FROM RECHARGE TO REEF:
ASSESSING THE SOURCES, QUANTITY, AND TRANSPORT OF GROUNDWATER ON TUTUILA ISLAND, AMERICAN SAMOA.

By Christopher K. Shuler

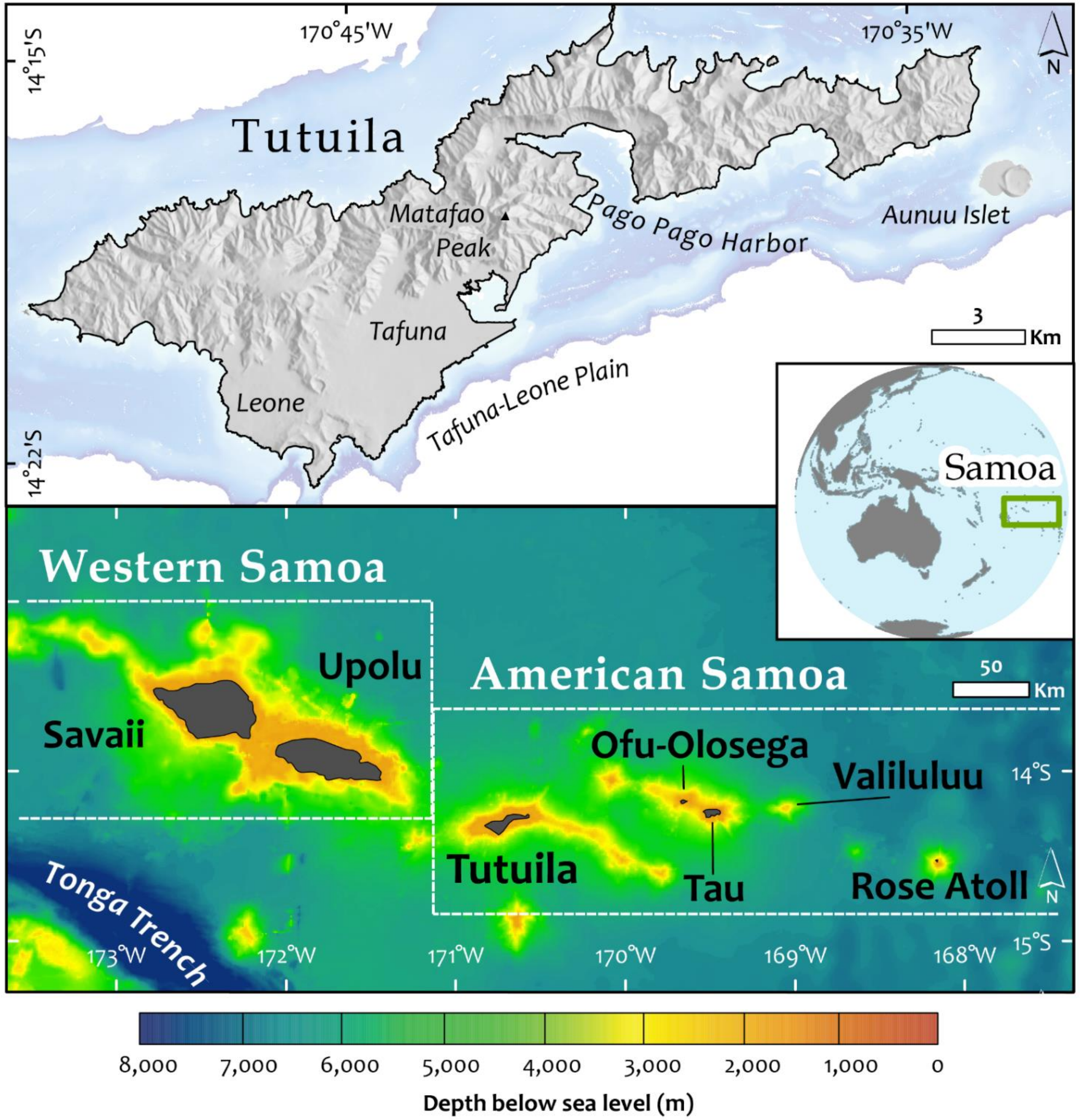
Regional Geology

Two eruptive mechanisms

1) Classic hot-spotting

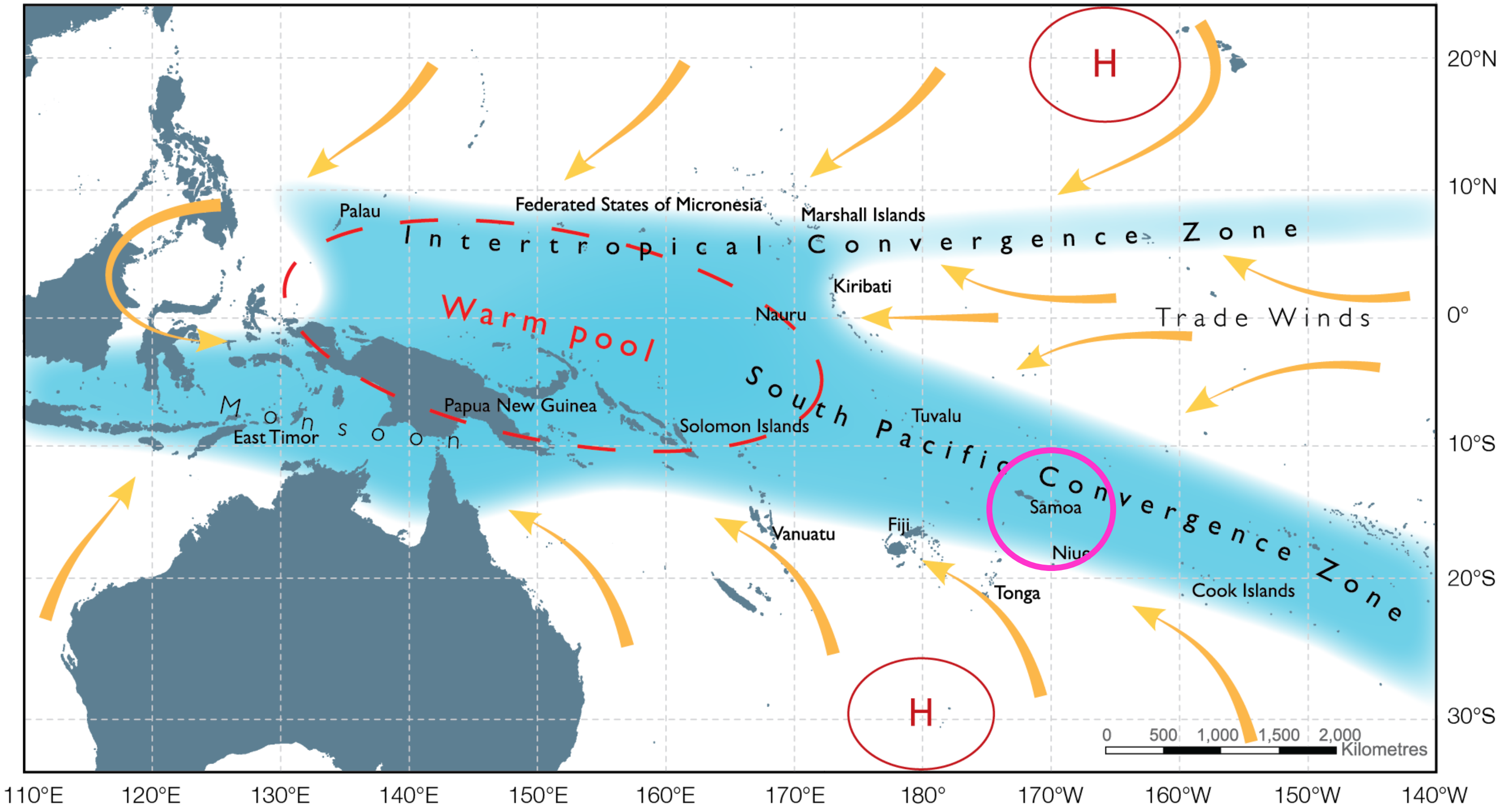
2) Lithospheric plate flexure

(Natland, 2003)



