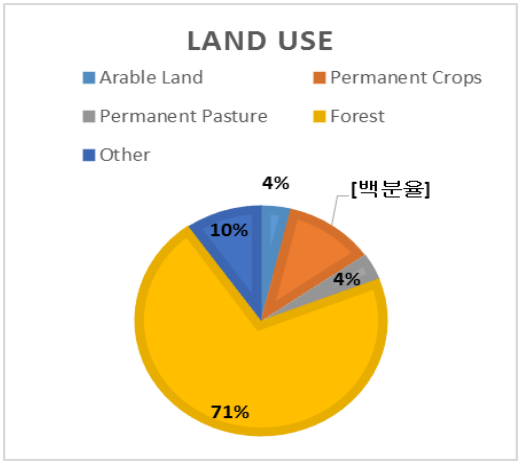
Avg Rainfall	Varies from north to south of Tonga with an estimated average of 2500 mm per annum

Problems with Water Resources

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



Tonga Blowholes



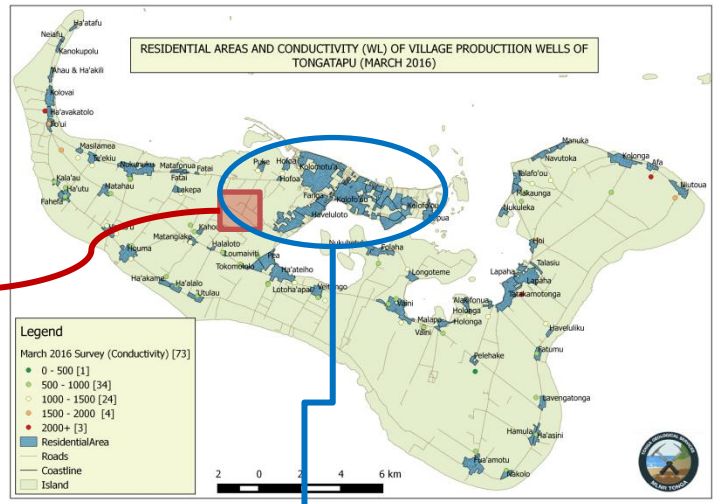
Source of Water	Drinking water coverage estimates					
	Urban (%)		Rural (%)		Total (%)	
	1990	2015	1990	2015	1990	2015
Piped onto premises	--	73	--	80	--	78
Other improved source	97	100	99	100	99	100
Other unimproved	3	0	1	0	1	0
Surface water	--	0	--	0	--	0

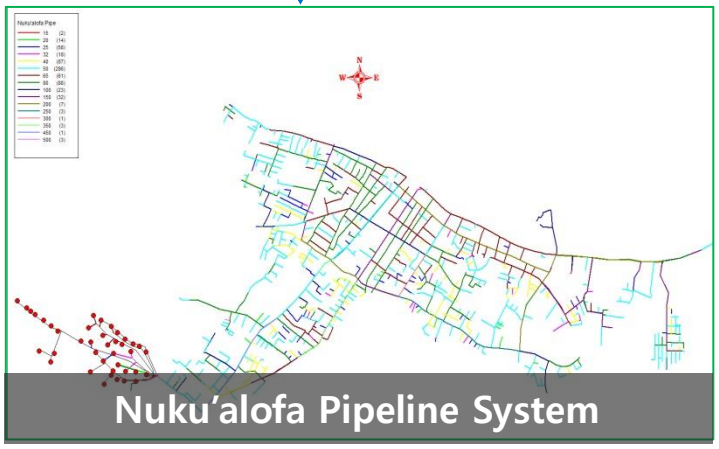
Water Resources in Tonga

Tonga Urban & Rural Water Distribution System

Urban

Groundwater
Pipe Line System



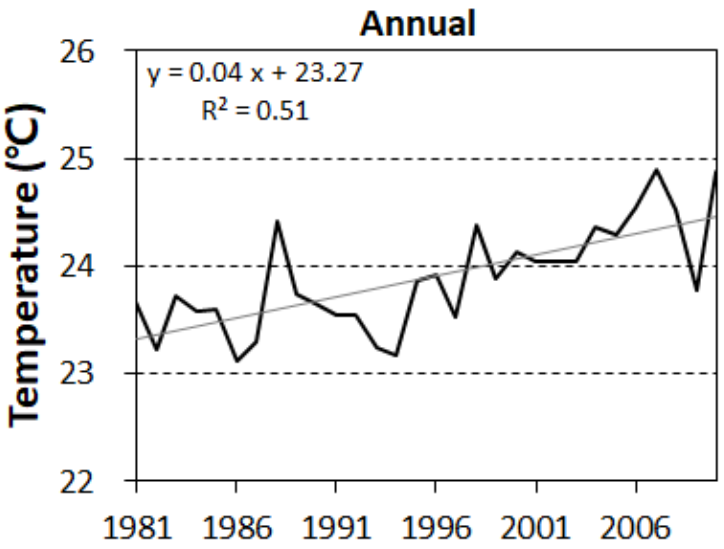


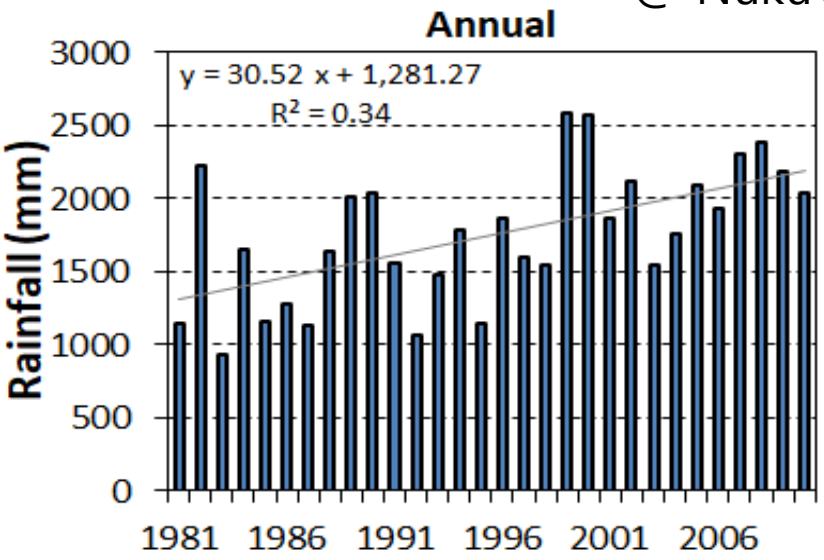
Rural

Rainwater
Harvesting

Climate: Historical Observation Data

@ Nuku'alofa





○ Annual Temperature: 23.9 ℃

- Max: Feb. 26.5 ℃
- Min.: Aug. 21.3 ℃

Last 30-year: Temperature was increased about 1.2 ℃

○ Annual Precipitation: 1,754 mm

-Wet Season: Nov. to Apr. 1,057 mm

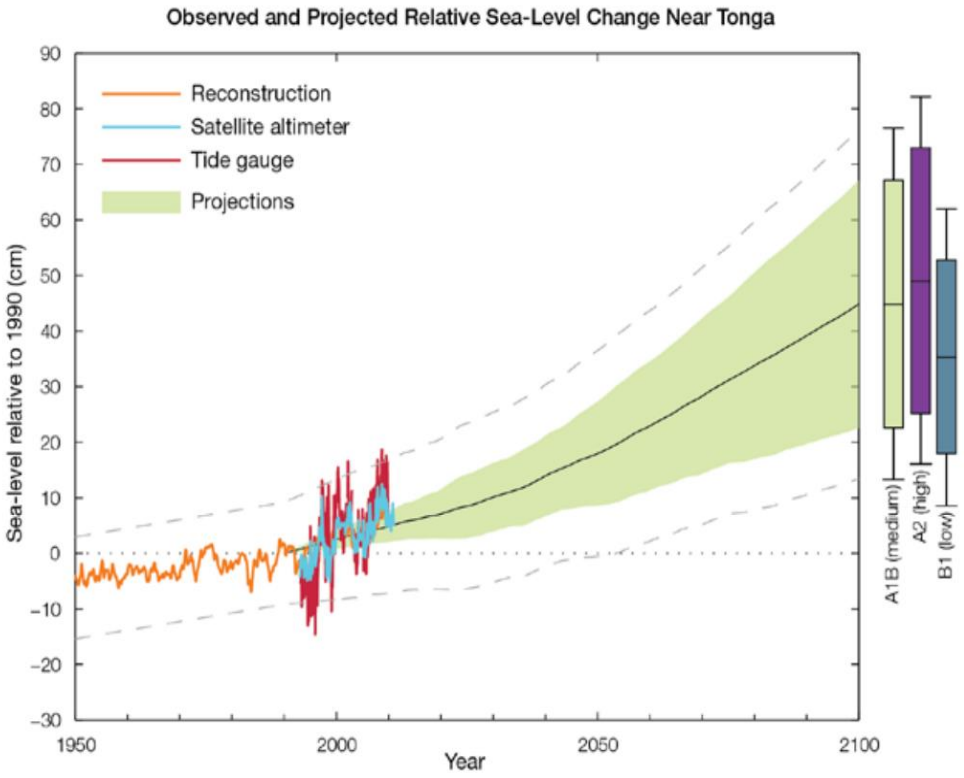
-Dry Season: May to Oct. 697 mm

Last 30-year: Precipitation was increased about 900 mm

Sea Level Rise under Climate Change

Observed and Projected relative sea level change

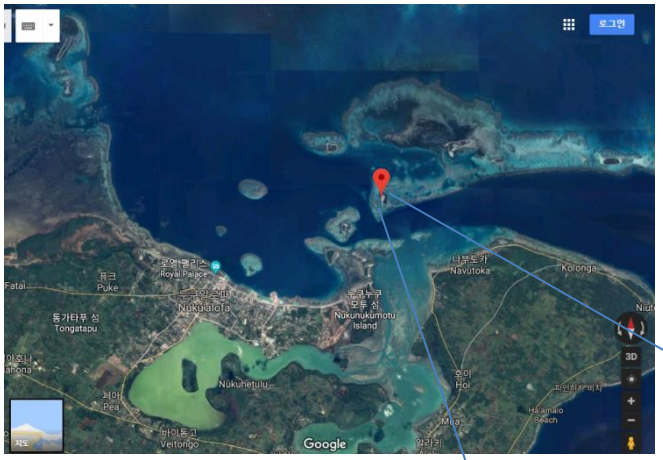
(PCCSP, 2014)



- Observation:
  Sea Level Change: **6.4 mm/year**
  (1993 to 2007)

- Climate Scenario Projection:
  2030-year: **5-15cm** increased
  2090-year: **20-60cm** increased

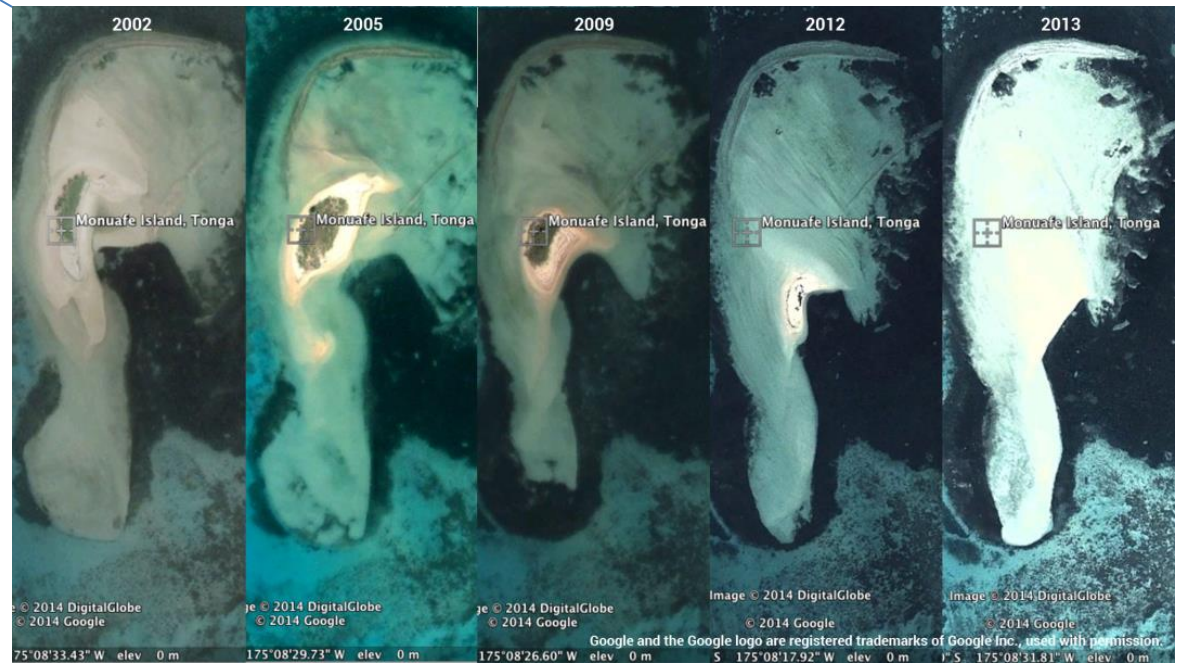
Sea Level Rise under Climate Change



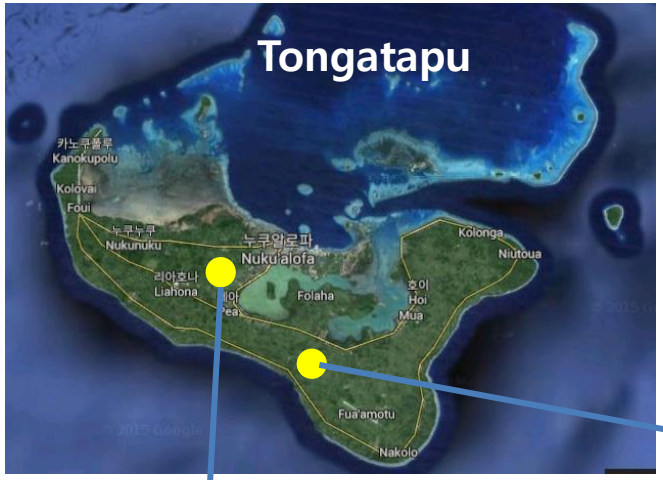
Monuafe Island

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



Soil Texture



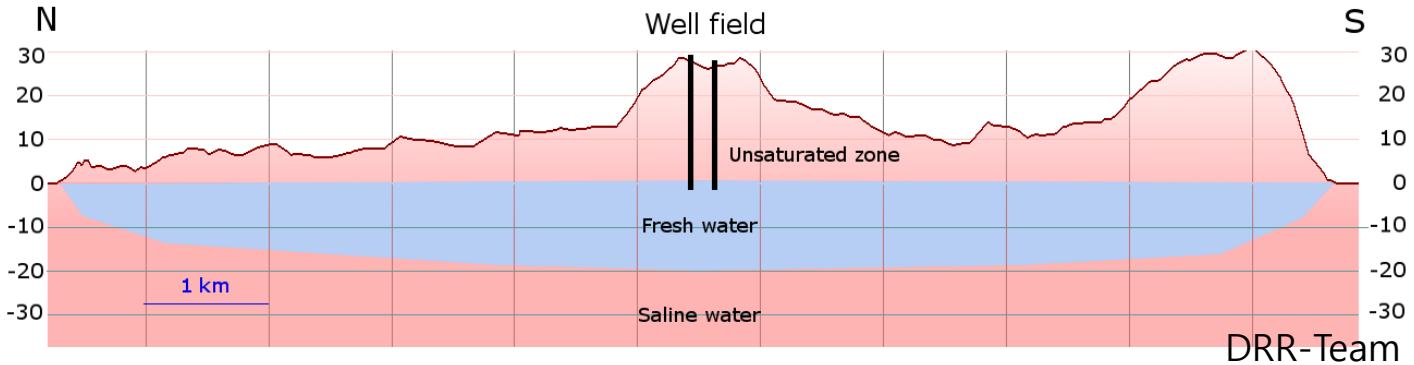
Picture of the exposed limestone aquifer in a quarry 5 km south-east of the Mataki'eua well field