Tutuila Climate

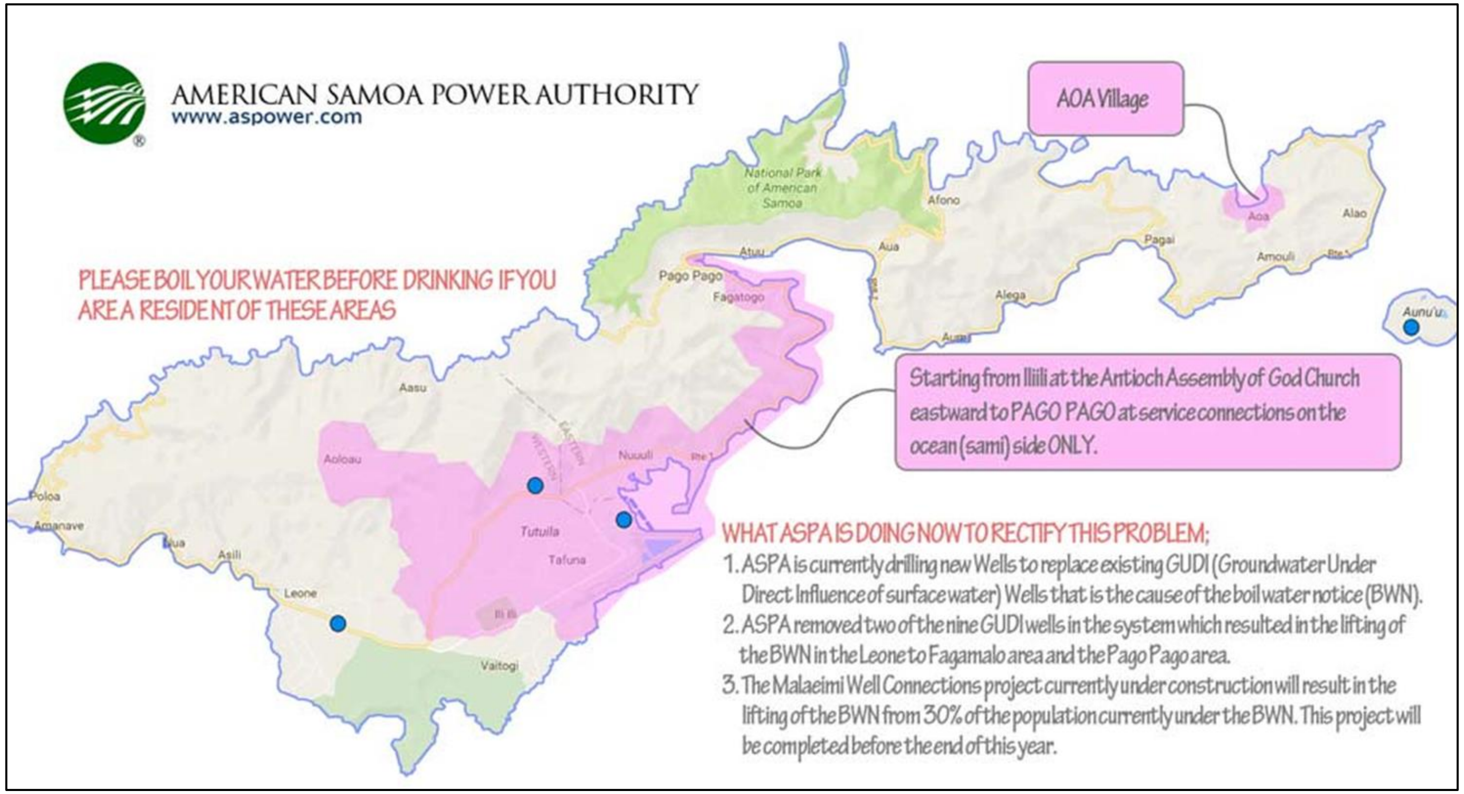
- In the doldrums
- 14° south latitude
- Prevailing south east winds
- Rainfall between 1,800 to 5,000 mm/yr (70–200 in/yr)
- Tropical storms cyclones once every-other year
- Rainy Season: Nov. – Mar.
  Dry Season: May – Aug.



(NWS, 2000; Kennedy et al., 1987).

Water Resource Challenges

- 2009 Boil-water-advisory
  (Vold, 2013)



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  (ASPA personal comm.)

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water pressure

Pago Pago, AS

86°

"NEED SOME HELP HERE ASPA"

Dear Editor: Hi. I'm mad, I'm angry, and I'm hurt right now. No matter how many times one calls ASPA Water, one gets no assistance. You are either lied to or you receive some ridiculous excuse. I have lived in American Samoa over 30 years now, this house, over 20. I was hired by (Utu) Abe Malae...

Read more

Photos Videos

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- Water demand > supply
  (ASPA personal comm.)
- Salinization of wells
  (Izuka, 1999)

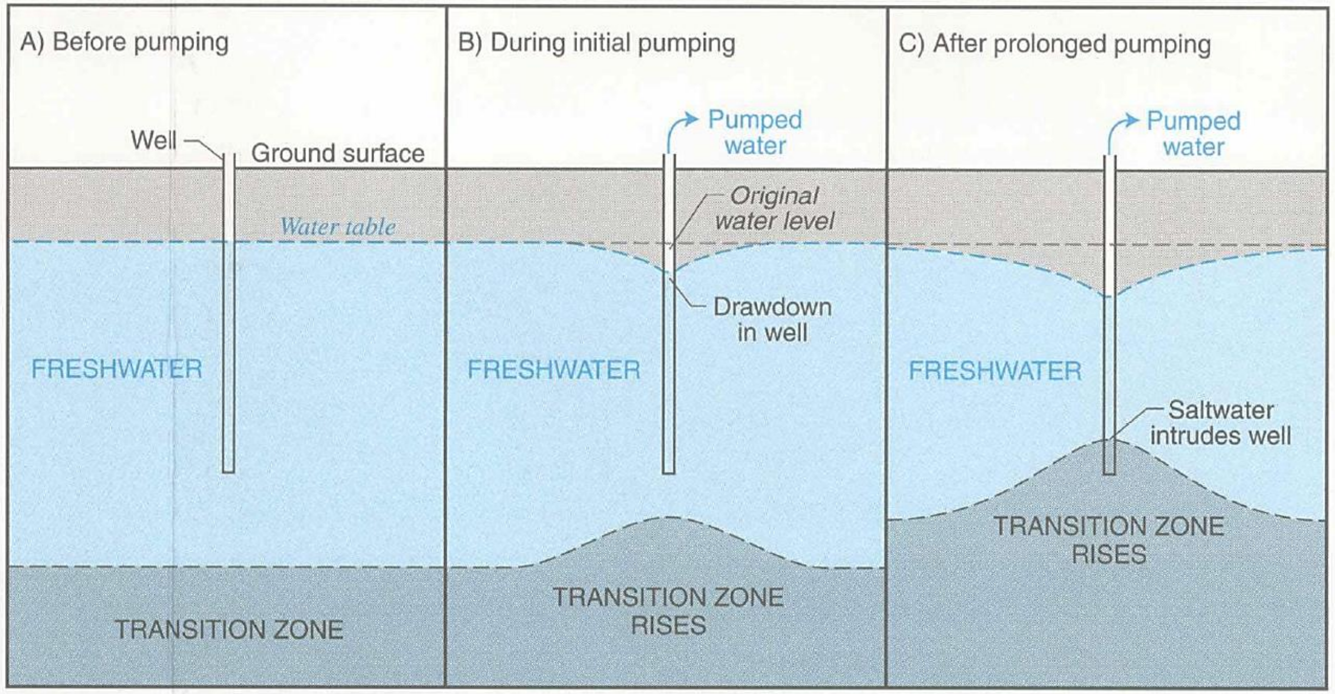

Figure 11. Diagram showing how chloride concentrations rise as a result of pumping from a well that penetrated close to the freshwater/saltwater transition zone.

(Izuka, 1999)

Water Resource Challenges

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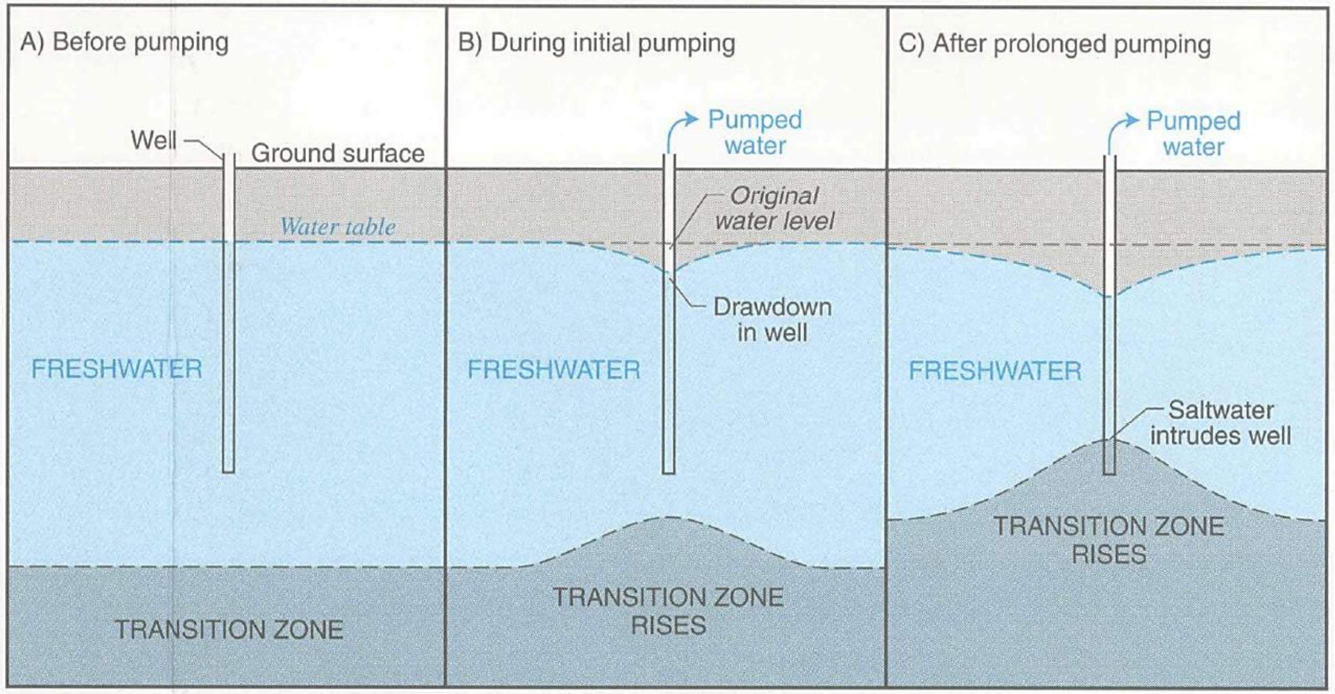
- Leaking water lines
  (Shuler, 2018)



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- Leaking water lines
  (Shuler, 2018)
- “Impaired” stream quality
  (AS-EPA, 2016)

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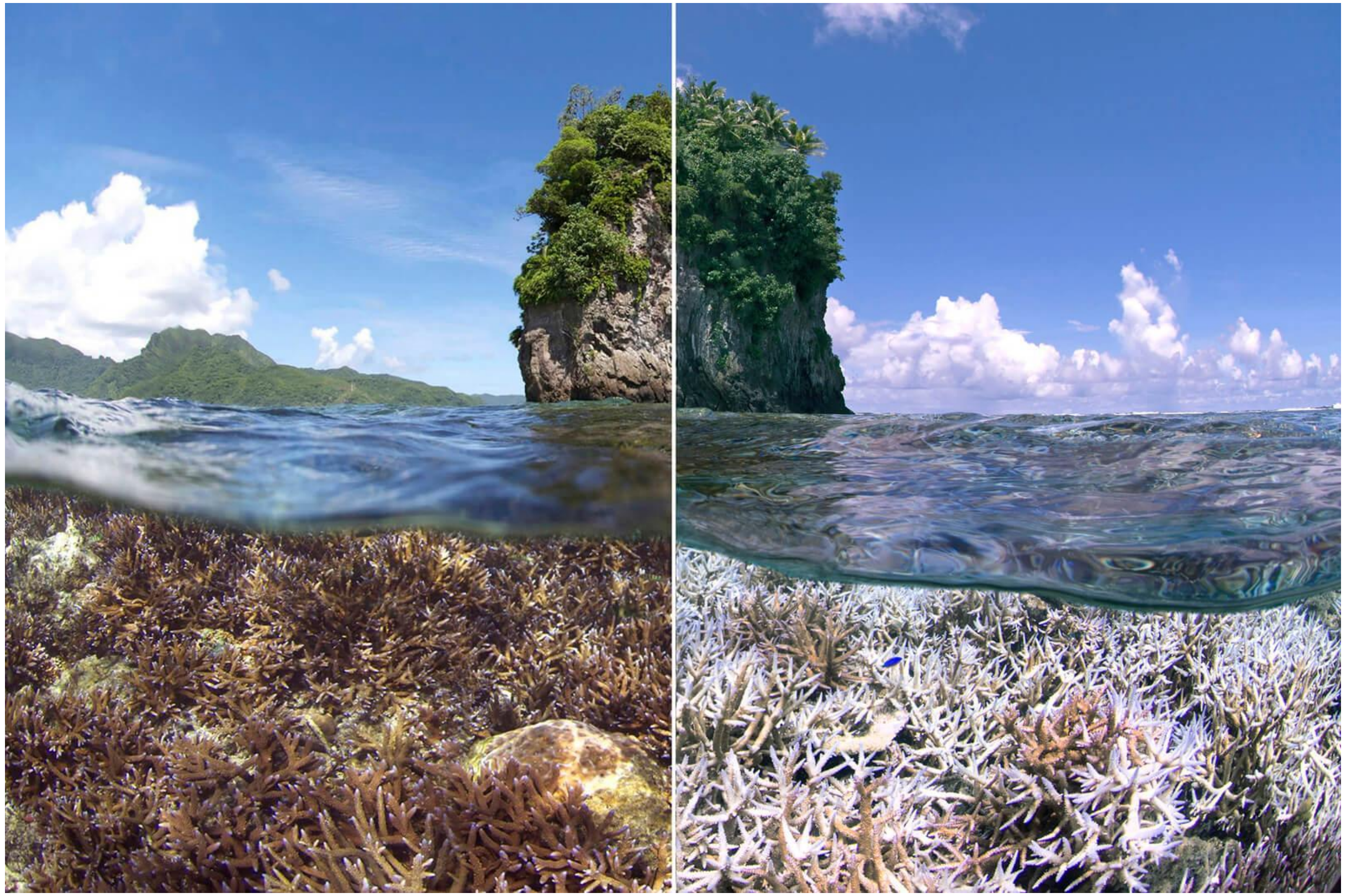
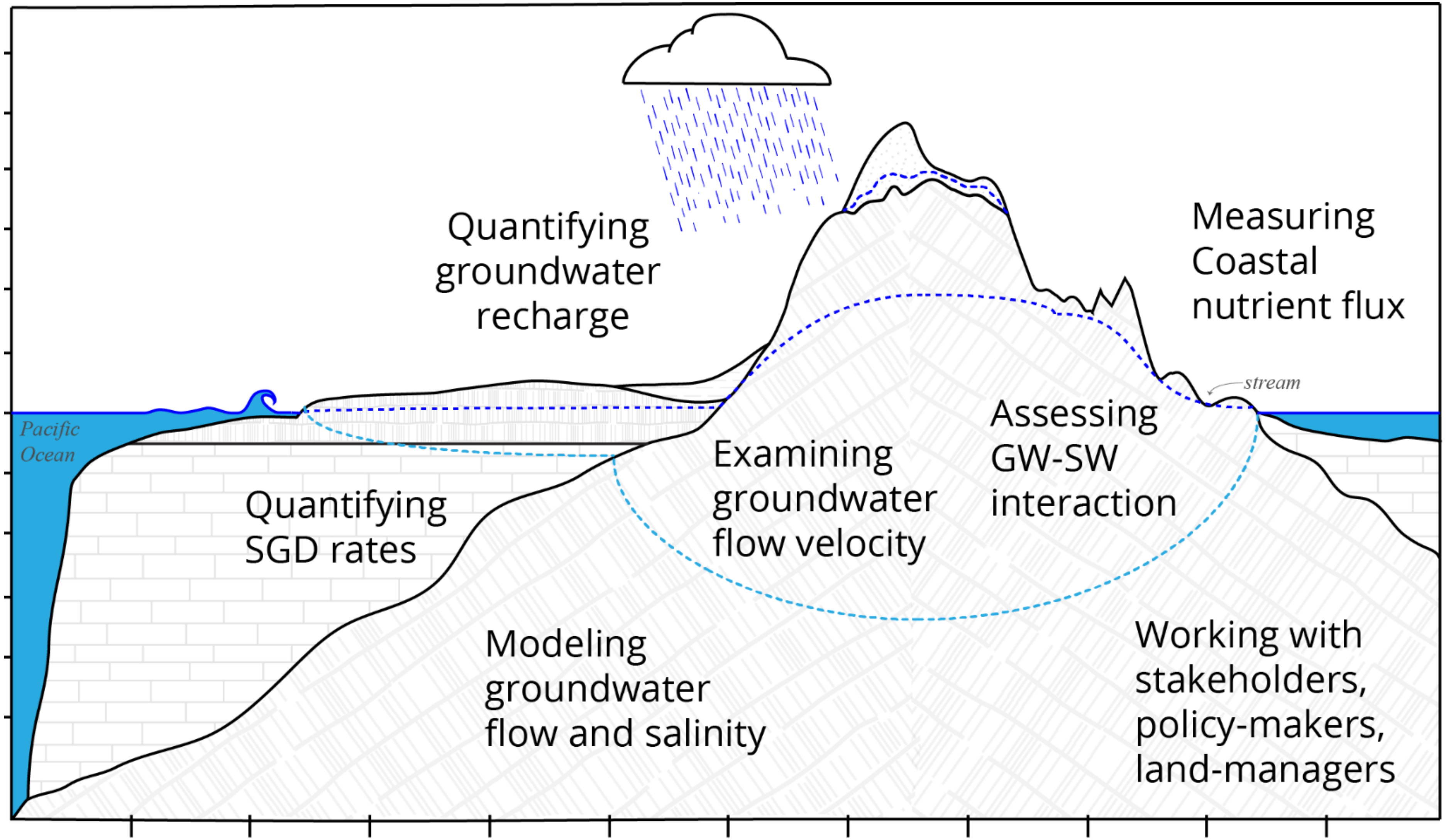
- Leaking water lines
  (Shuler, 2018)
- “Impaired” stream quality
  (AS-EPA, 2016)
- Declining reef health
  (NOAA-CRCP, 2013)



(https://coralreefs.blogs.rice.edu/2016/02/18/even-resilient-reefs-in-american-samoa-threatened-by-mass-bleaching/)

Addressing Water Challenges

aka Presentation Outline:



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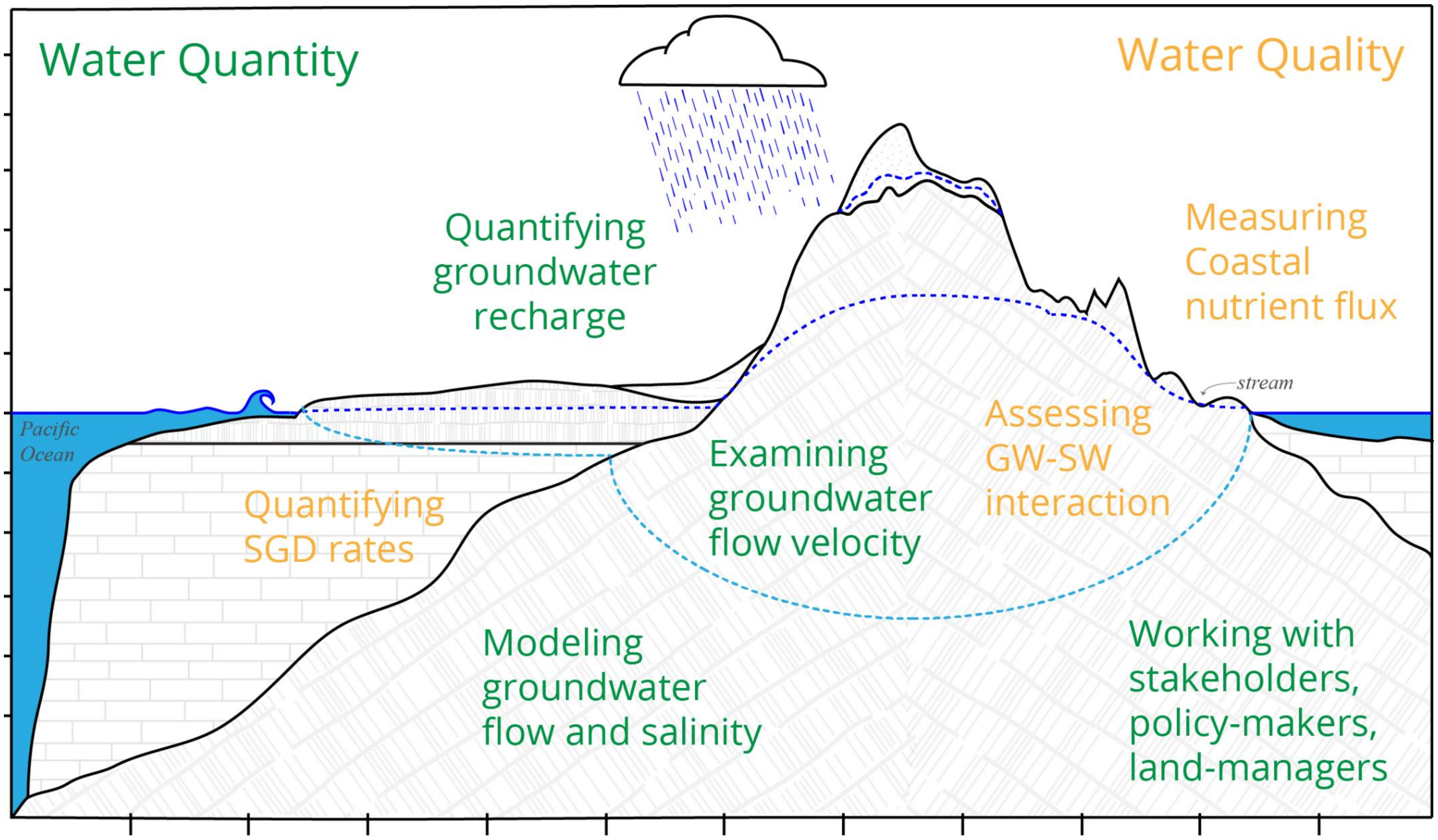
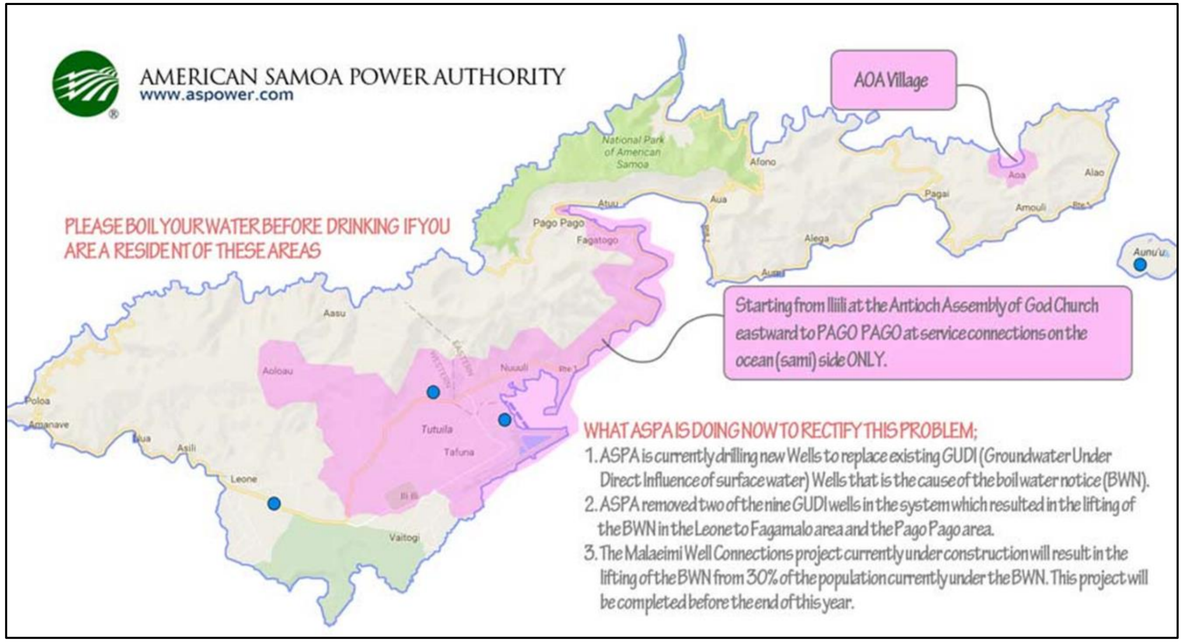


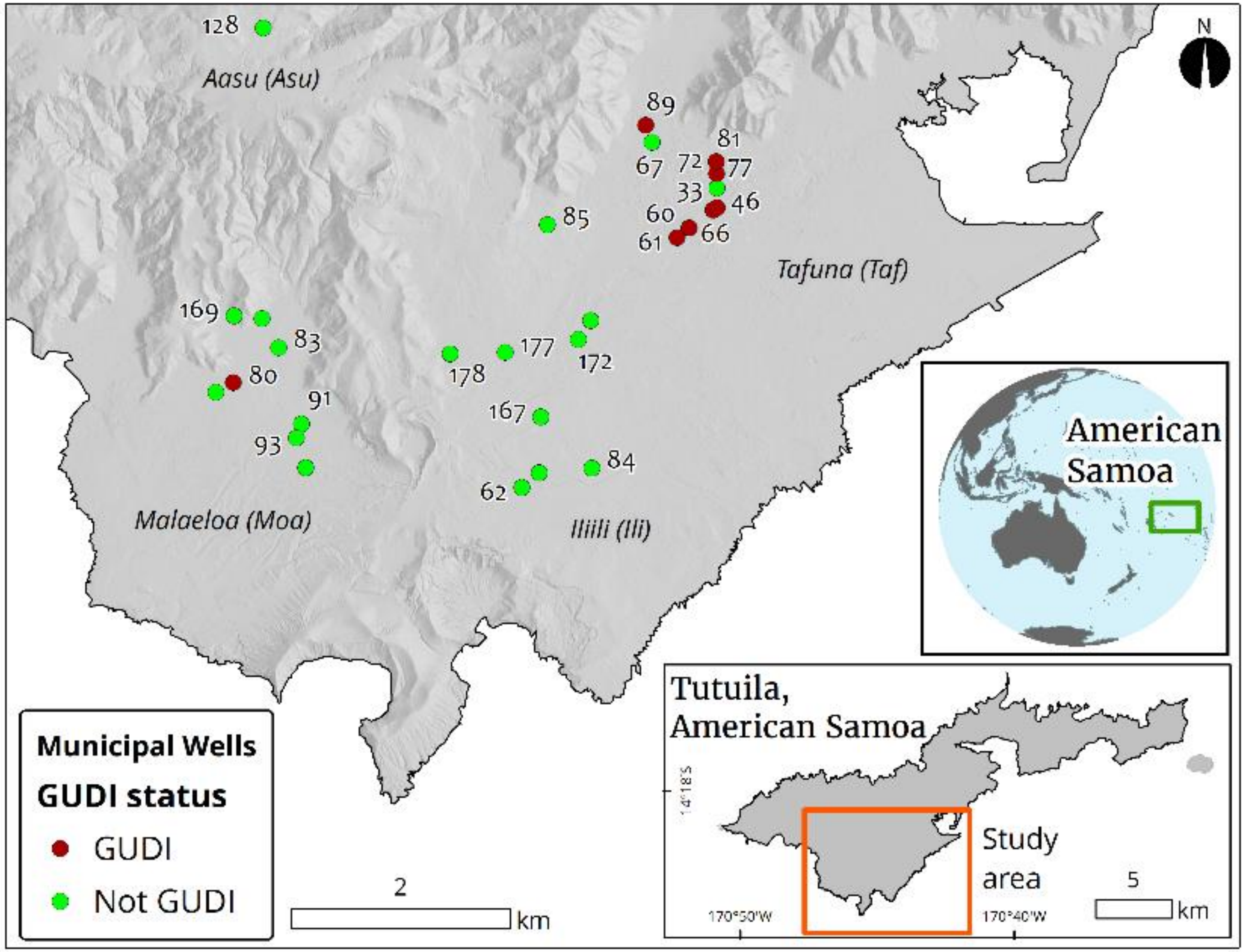
Water Quality

part 1

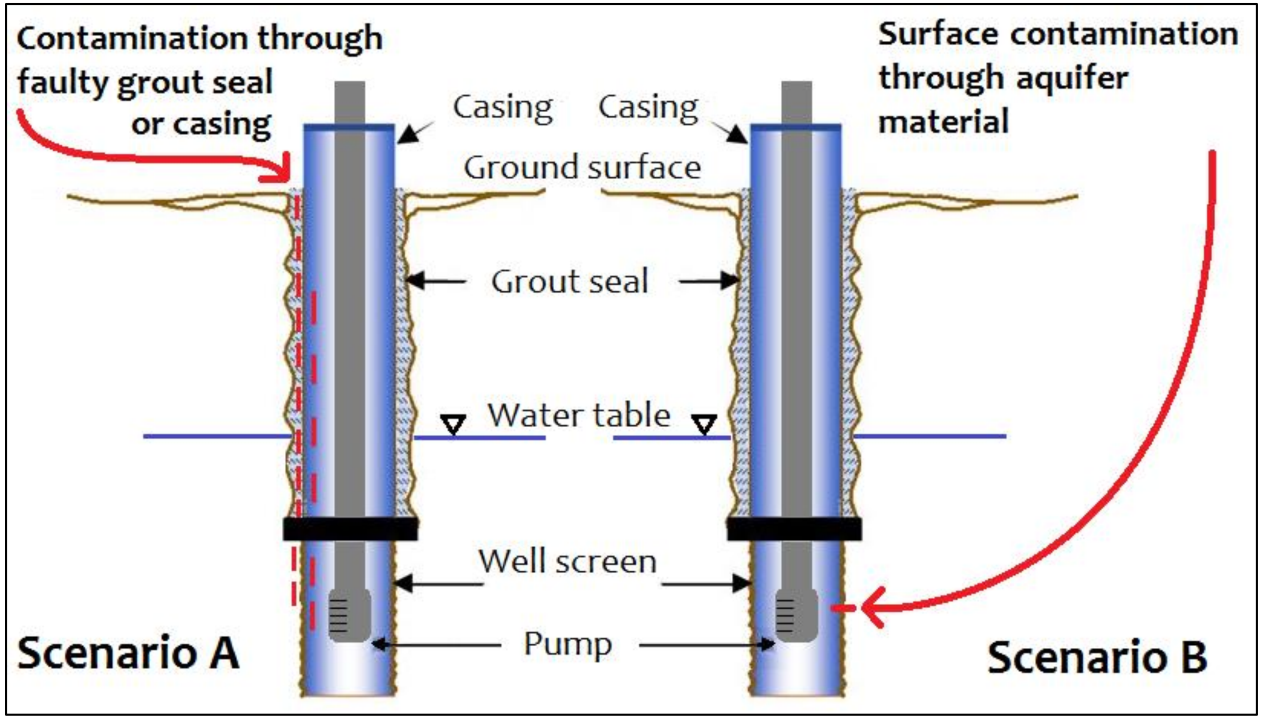


Motivation

Boil water advisory due to groundwater under the direct influence (GUDI) of surface water