Soil mantle of variable thickness developed in volcanic ash deposits

Water Resources Assessment

Underground Water

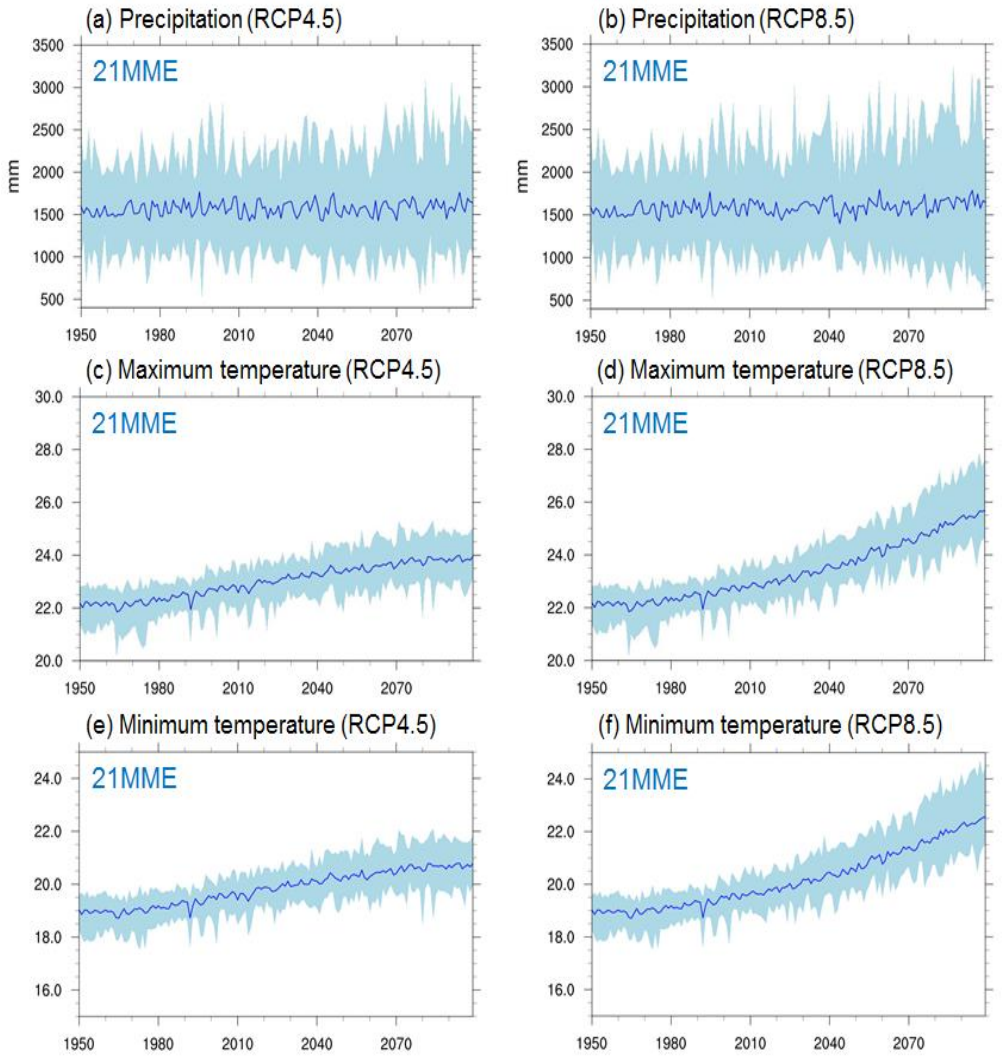
Location of a North-South elevation profile through the Mataki'eua public water supply well field area



DRR-Team Mission Report, 2016

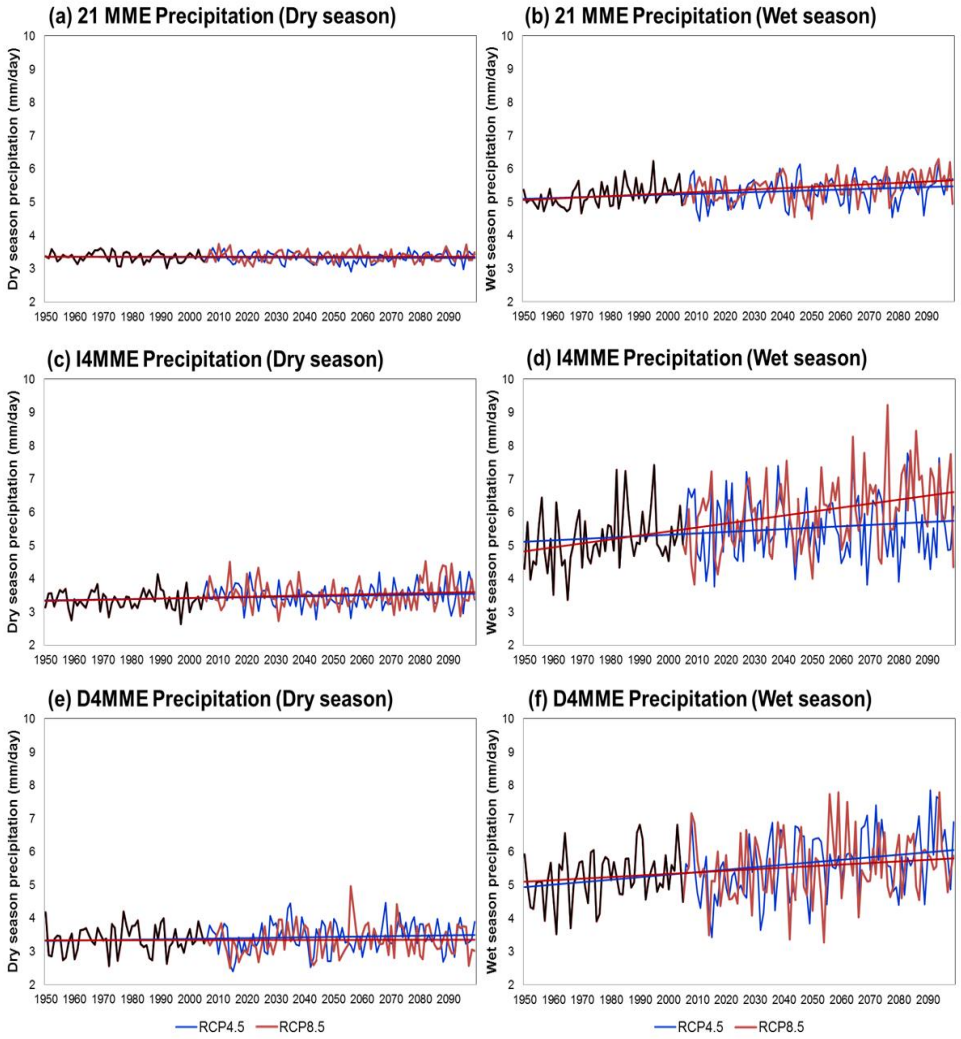
Climate Change in Tongatapu

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.



Climate Change in Tongatapu

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.

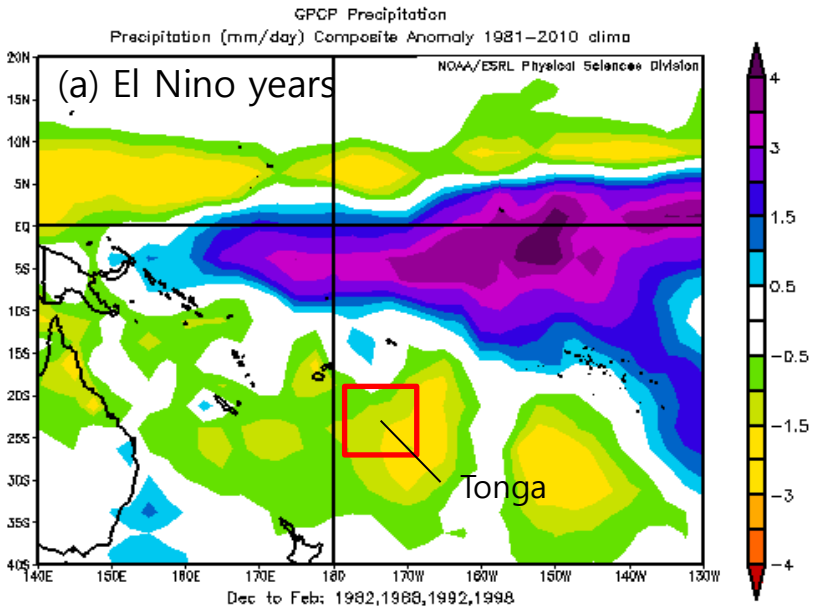


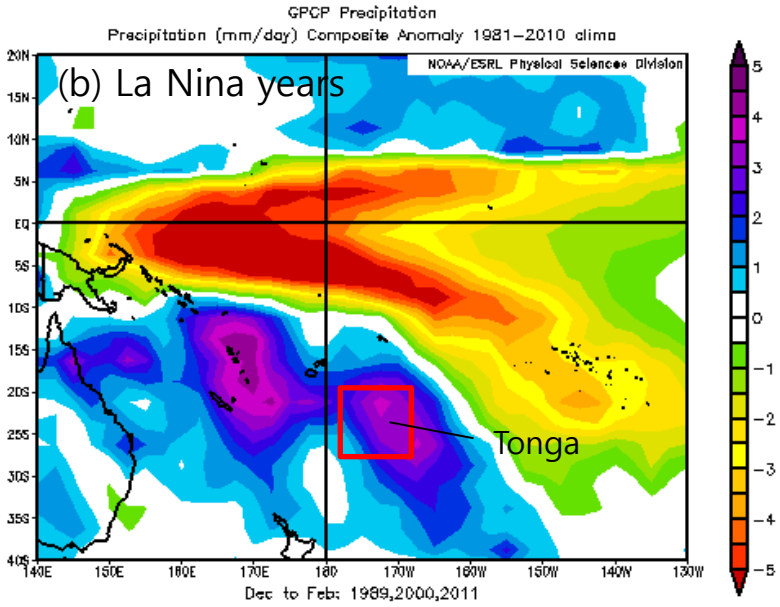
Observed Rainfall

GPCP Precipitation in Tonga

➢ **ENSO teleconnection**

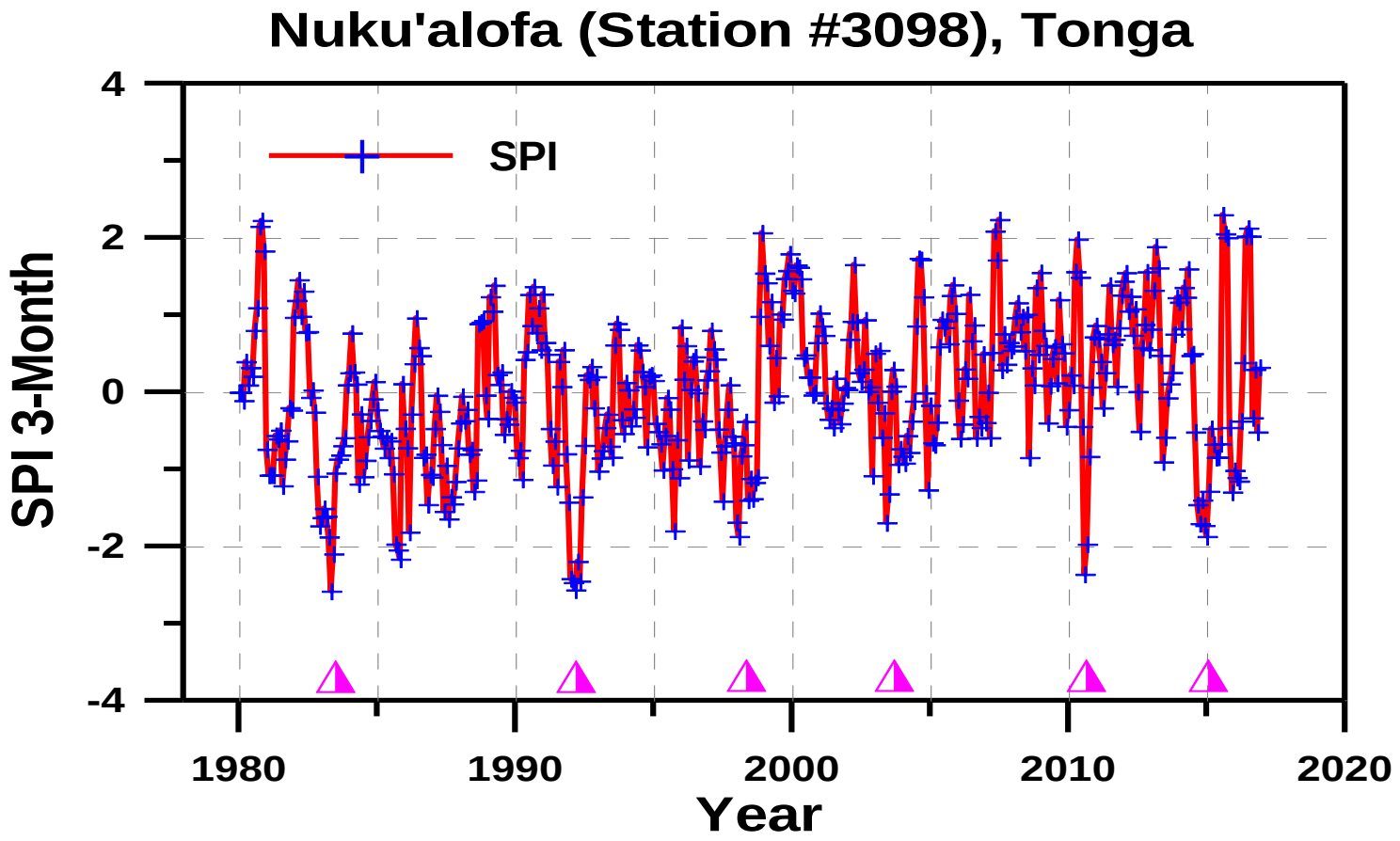
Impacts of El Niño and La Niña Episodes on Rainfall





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

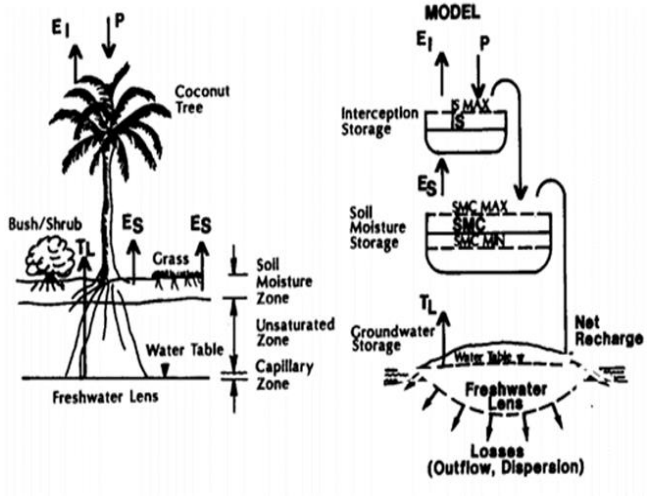
SPI 3-month drought index and strong El Nino years



Groundwater Recharge Calculation using WATBAL model in Tongatapu

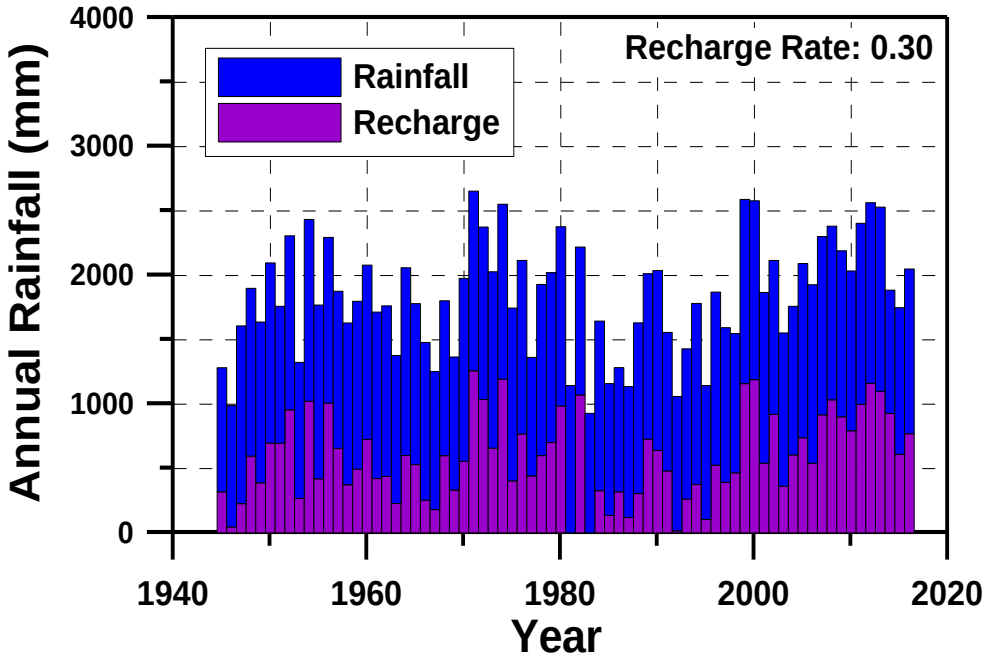
➢ WATBAL model

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



By Falkland and Woodroffe, 1997

➢ Groundwater Recharge

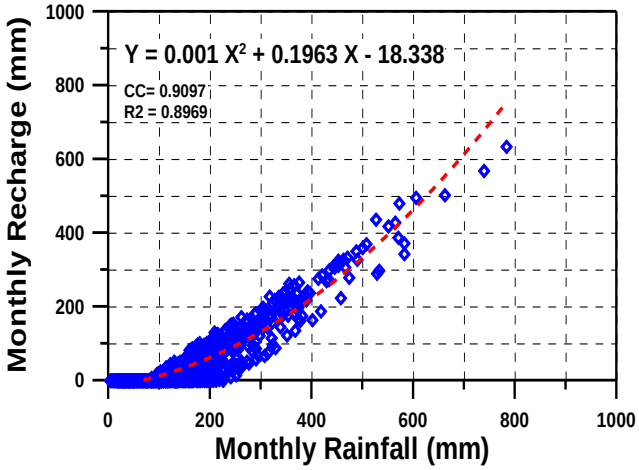


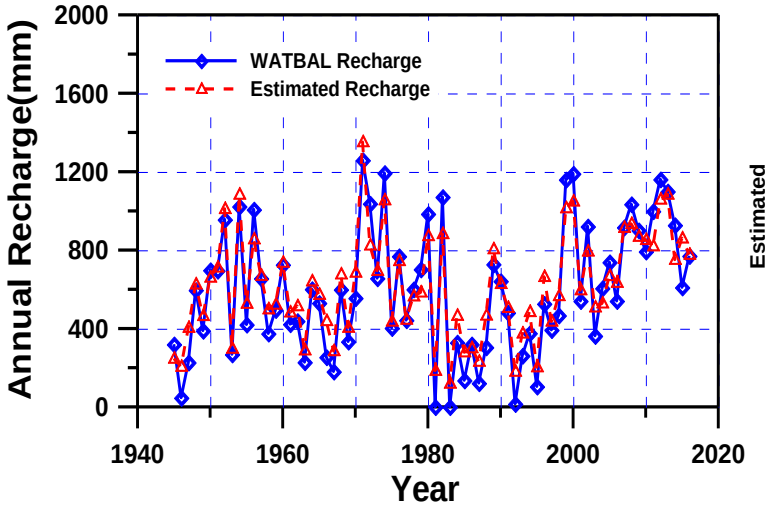
➢ Hamon(1963) Potential Evapotranspiration

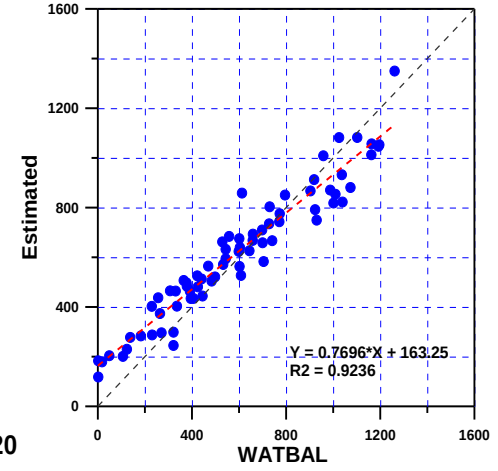
$$PET = k \times 0.165 \times 216.7 \times N \times \left(\frac{e_s}{T + 273.3} \right), \qquad e_s = 6.108 e^{\left(\frac{17.27T}{T + 237.3} \right)}$$

Annual rainfall and groundwater recharge model in Tongatapu

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







III Project Main Outputs

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

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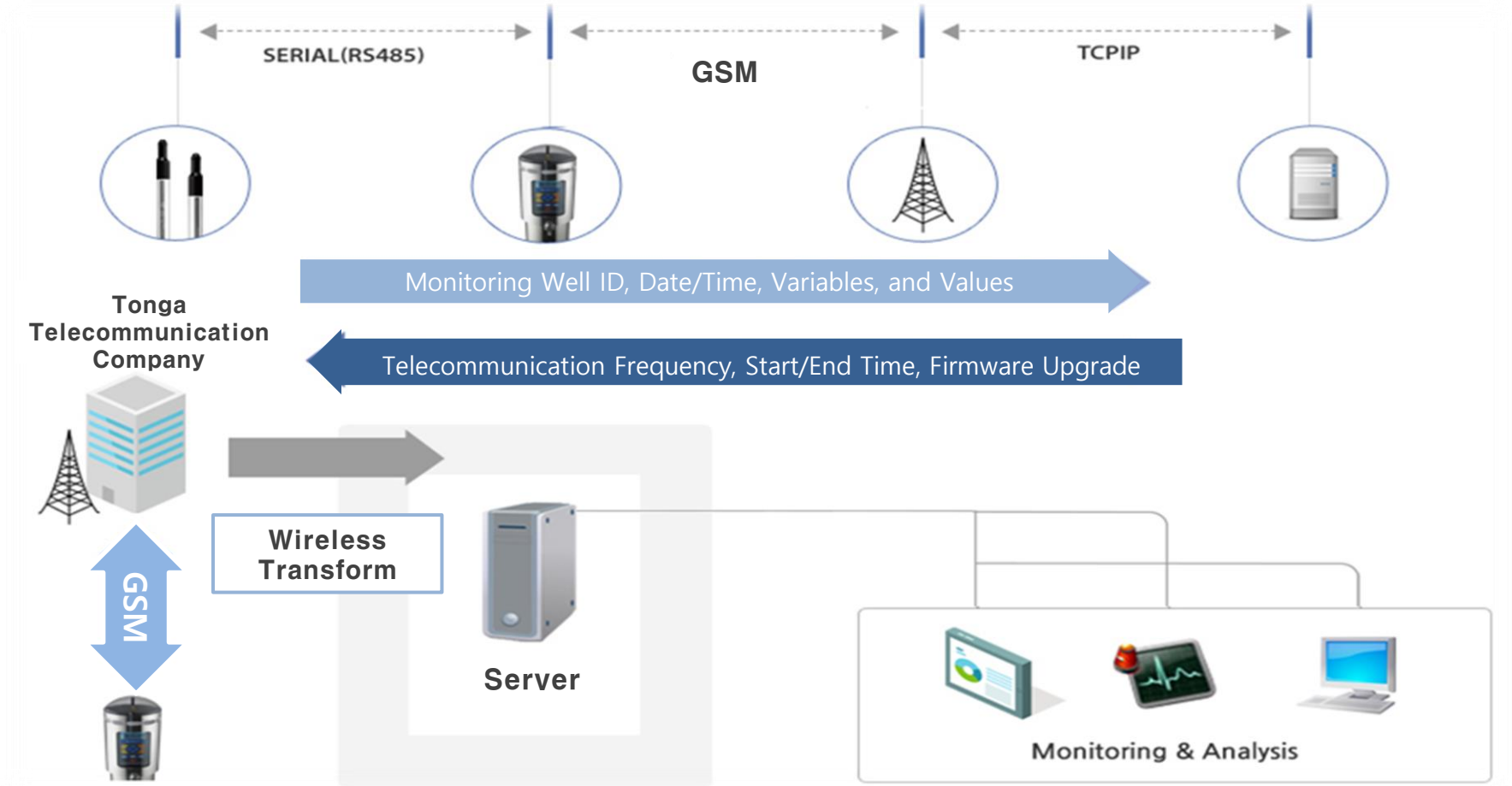
Tonga GW Monitoring System (ToGWMS)

Real-Time Groundwater Monitoring System

Wireless Telecommunication System for Real-Time Groundwater Monitor



Tonga GW Monitoring System (ToGWMS)

Real-Time Groundwater Monitoring System

Sensor

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

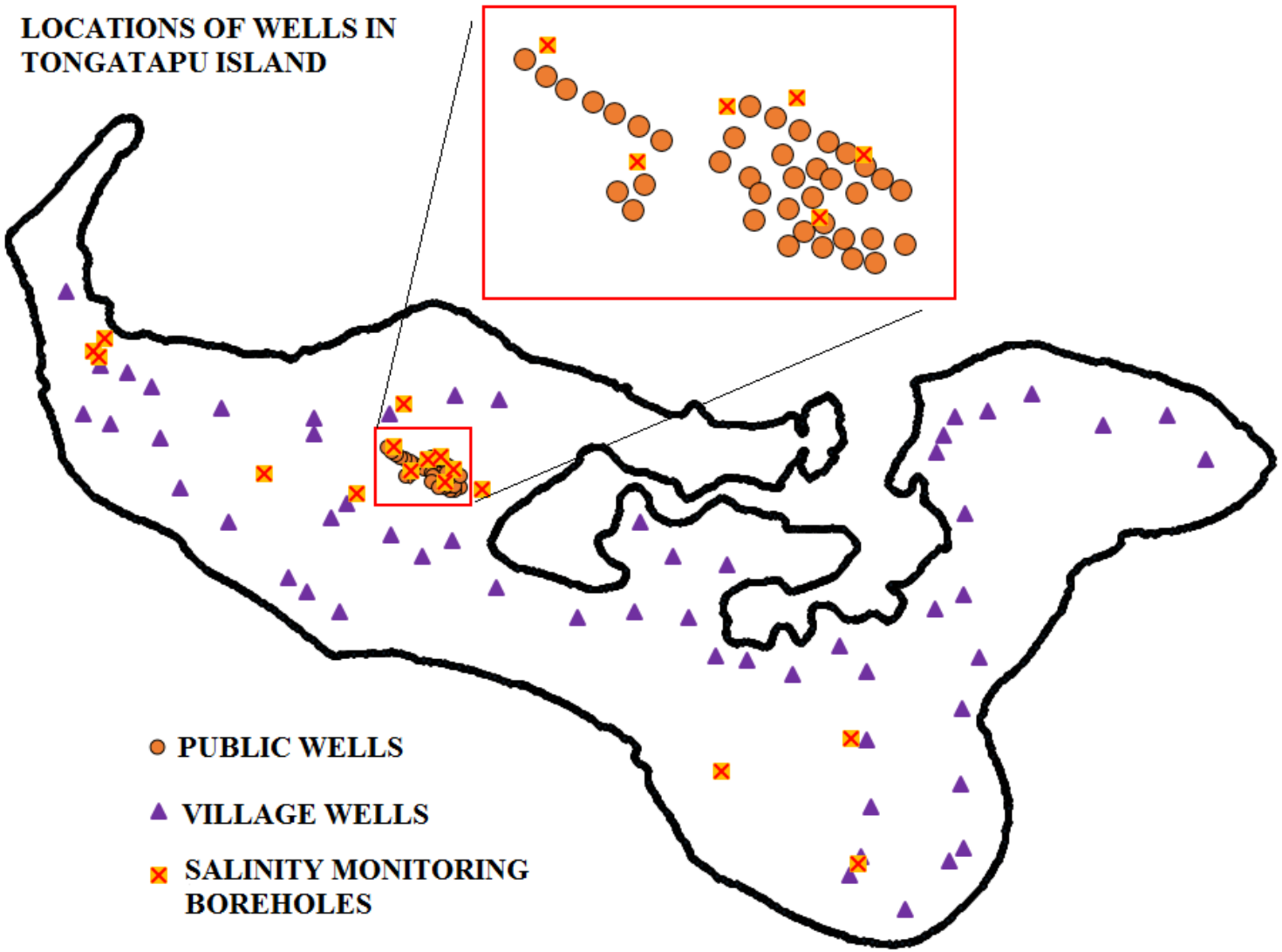
Data Logger

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

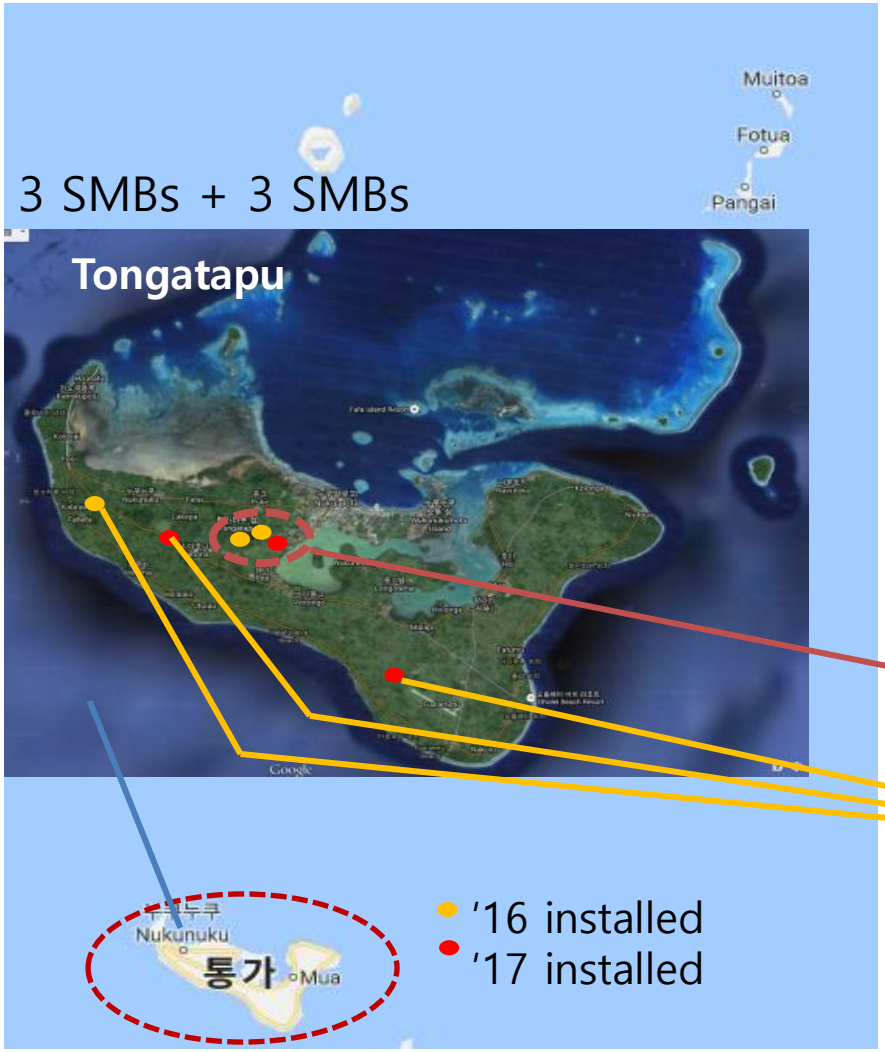
STU-CAP

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

Tongatapu Well Locations



Locations of the data loggers and sensors



TOTAL

- 6 SMBs
- 6 Data Loggers
- 9 Sensors

Multi-Sensors

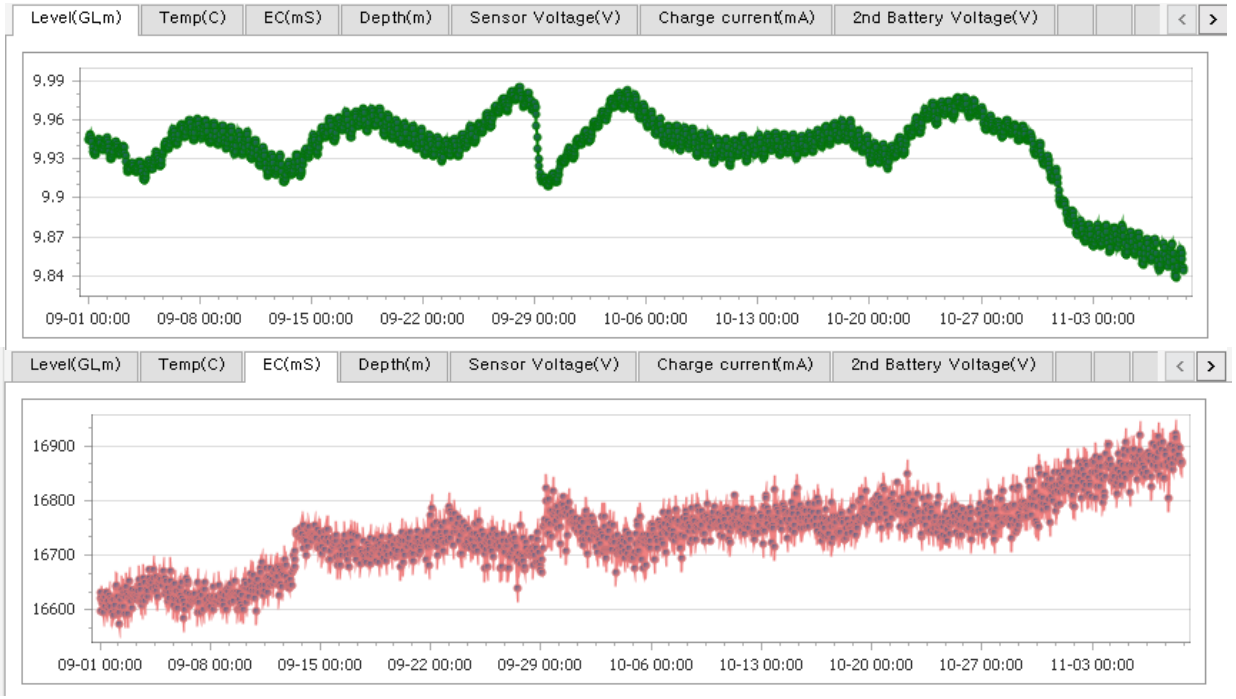
Single Sensors


The Real-Time Groundwater Monitoring System

Tonga GW Monitoring System (ToGWMS)

Real-Time Groundwater Monitoring System

Mataki 'Eua Well Field



Tonga GW Monitoring System (ToGWMS)

Real-Time Groundwater Monitoring System

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)	• Tube #3: 16.50m • Tube #4: 22.50m	• Tube #3: 30.00m • Tube #4: 26.82m	• Tube #2: 17.00m
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).