Hypothesis

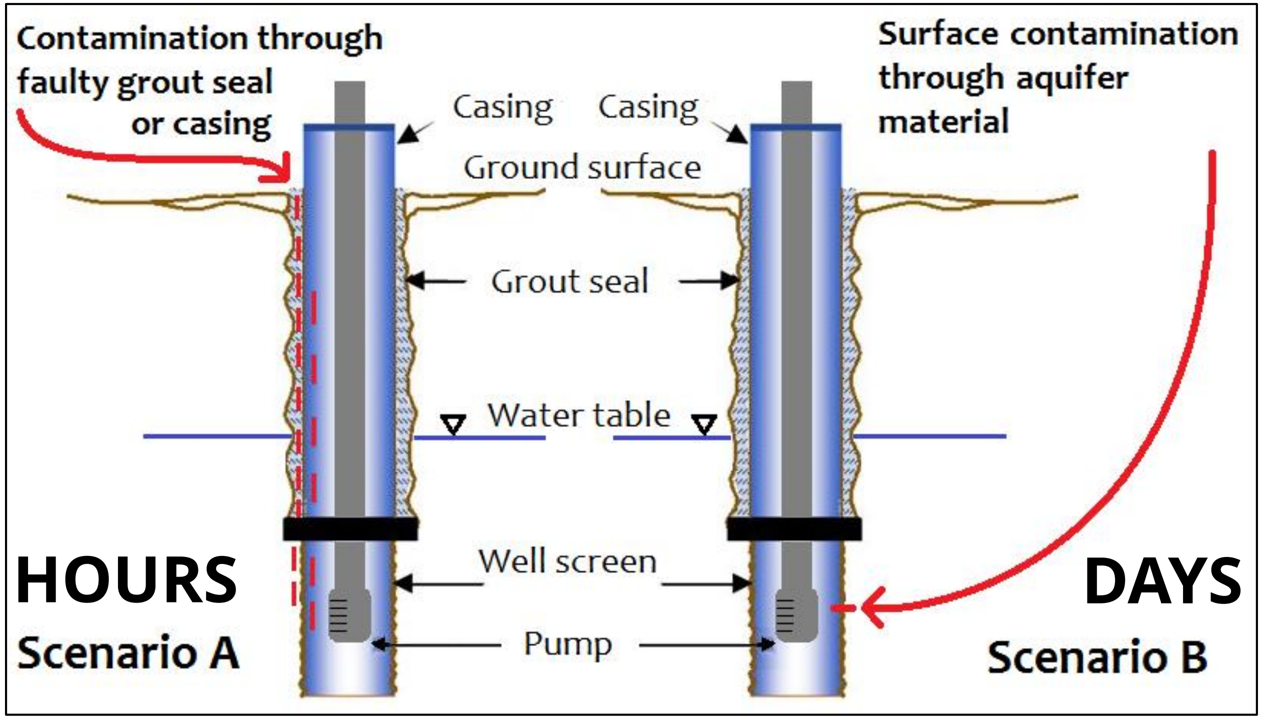


Contamination through faulty grout seal or casing
Surface contamination through aquifer material
Casing
Casing
Ground surface
Grout seal
Water table
Well screen
Pump
Scenario A
Scenario B

Hypothesis

Theory:

Transport down a compromised casing should be rapid = **HOURS**



Theory:

Transport through aquifer material should be slow = **DAYS**

Study Goal: Assess groundwater transport times

Methods: Geochemical Tracer Sampling

Turbidity

-Turbidity and rainfall

-Continuous timeseries at individual wells

- Collected by ASPA and AS-EPA

Indicator bacteria

- Monthly and rainfall event samples
- IDEXX Colilert 18
- Total coliform (TC) and *E. coli*

Water isotopes

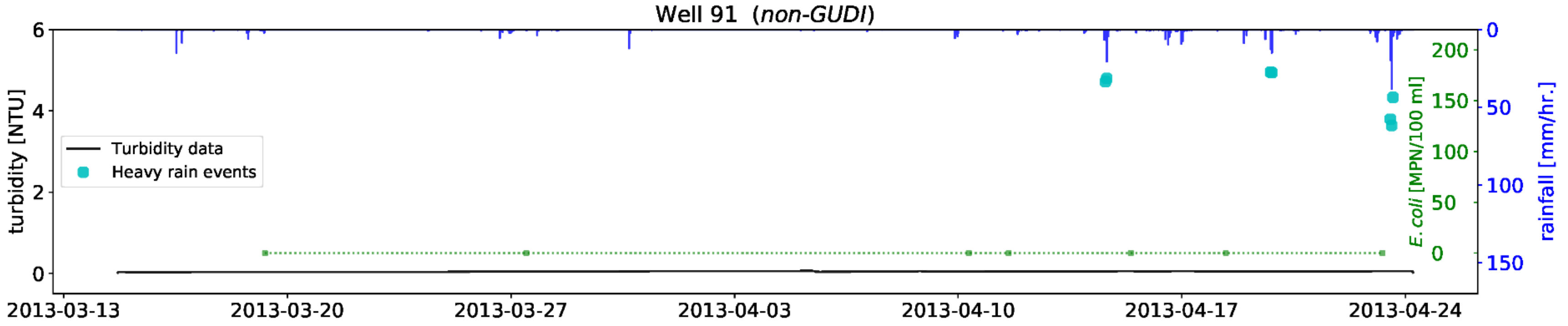
- Groundwater and rainfall

- Monthly and rainfall event sampling

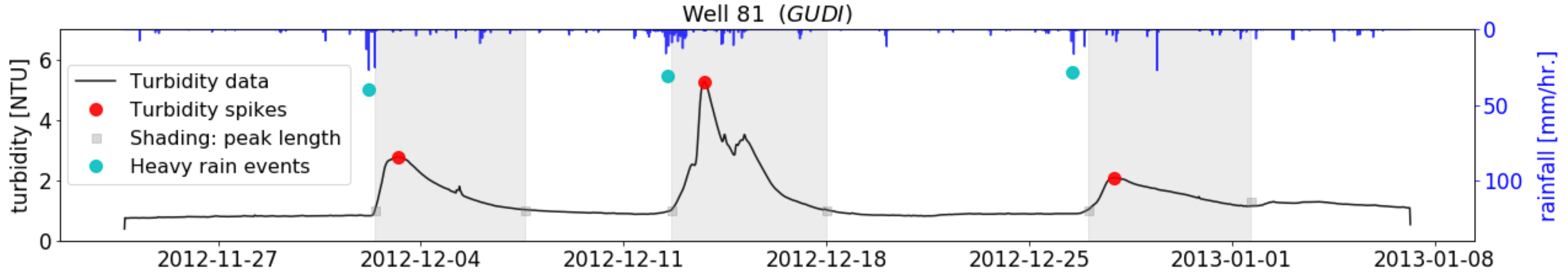
Turbidity Findings

- All Tafuna wells show similar peaks
- Turbidity spikes 12-79 hrs after heavy rain
- Non-GUDI wells show little response
- Except for Well 169, which has a casing hole