Tonga GW Monitoring System (ToGWMS)

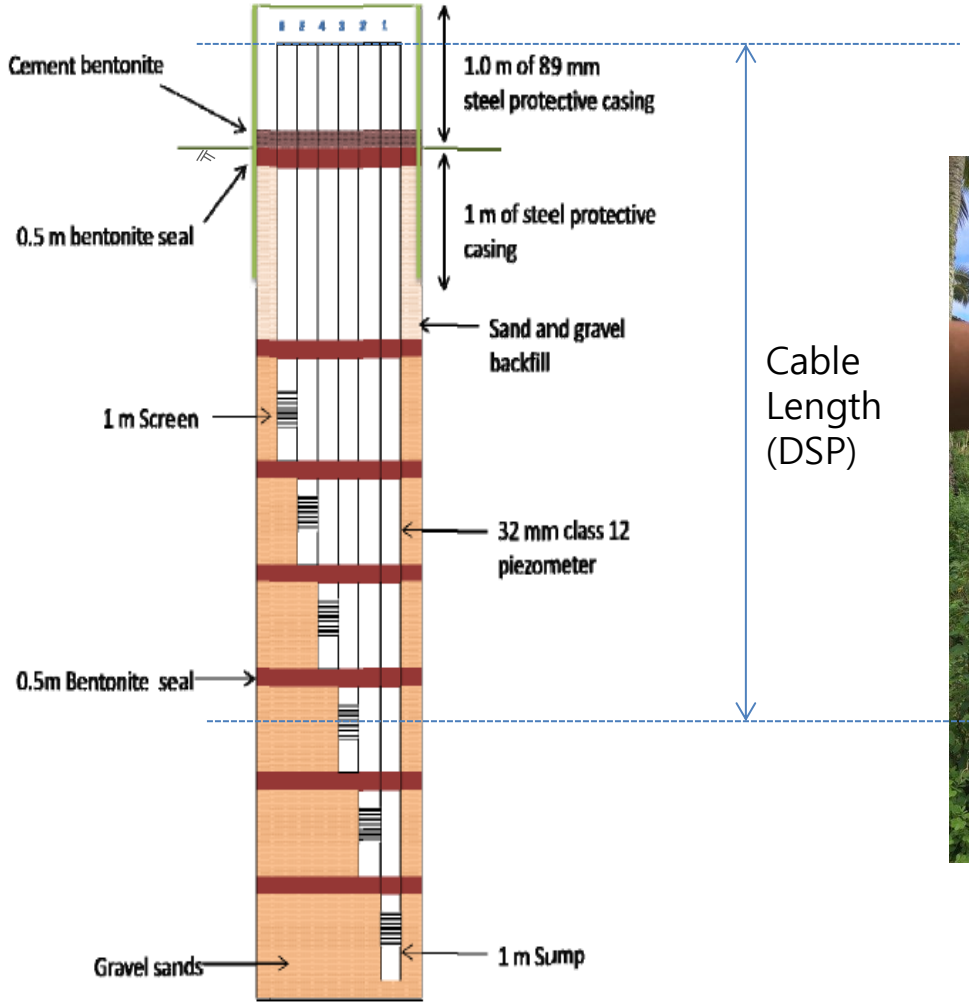
Real-Time Groundwater Monitoring System

The sensors and data Loggers are installed in 2017

SMBs	SMB 01	SMB 08	SMB 09
Address	South side of track between Mataki'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)	• Tube #2: 19.79m • Tube #3: 14.70m	• Tube #5: 19.00m	• Tube #4: 38.00m
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)

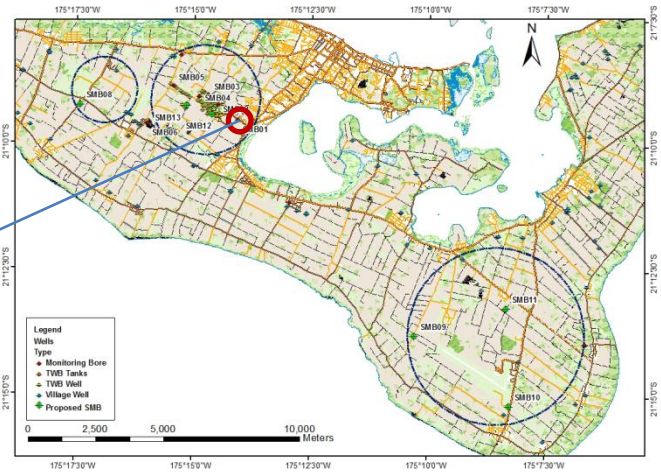


*Base Map Source: Kate (2012), Expansion of the salinity monitoring network across Tongatapu, pp. 1-55.

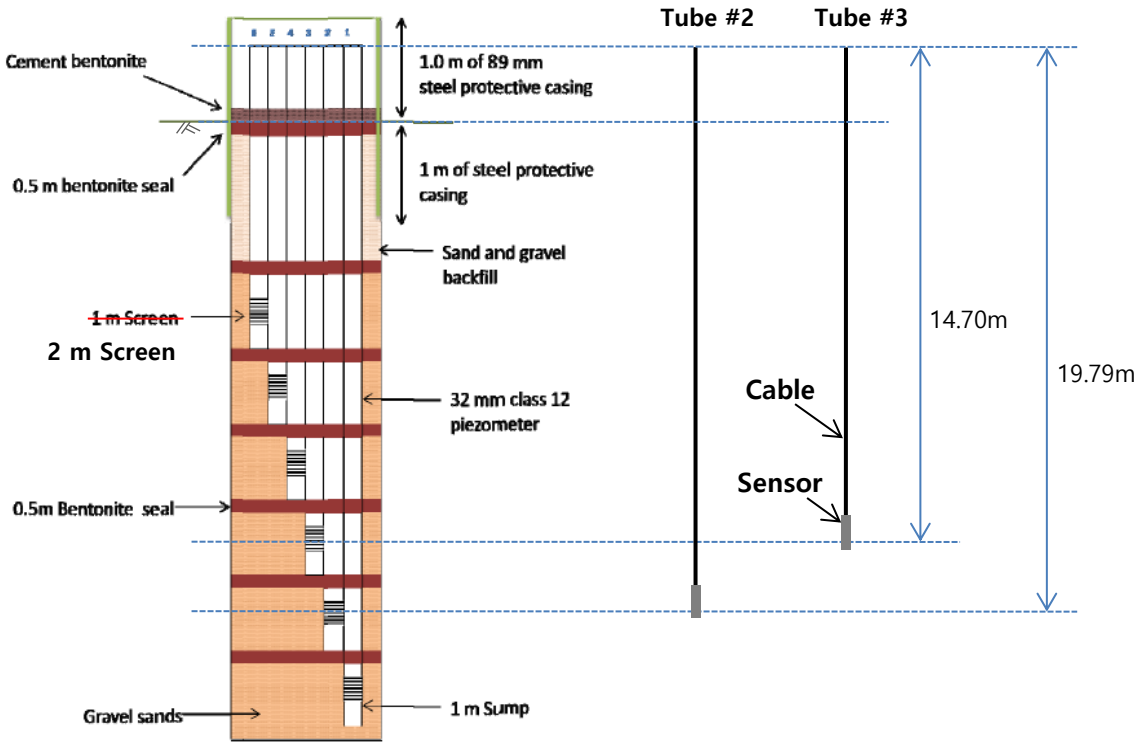
SMB01

Multi-Sensor
Tube #2, Tube #3

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



Location of sensors

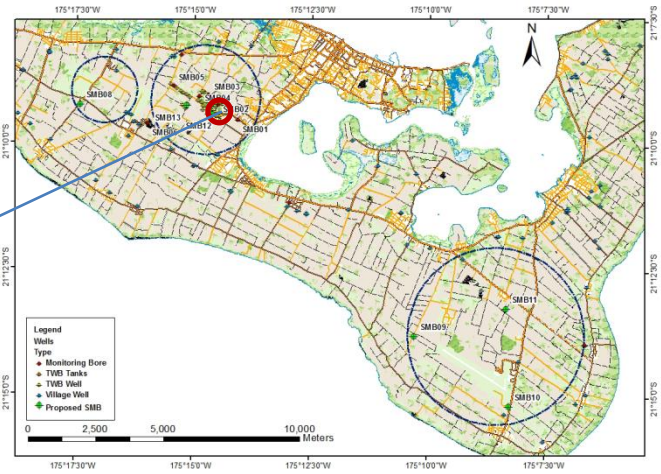


SMB01 to SMB07 and SMB14 to SMB16:
Leave 1 meter sump at base of screen and slot 2 meters

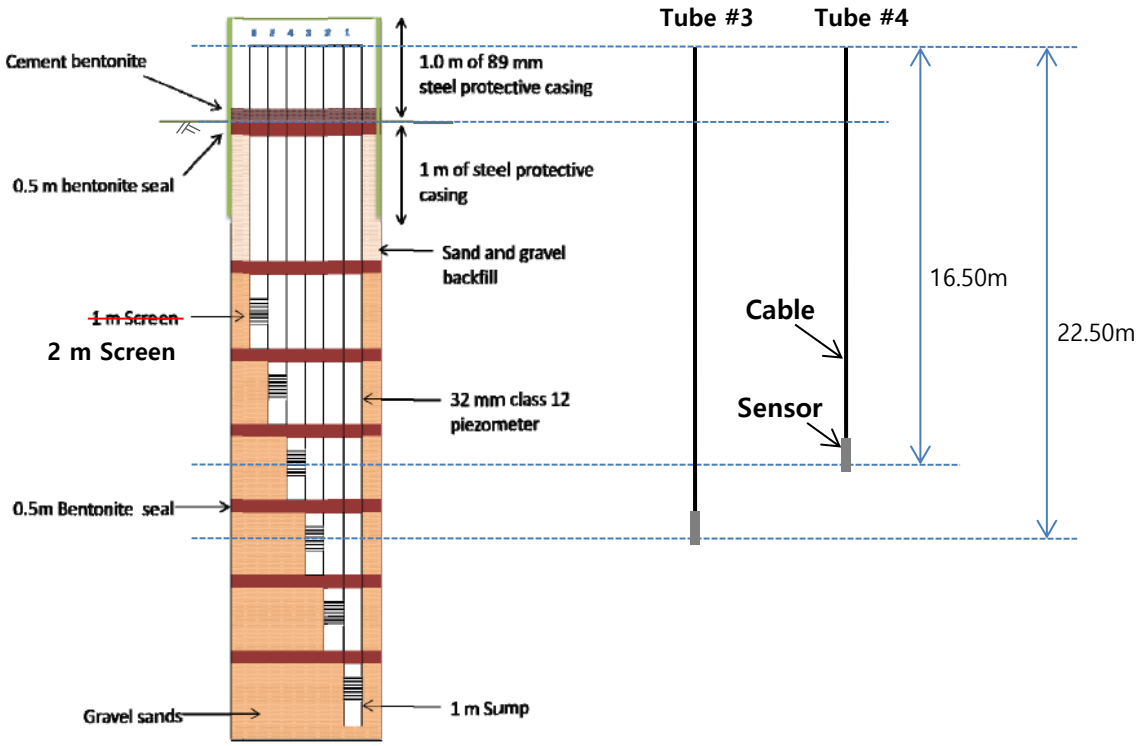
SMB02

Multi-Sensor
Tube #3, Tube #4

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



Location of sensors

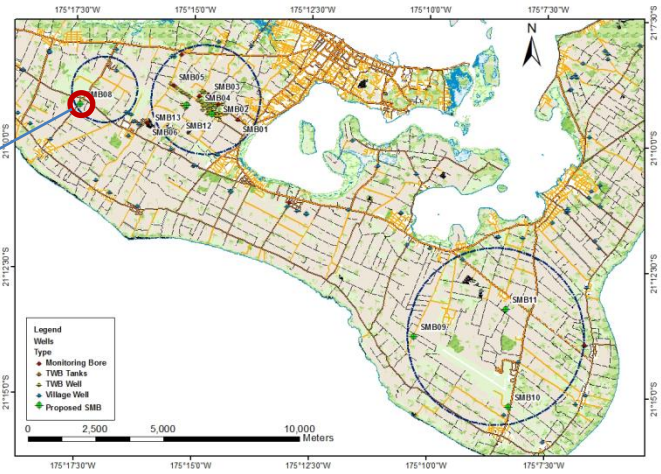


SMB01 to SMB07 and SMB14 to SMB16:
Leave 1 meter sump at base of screen and slot 2 meters

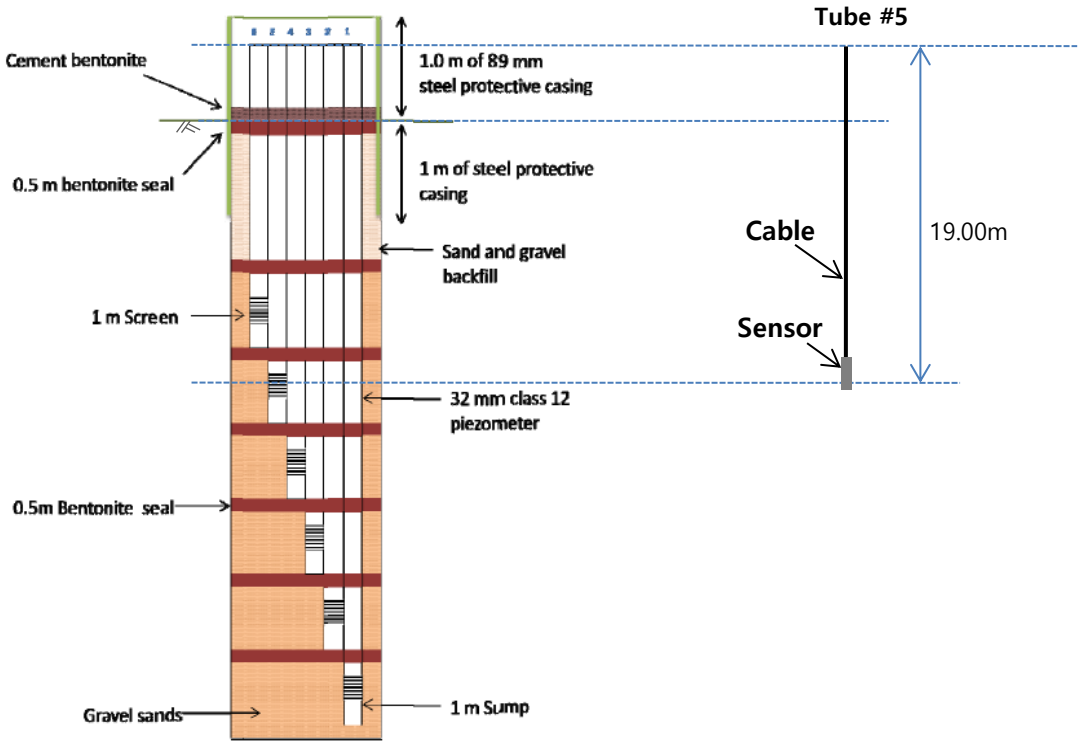
SMB08

Single Sensor
Tube #5

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



Location of sensor

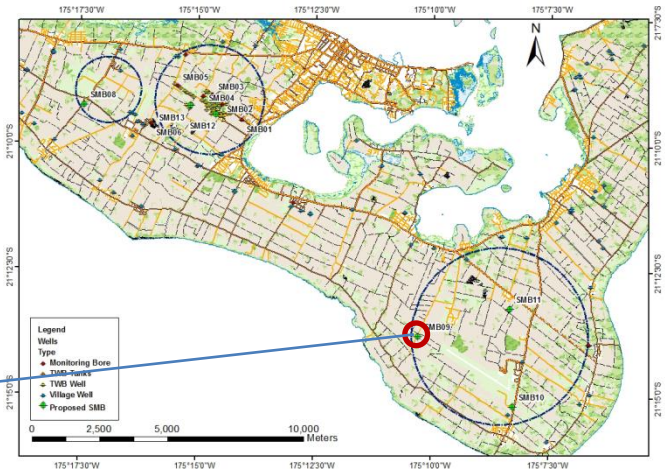


SMB08 to SM13:
Leave 1 meter sump at base of screen and slot 1 meters

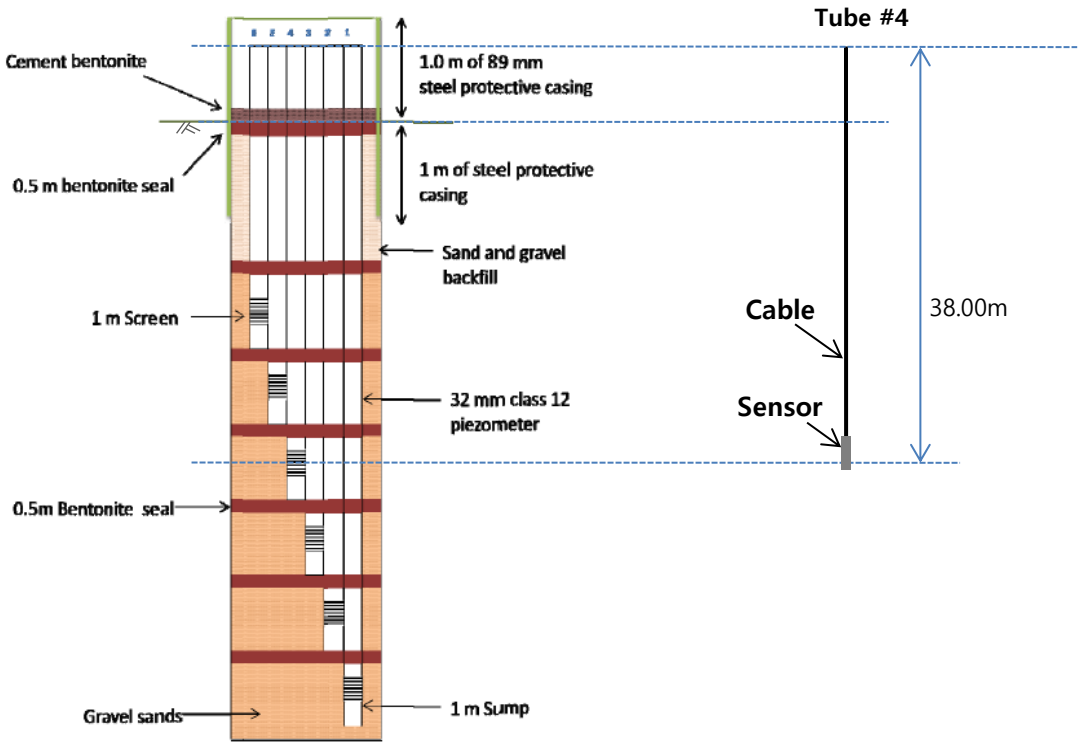
SMB09

Single Sensor
Tube #4

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



Location of sensor

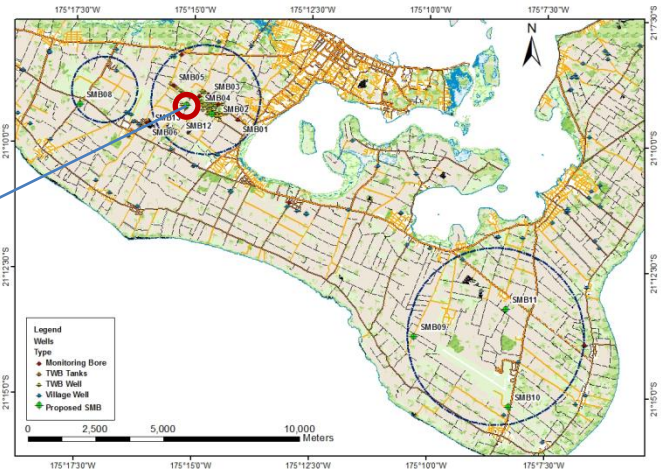


SMB08 to SM13:
Leave 1 meter sump at base of screen and slot 1 meters

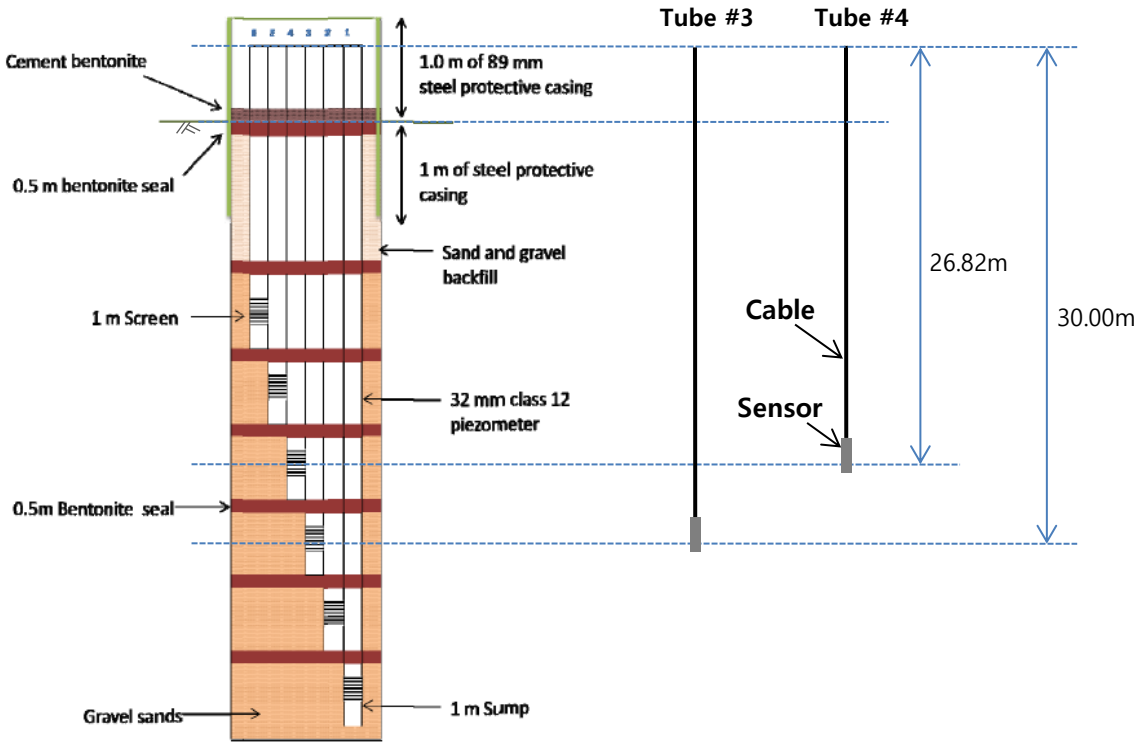
SMB13

Multi-Sensor
Tube #3, Tube #4

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



Location of sensors

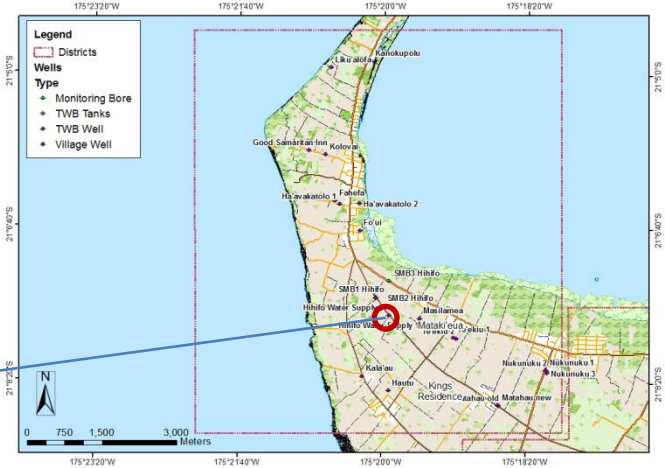


SMB08 to SM13:
Leave 1 meter sump at base of screen and slot 1 meters

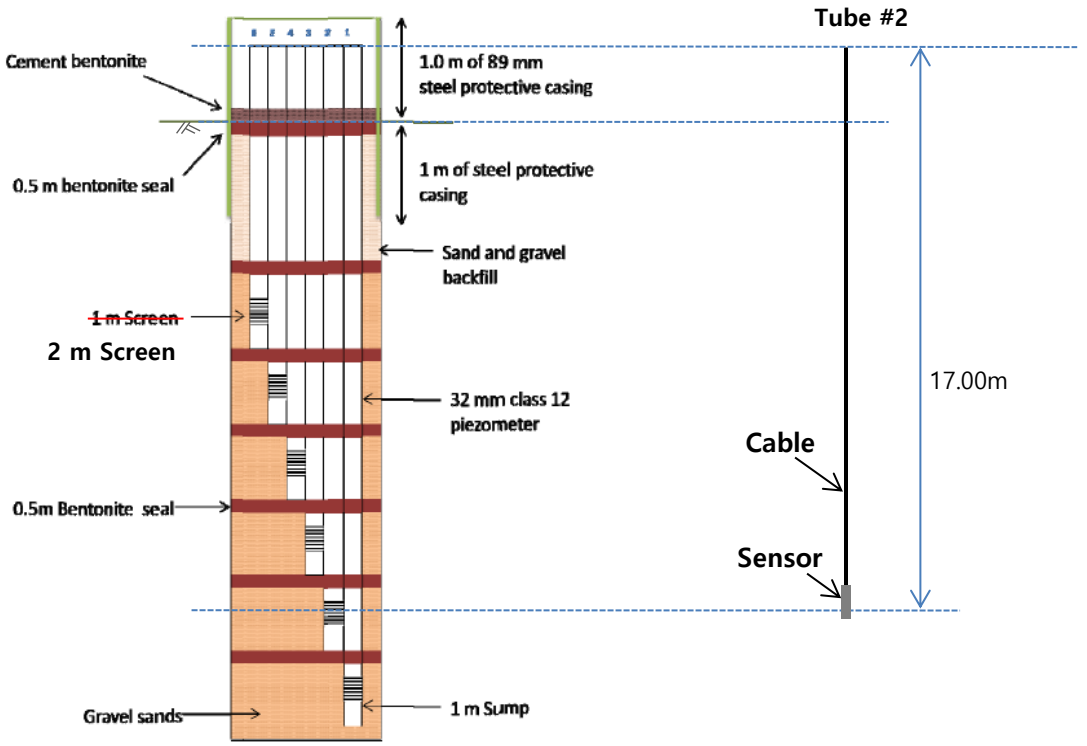
SMB15

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

Development of Tonga Groundwater Flow Model

Tonga Groundwater Flow Model (ToGFlow)

Model Characteristics

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

Model Geometry

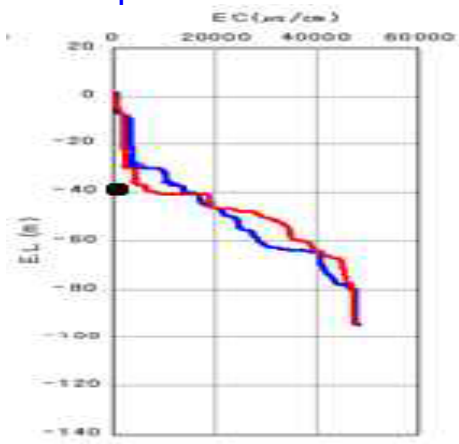
- Original Geometry
- Coordinate Rotation and Translation are needed
- Non uniform mesh 100 m X 100 m;
  25 m X 25 m in well field
- Elements: 89200 and Nodes:89824
- Coastal Boundary

Governing Equations

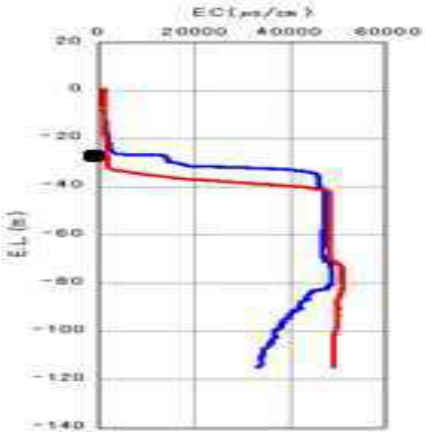
$$\frac{\partial}{\partial x_i}\left[K_{ij}^f \; b^f \; \frac{\partial h^f}{\partial x_j}\right] + \alpha_T^f \lambda'^f h^f + \alpha_B^f \lambda'^f h^f = b^f S_s^f \frac{\partial h^f}{\partial t} - \theta \frac{\partial \xi}{\partial t} - Q^f \qquad (i,j=1,2) \qquad (1)$$

$$\frac{\partial}{\partial x_i}\left[K_{ij}^s \; b^s \; \frac{\partial h^s}{\partial x_j}\right] + \alpha_T^s \lambda'^s h^s + \alpha_B^s \lambda'^s h^s = b^s S_s^s \frac{\partial h^s}{\partial t} + \theta \frac{\partial \xi}{\partial t} - Q^s \qquad (i,j=1,2) \qquad (2)$$

Dispersion



Advection



Development of Tonga Groundwater Flow Model

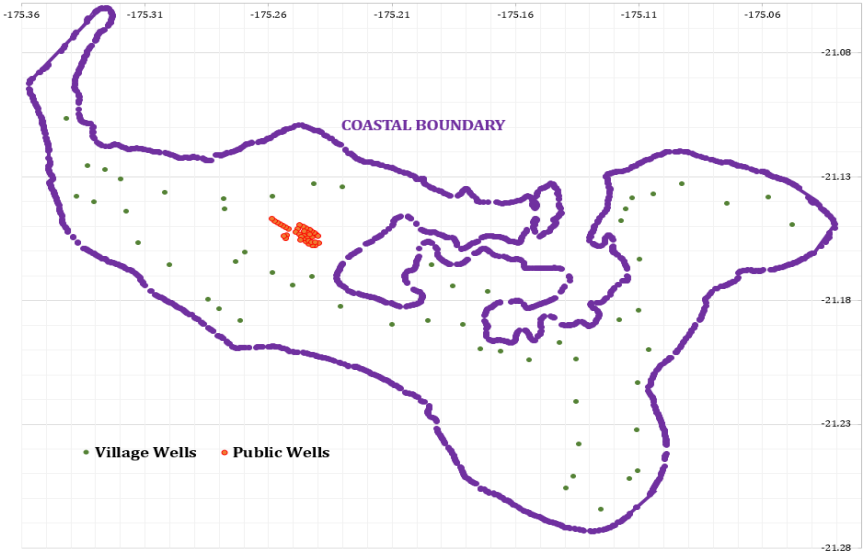
Tonga Groundwater Flow Model (ToGFlow)