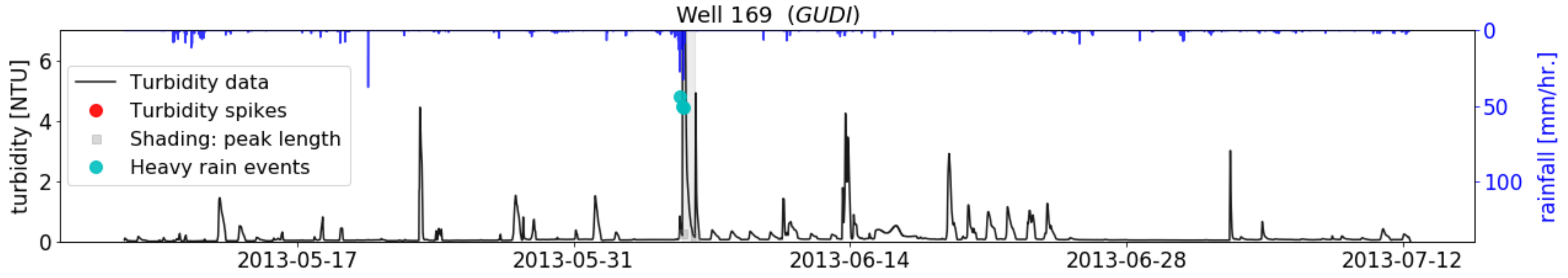
Typical non - GUDI well

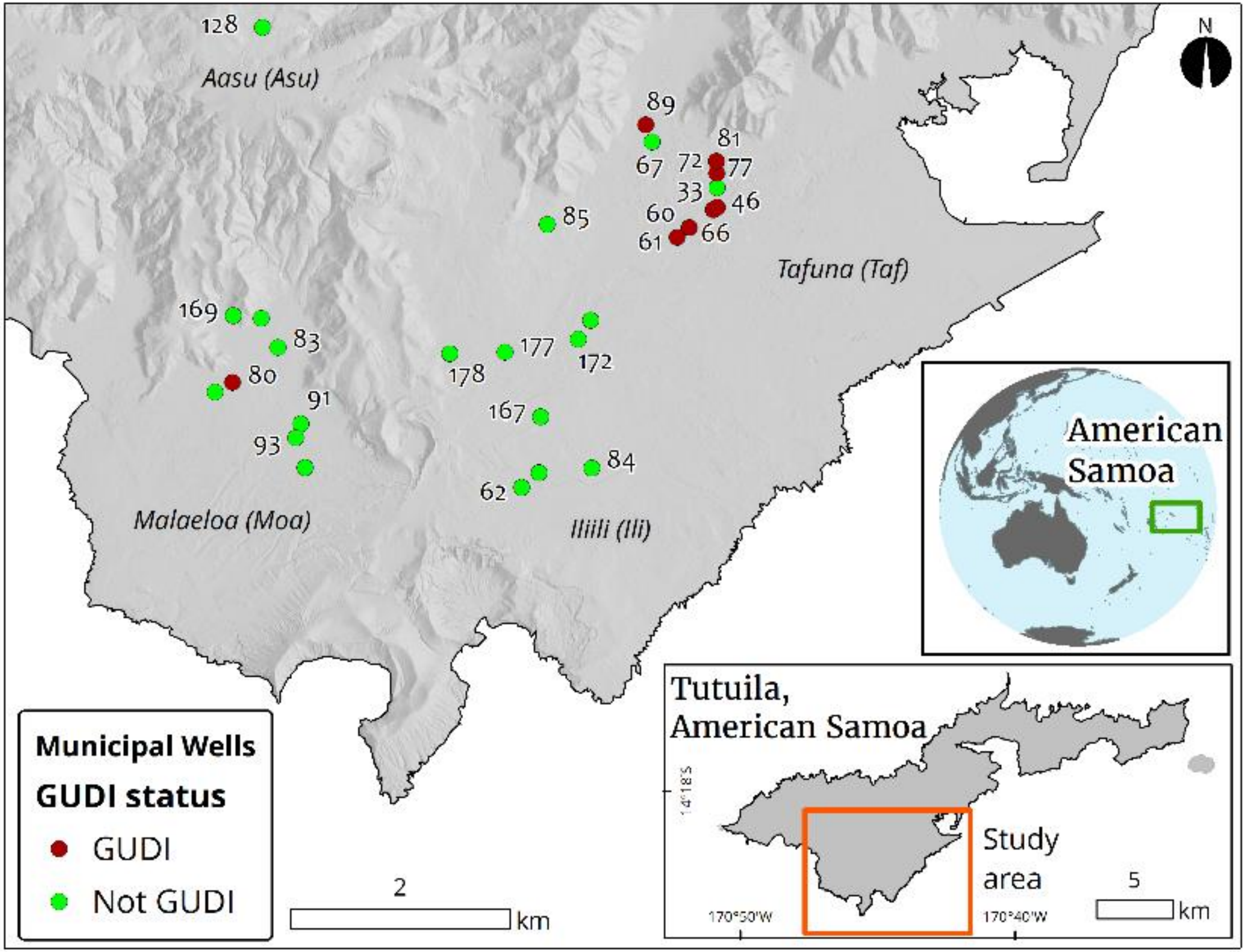


Typical Tafuna GUDI well



Well with hole in casing





128
Aasu (Asu)
89
81
67
72
77
33
46
85
60
66
61
Tafuna (Taf)
169
83
177
172
178
80
91
167
93
84
62
Malaeloa (Moa)
Iliili (Ili)
N
American
Samoa
Tutuila,
American Samoa
14°18'S
Study
area
5
km
170°50'W
170°40'W
Municipal Wells
GUDI status
GUDI
Not GUDI
2
km

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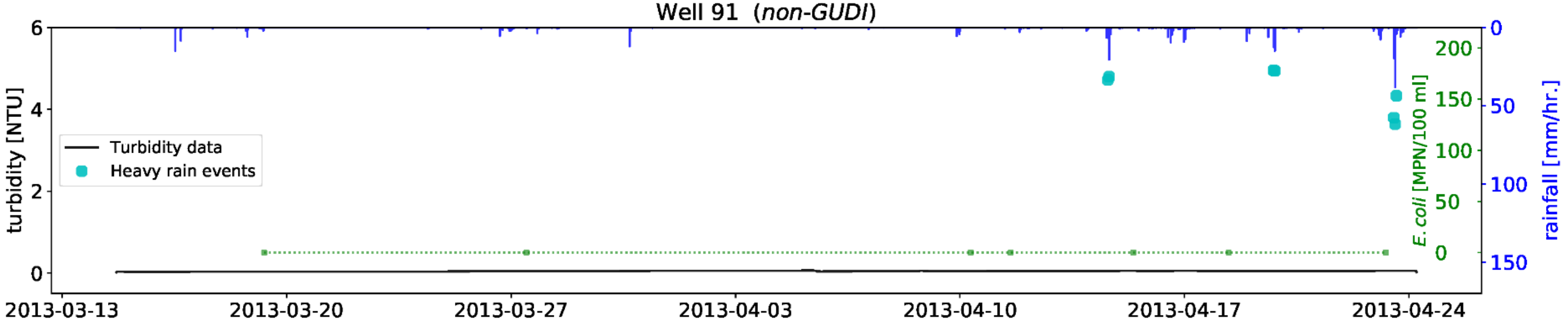

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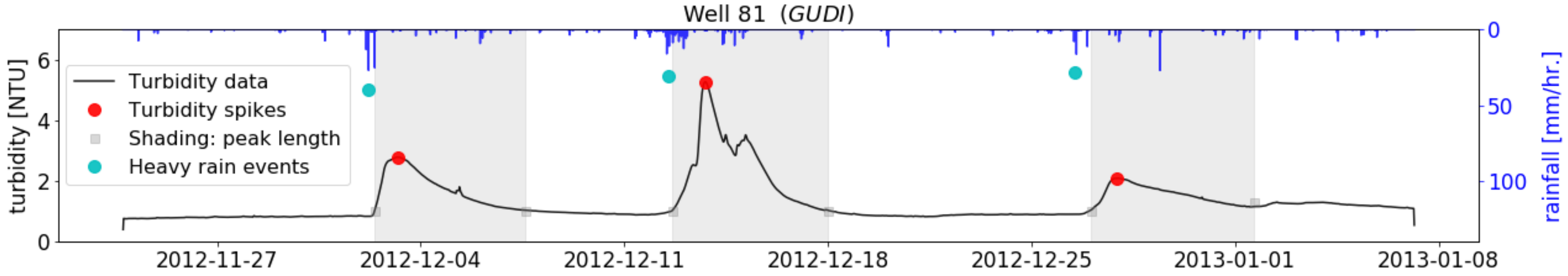
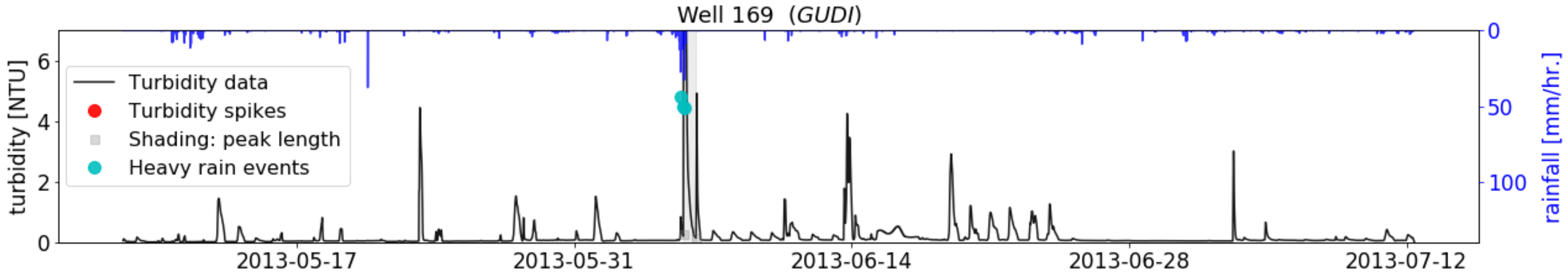
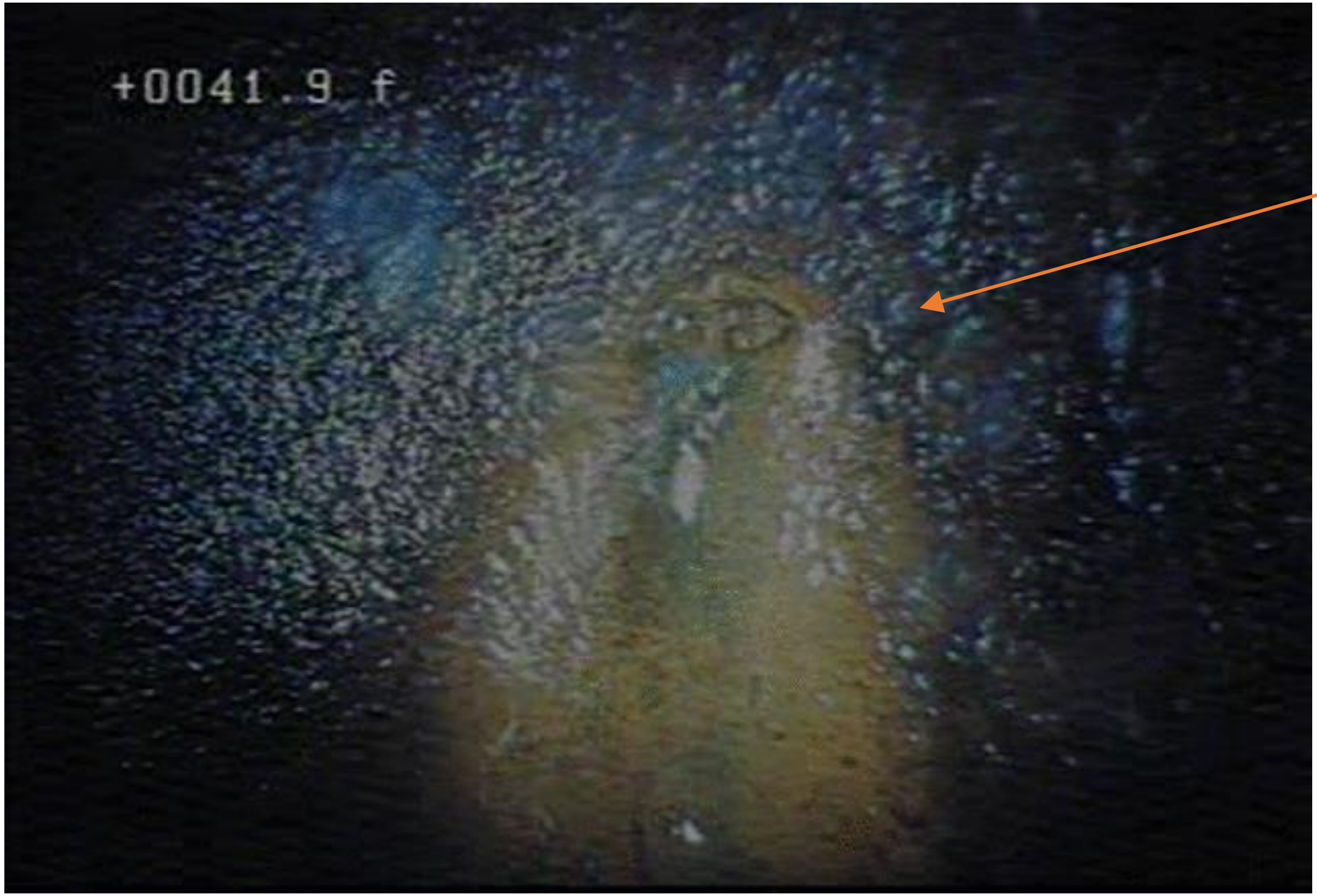


Well with hole in casing



Well 169 video log



Hole in casing

Conclusions

- **Well 169:** Turbidity travel time (hole in casing) = 3 to 4 hours

Tafuna GUDI wells

- Turbidity breakthrough time of 37 ± 21 hours
- Microbial breakthrough time of 18 to 63 hours
- Water isotope breakthrough time of 1 to 5 days
- Matches expected travel time through permeable aquifers

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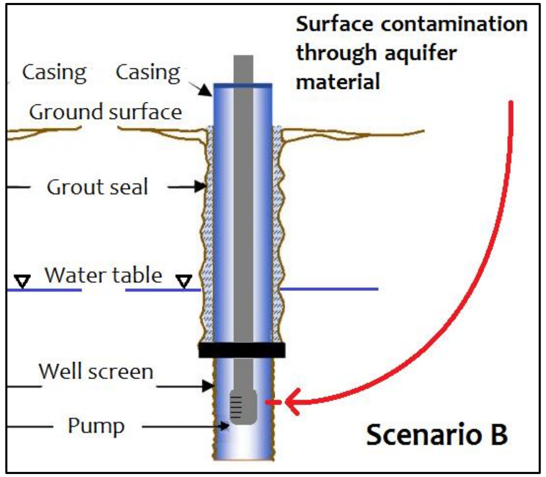


Overly-permeable aquifer material, not faulty well casings, is most probable mechanism of contamination in N. Tafuna GUDI wells

Water Quality

part 2

Coastal Water Quality: Examining Submarine Groundwater Discharge (SGD), Groundwater-Surface Water Interaction and Nutrient Fluxes Across Land Use Gradients

Questions and Objectives

(1) Does coastal nutrient loading vary with human land-use?

- Quantify SGD and baseflow-stage surface water nutrient loading.

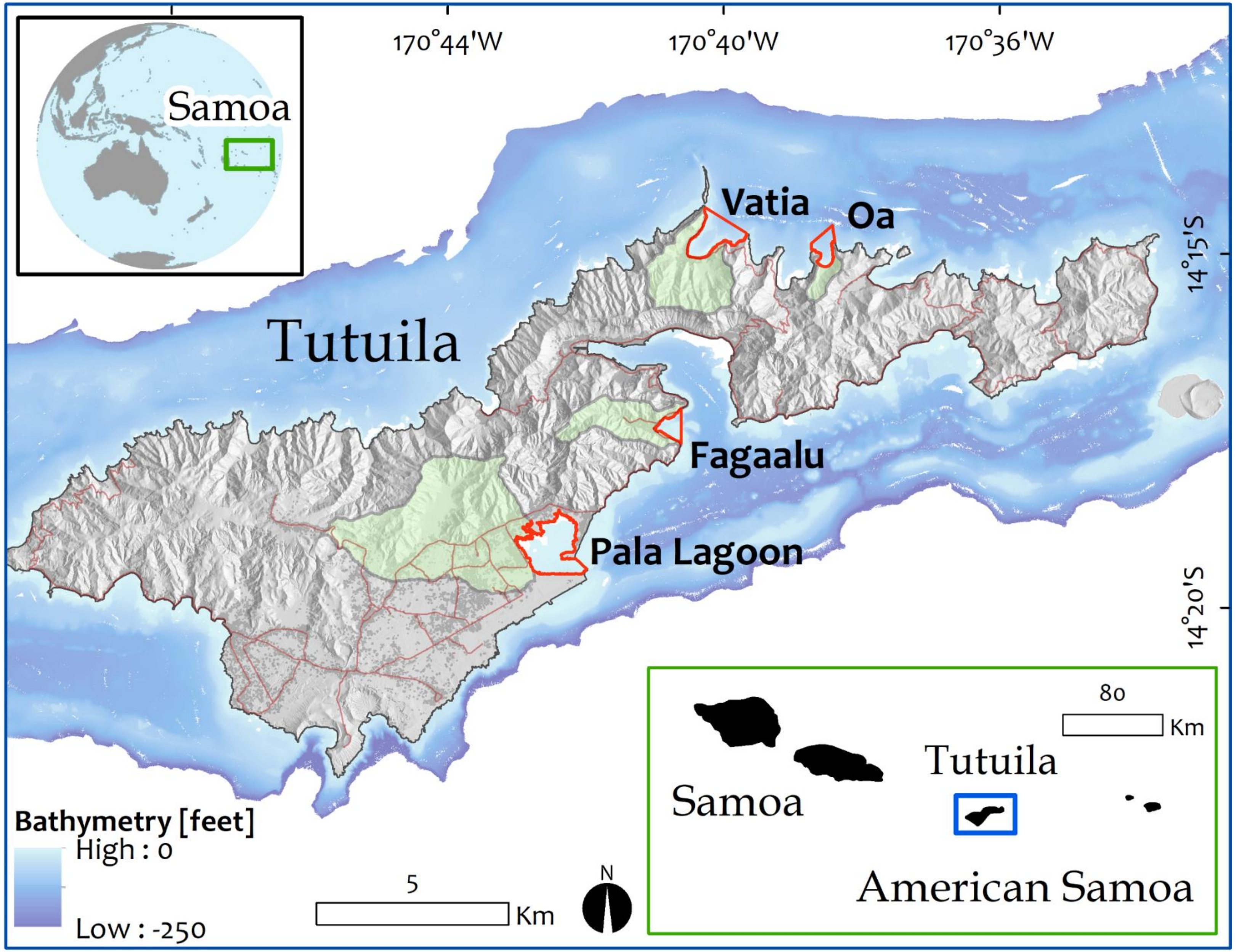
(2) How does the benthic ecosystem respond to variation in nutrient delivery?

- Assess macroalgal tissue N parameters.

(3) What are likely nutrient sources?

- Examine $\delta^{15}N$ signature in algae and water.

Study Locations



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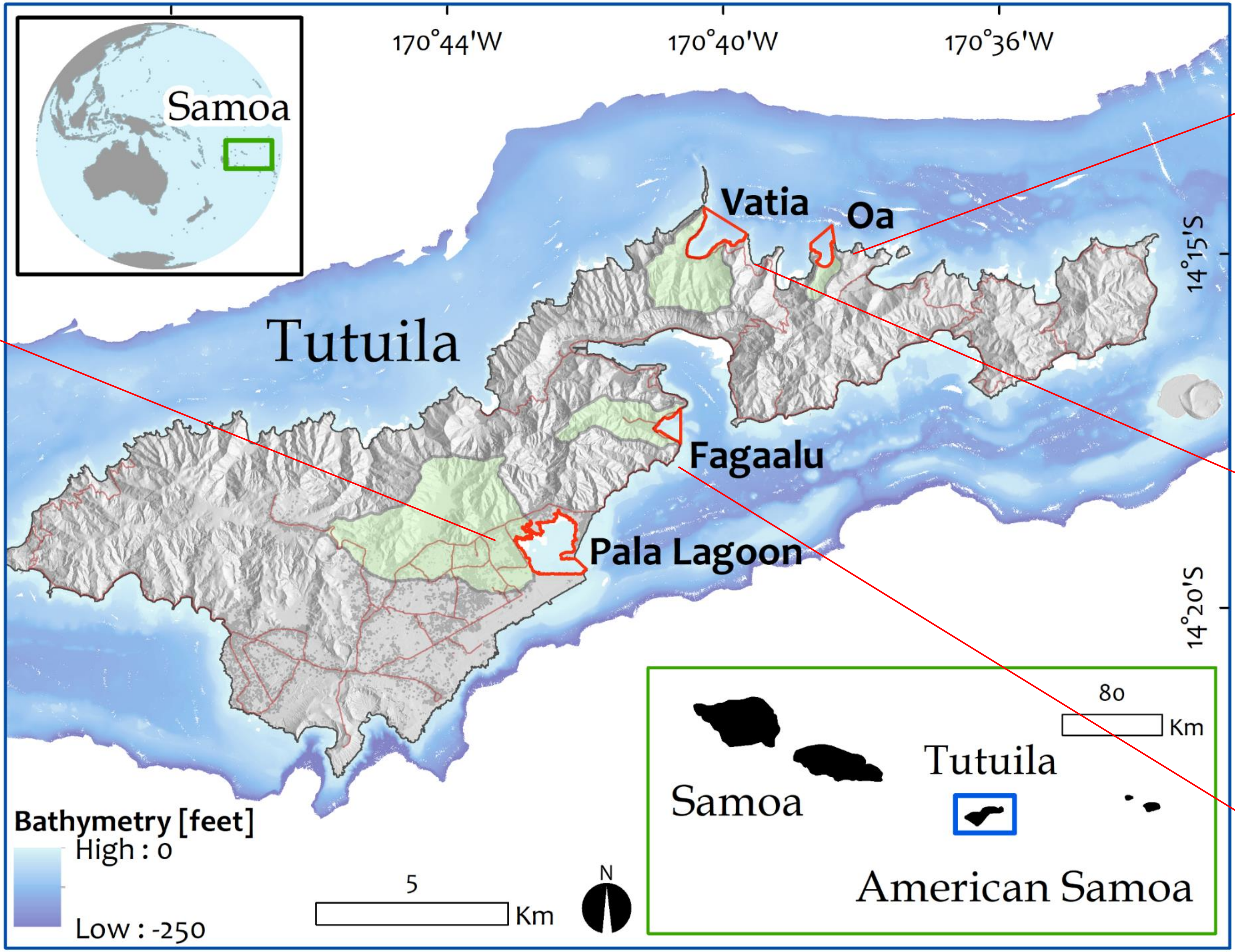