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^3/day per Well
- 56 Village wells :125 m^3/day per Well

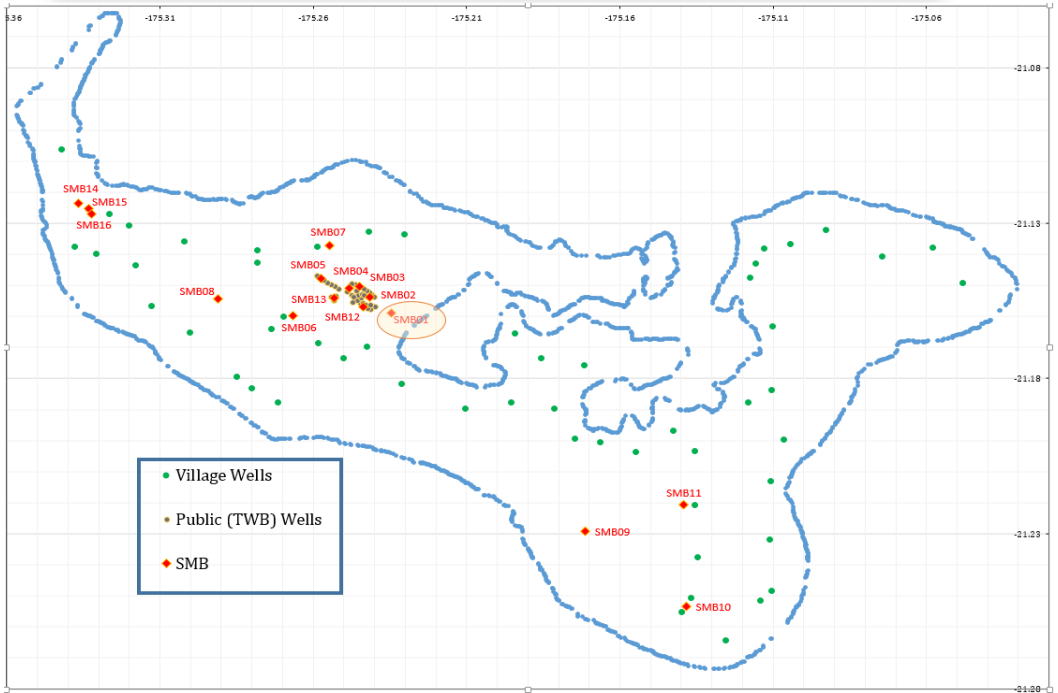


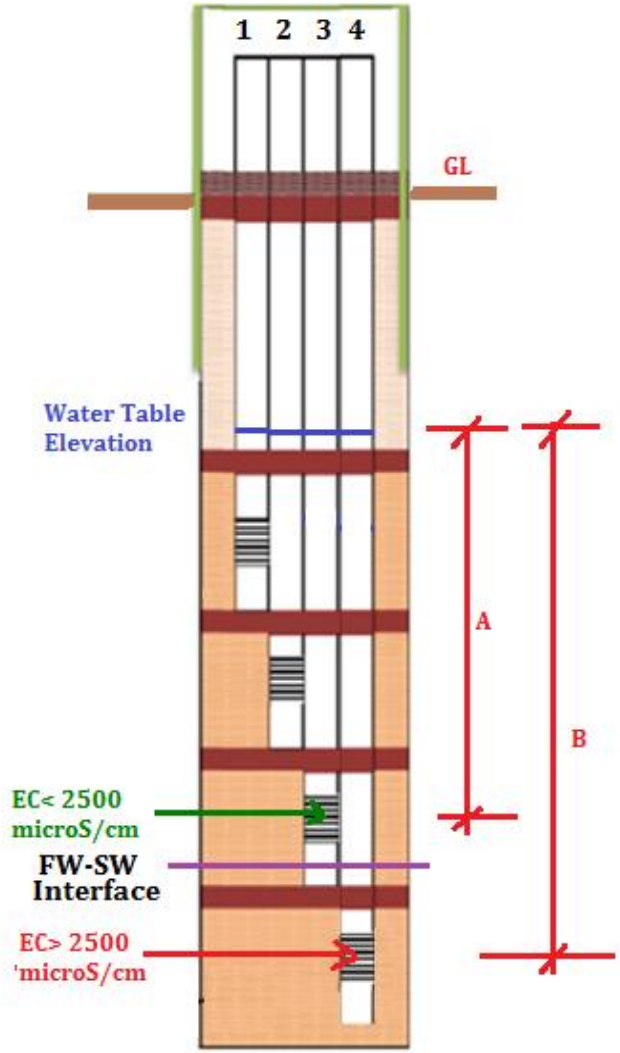
Development of Tonga Groundwater Flow Model

Tonga Groundwater Flow Model (ToGFlow)

Calibration and Validation

- Freshwater-Saltwater interface
- SMBs with constant FW-SW interface
- K value 3600 m/day
- Validation - January 2015 data





Tonga Groundwater Flow Model (ToGFlow)

Limitations

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

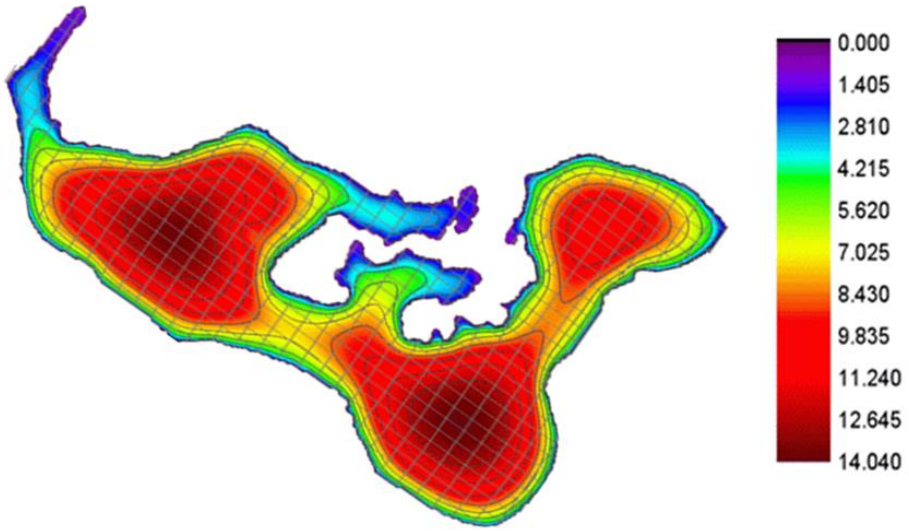
Range Input values

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^3/day	250 m^3/day
8	Pumping Rates-Village Wells	50-450 m^3/day	125 m^3/day
9	Monitoring Wells		16

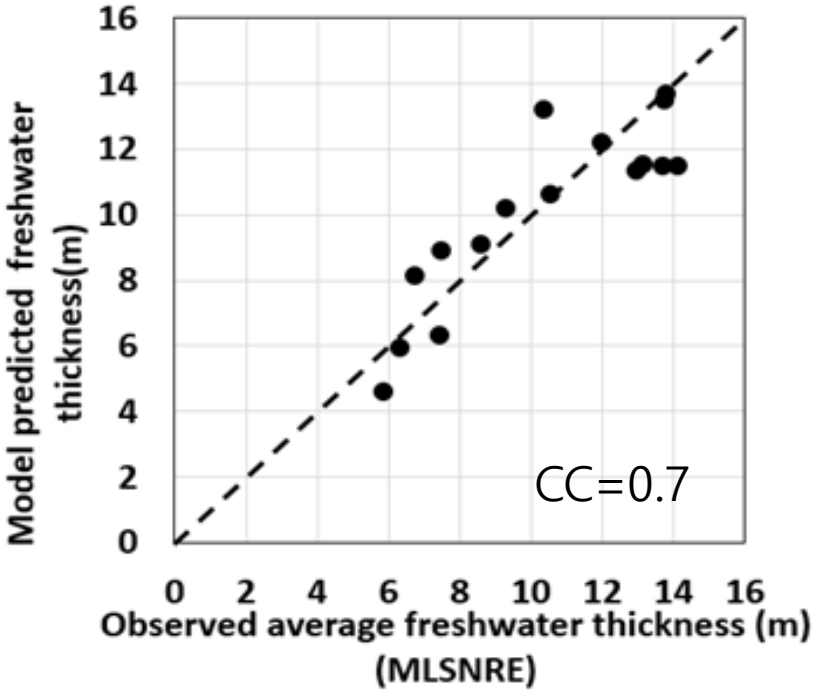
Tonga Groundwater Flow Model (ToGFlow)

Steady state analysis results

➢ Freshwater Thickness (m)

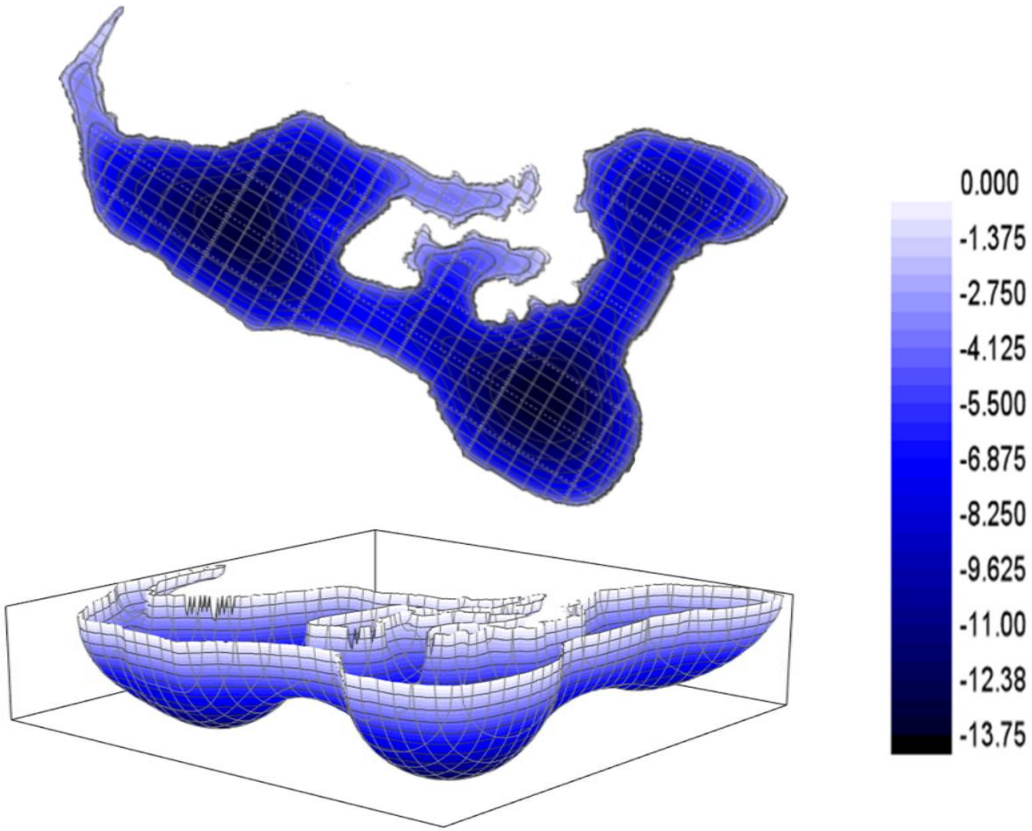


Validation of steady state model



Tonga Groundwater Flow Model (ToGFlow)

Freshwater –Saltwater Interface Elevations



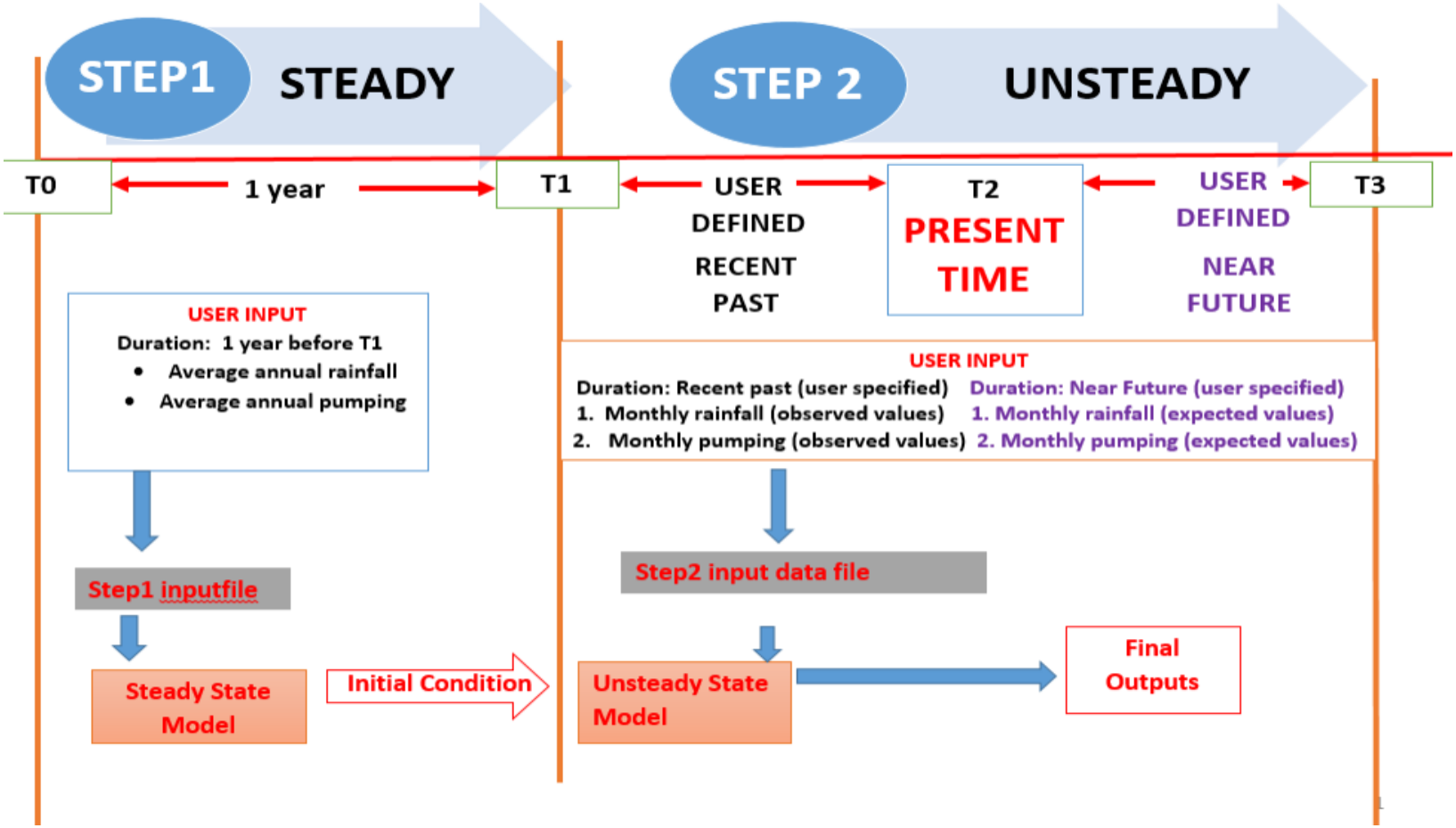
Present Freshwater Resources in Tongatapu Island

Average FW Thickness (m)	Maximum FW Thickness (m)
8.42	14.04

Total Volume of Usable FW (m^3)	Total Volume of FW (m^3)
193,800,000	2,123,000,000

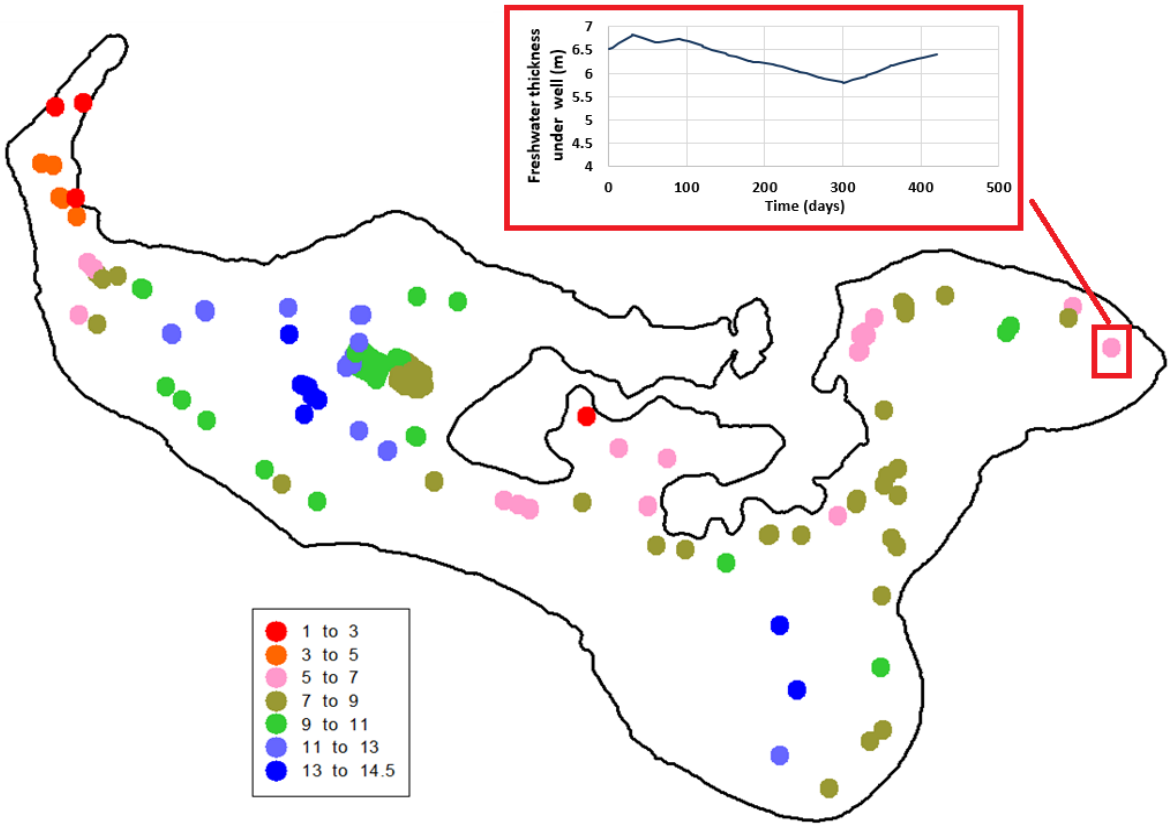
Tonga Groundwater Flow Model (ToGFlow)

Near future modeling (Unsteady)



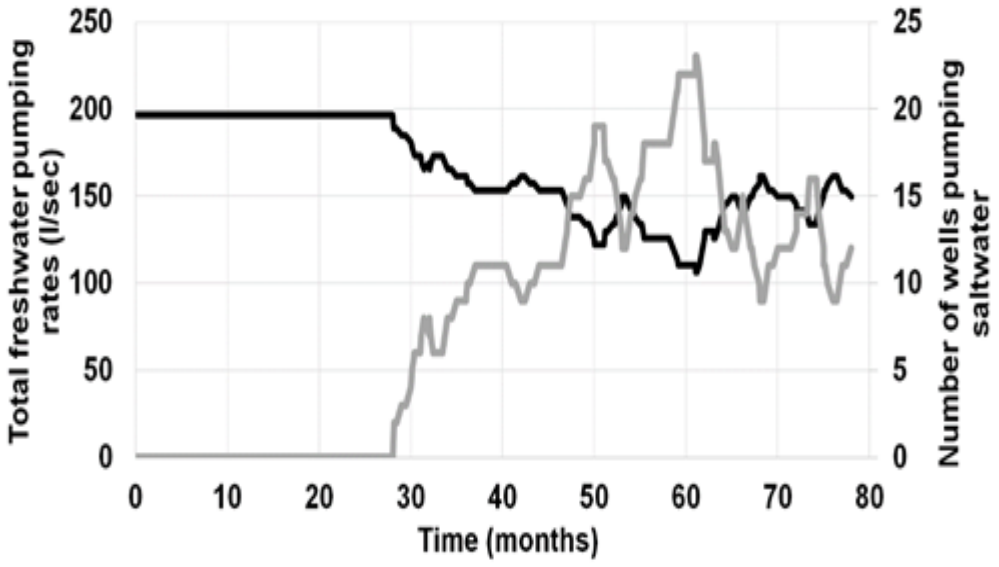
Tonga Groundwater Flow Model (ToGFlow)

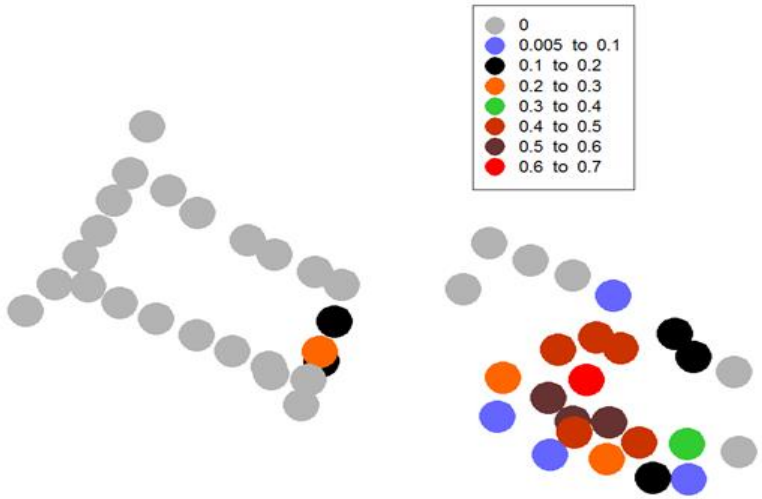
Average freshwater thickness (m) under the pumping wells (inset shows the temporal variation) during the 3/2017 to 4/2018



Tonga Groundwater Flow Model (ToGFlow)

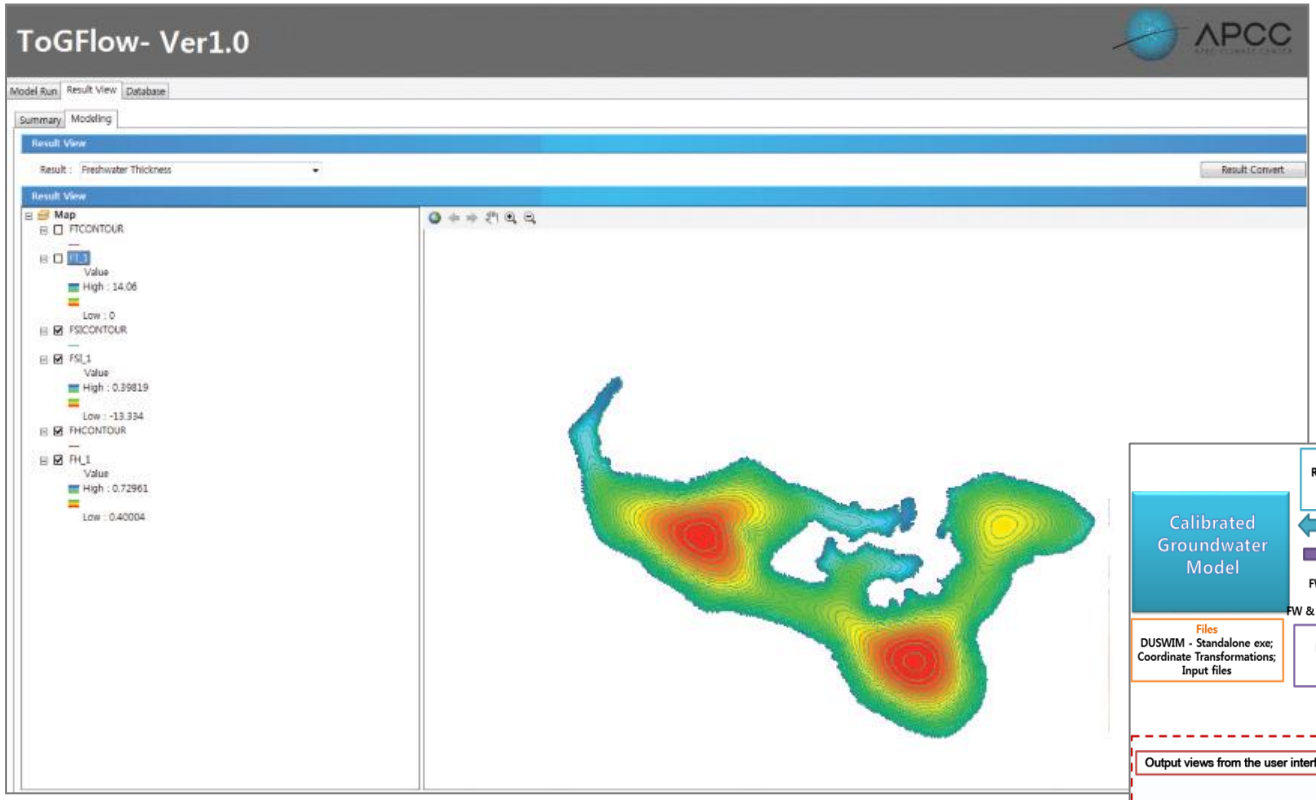
- Number of saltwater intruded wells (grey lines) and rate of freshwater pumping (black lines) for constant pumping rates
- Locations and ratios of saltwater intruded pumping wells at Mataki'eua and Tongamai

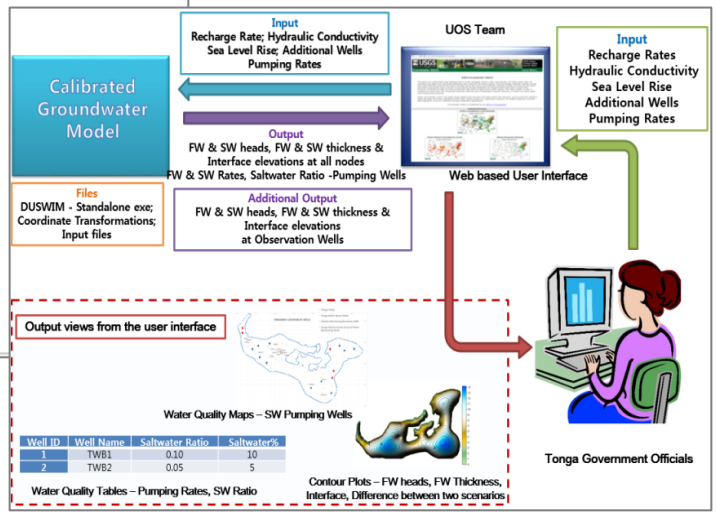




Tonga Groundwater Flow Model (ToGFlow)

ToGFlow allows 'easy to run' by adjusting parameters and model simulation



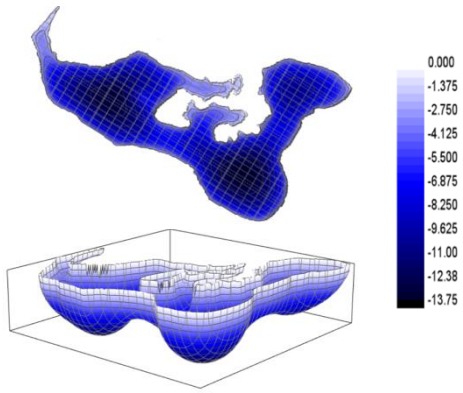


Integrated system for web based groundwater modeling

Web Based Groundwater Information System

Groundwater Information System (ToGWIS)

01 MONITORING



02 MODELING

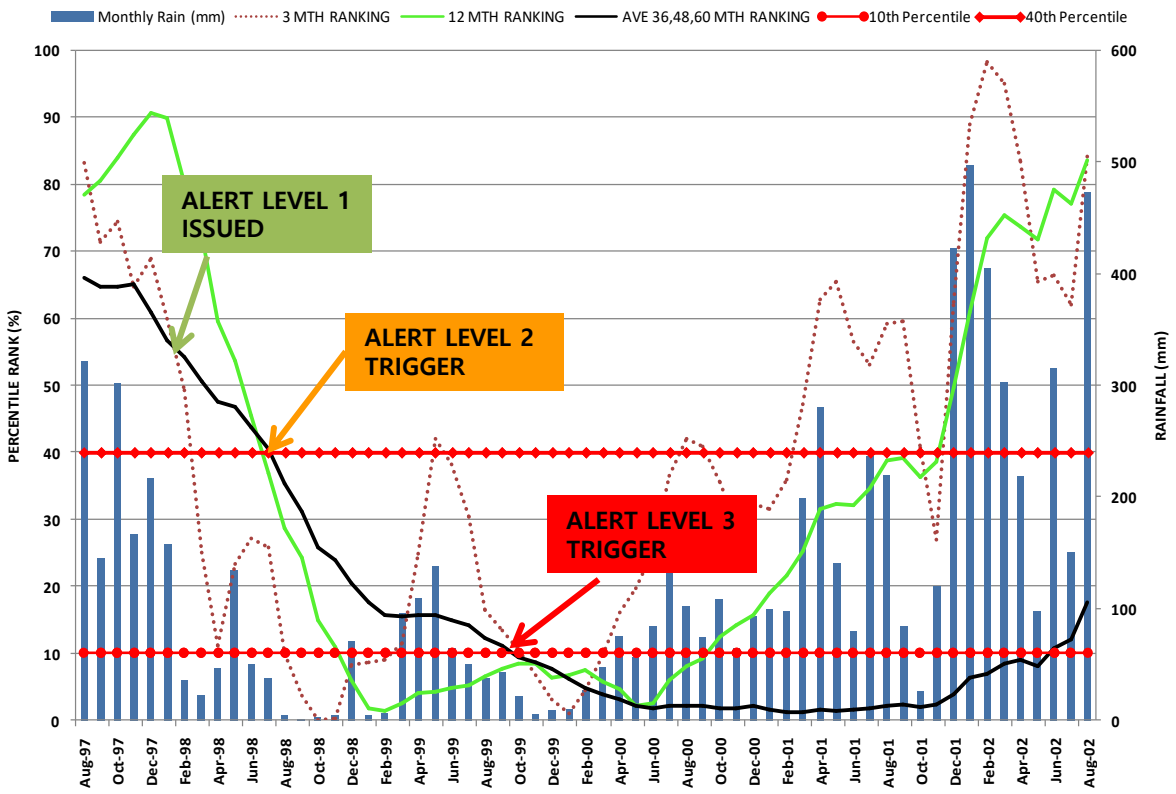
03 MANAGEMENT

ONE STOP SOLUTION FOR GROUNDWATER MANAGEMENT

Water Resources Risk Management

Drought: Decision Support

Example: 1998-2001 Drought



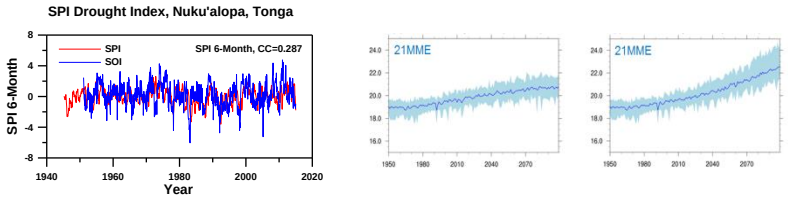
- Real-time Monitoring
- Seasonal Prediction
- Groundwater Recharge
- Groundwater Modeling
- Groundwater Alert

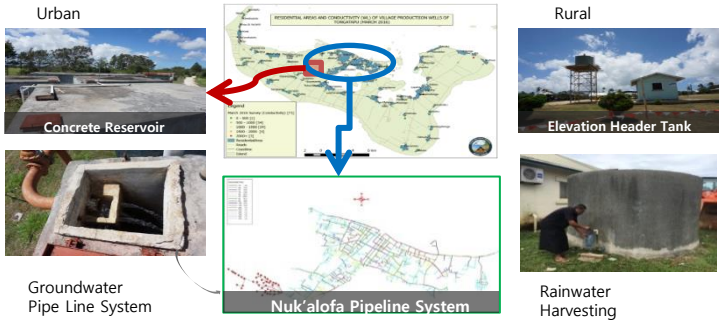
Source: GOVERNMENT OF KIRIBATI (2011) DROUGHT RESPONSE PLAN FOR SOUTH TARAWA

Integrated groundwater management system

Climate Smart Groundwater Information System

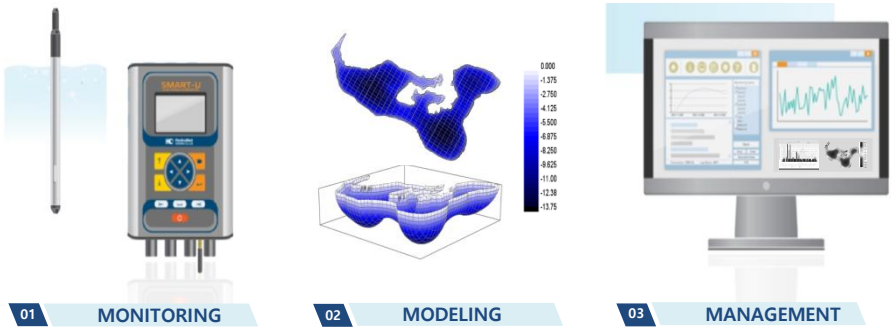
❖ Climate Information for Management of the Urban and Rural Water distribution system





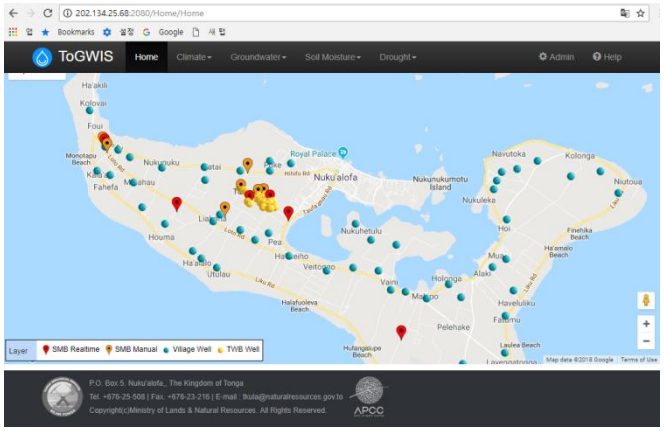
❖ Real-Time groundwater monitoring system

❖ Smart-Groundwater Management System



ONE STOP SOLUTION FOR GROUNDWATER MANAGEMENT

❖ Service: Tonga GroundWater Information system (ToGWIS)



ToGWIS: http://202.134.25.68:2080

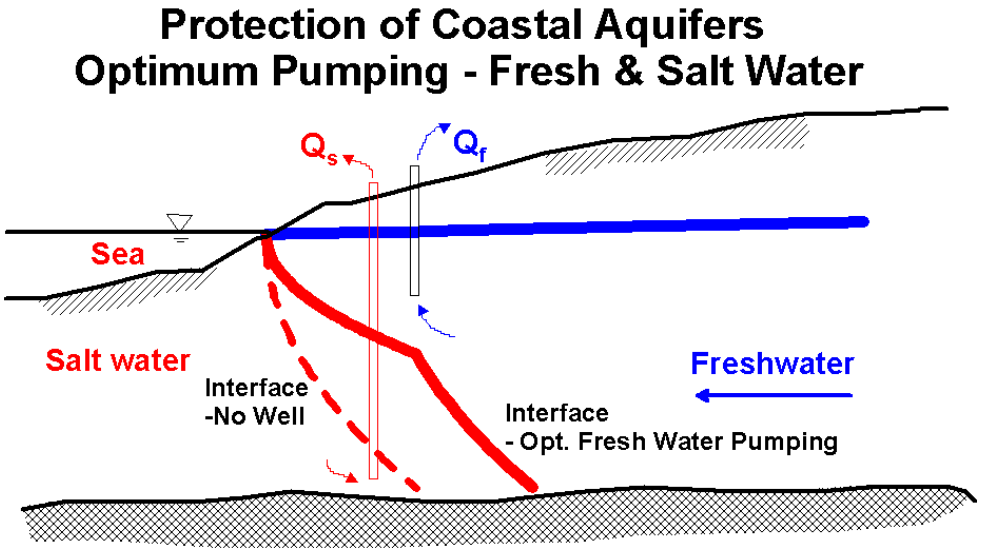
IV Concluding remarks

APCC
APEC CLIMATE CENTER

Short- and Long-term Measures

❑ 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

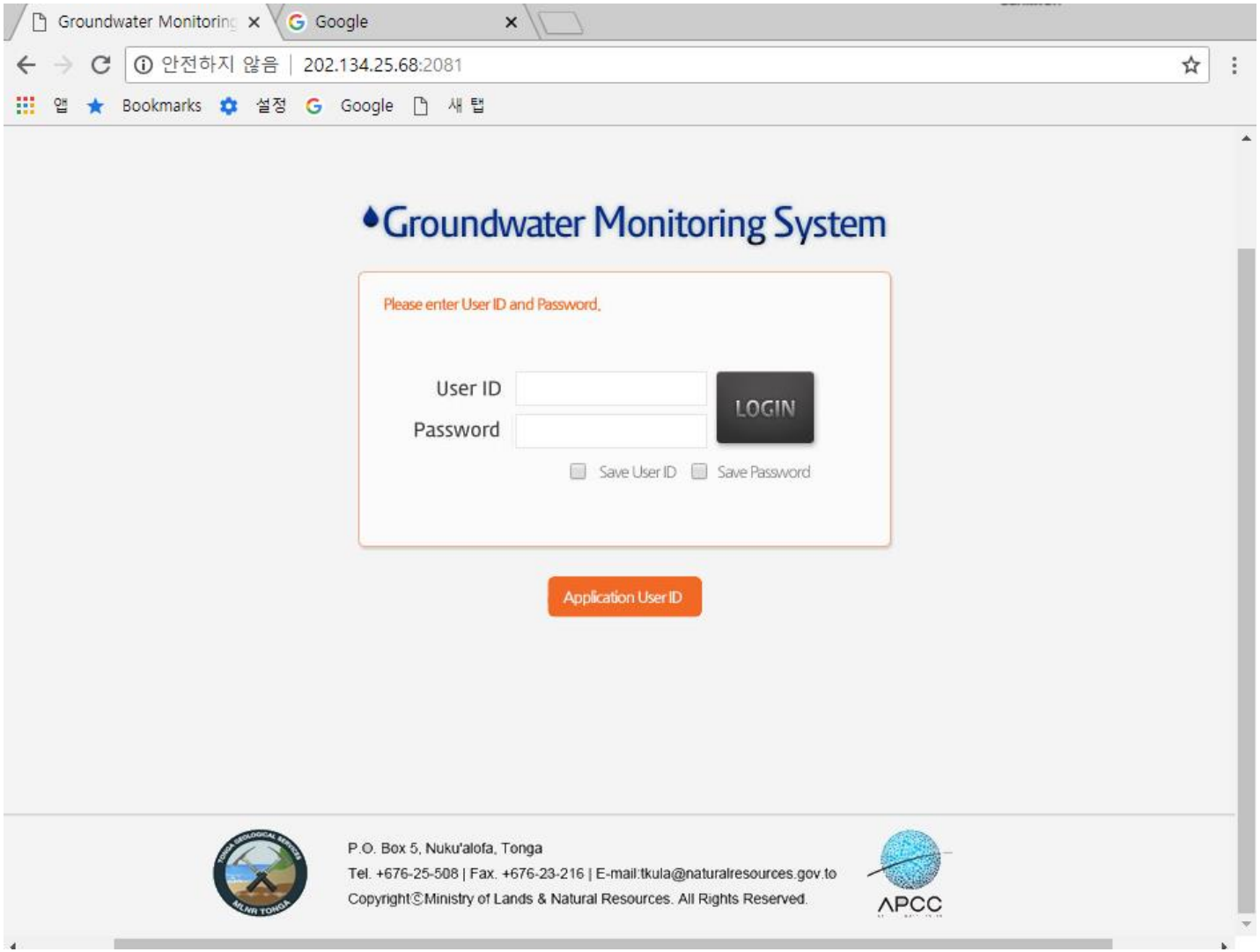
1. Monitoring wells
2. Management of the Fangaua Lagoon
3. Leak detection and reduction of water distribution pipe network
4. Water quality

❑ Policy Recommendations

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

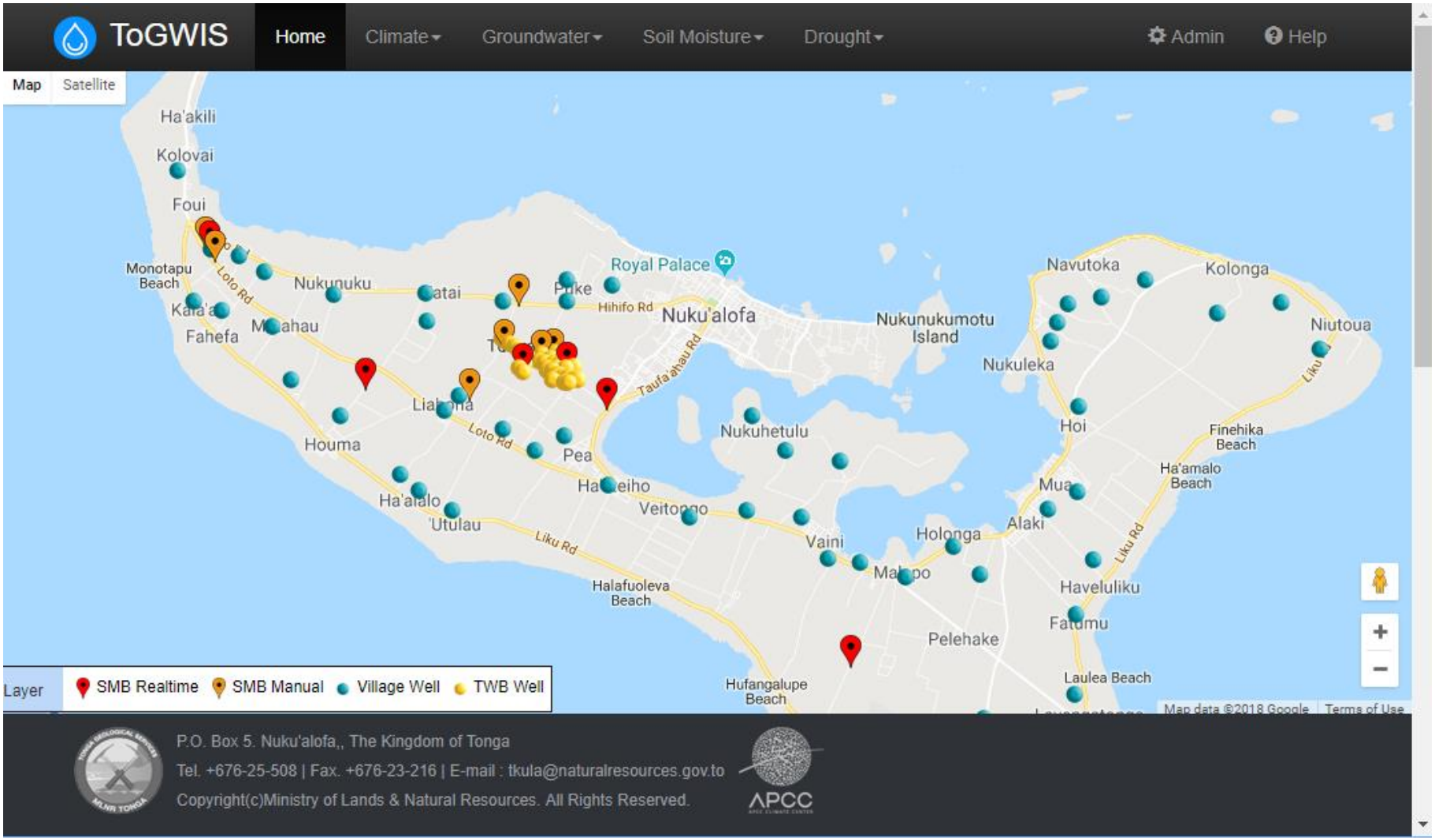
Tonga Groundwater Monitoring System

http://202.134.25.68:2081/



Tonga GW Information System (ToGWIS)

http://202.134.25.68:2080



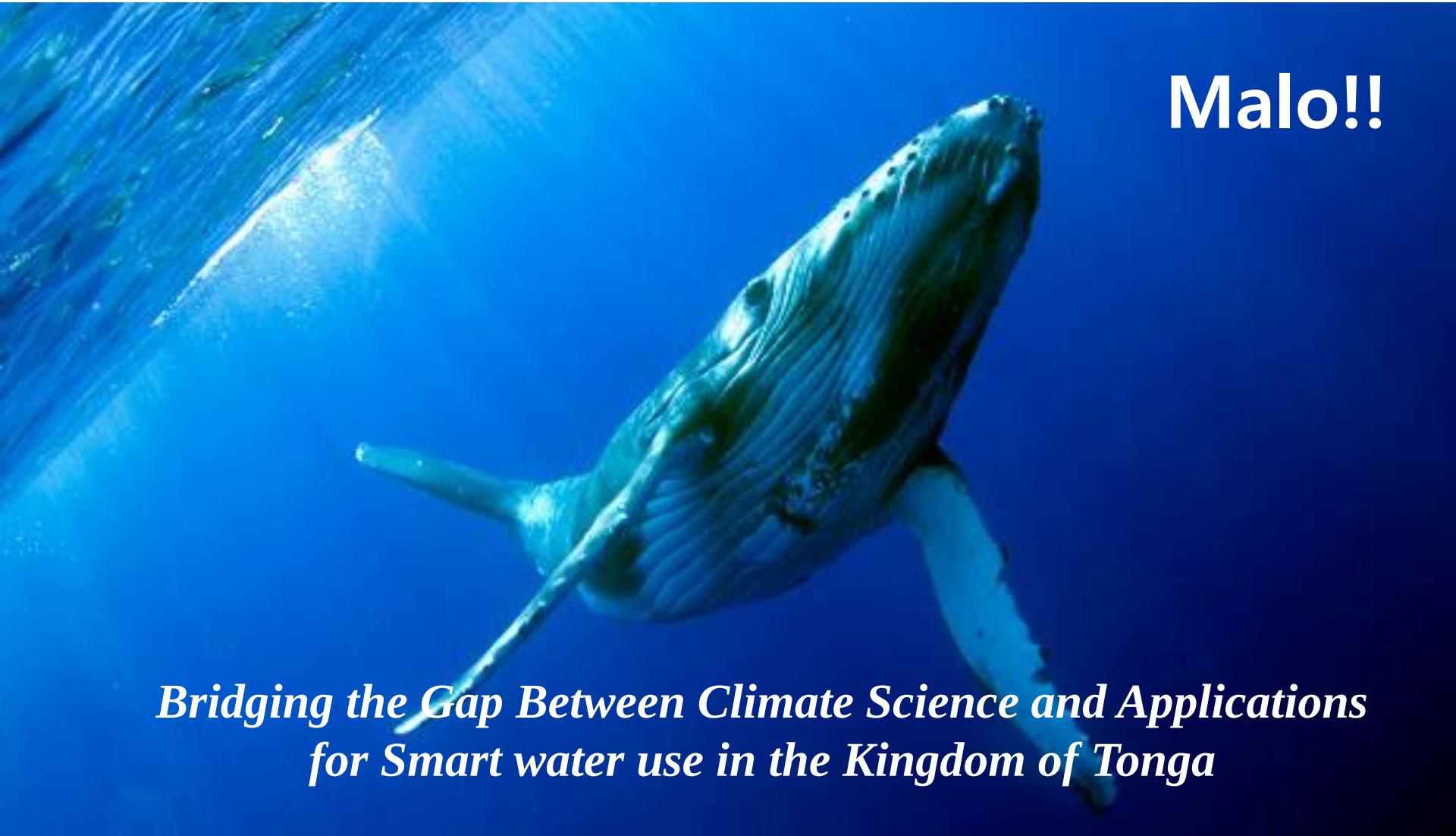
Video Clip

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

Running time: 10:47

https://www.youtube.com/watch?v=zjvk95TtJIk

Thank you for your attention!



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