Pristine:
0/km²

Impacted:
480/km²

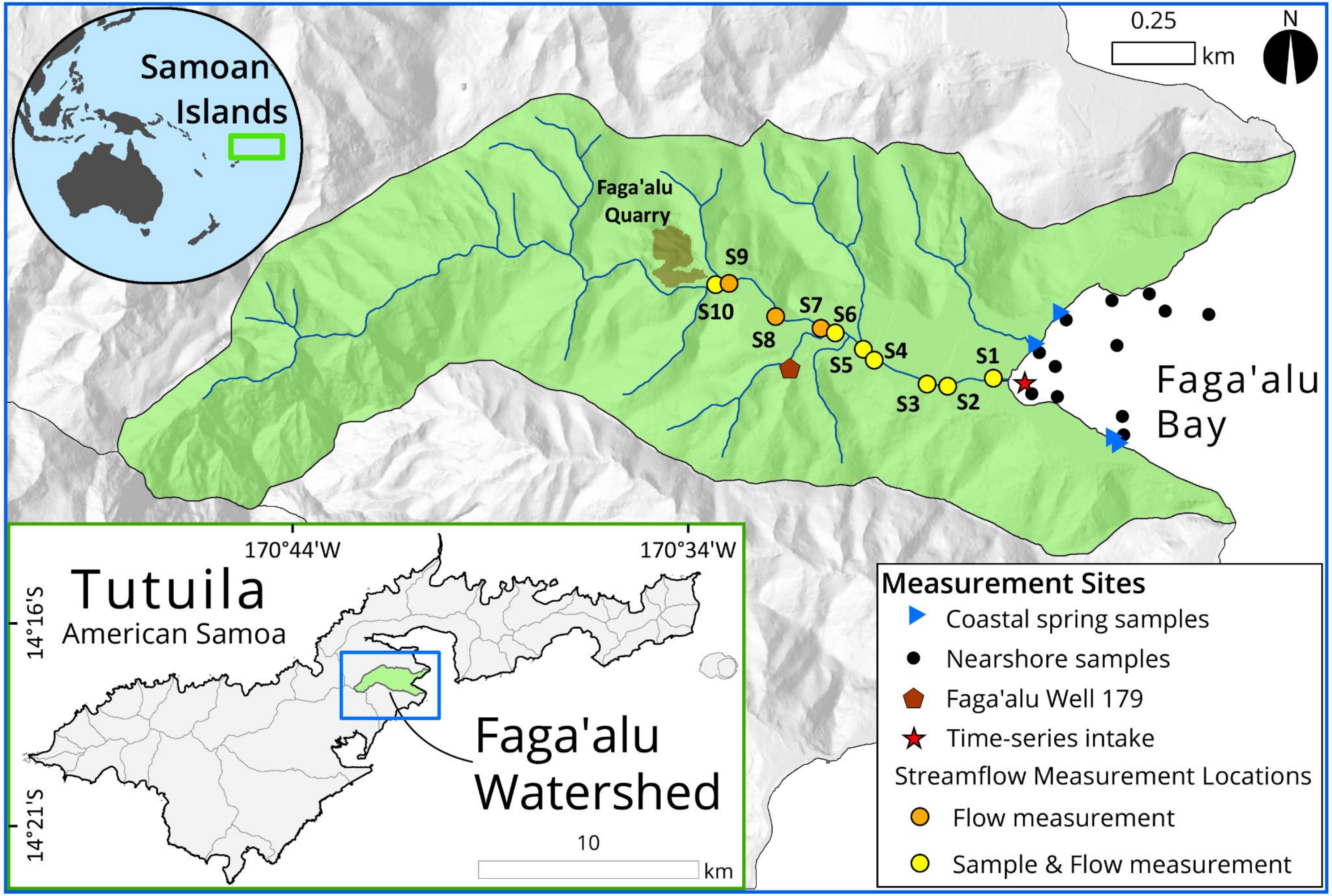
Intermediate
132/km²

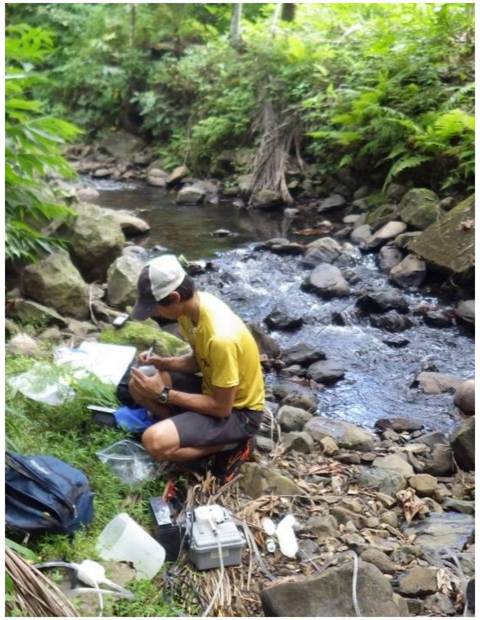
Intermediate – Impacted
404/km²

Population density by watershed (people/km²)

(DiDonato, 2004)

Focused Stream Study Location





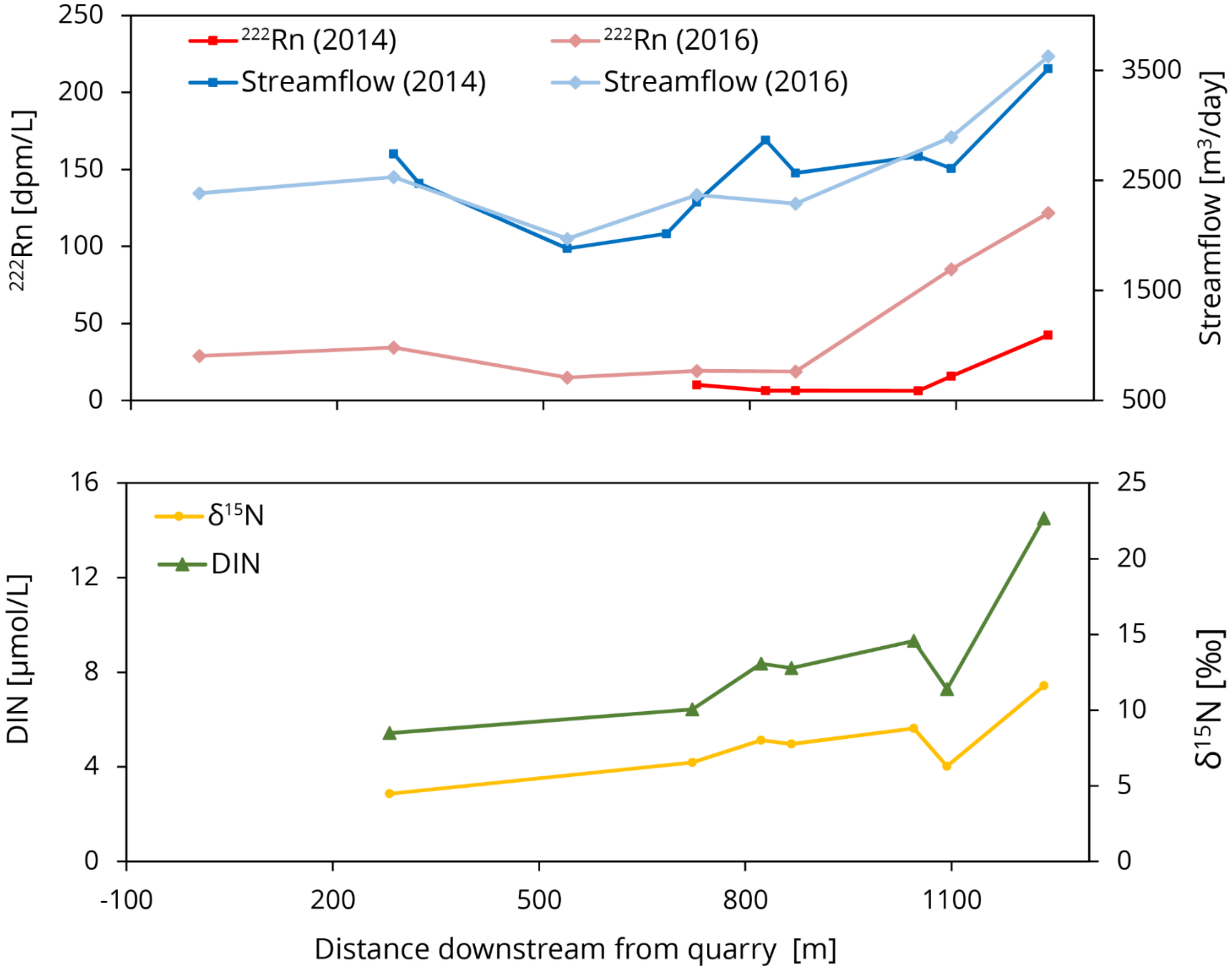
Findings: Surface Water – Groundwater Interaction

Seepage run results:

As stream nears coast:

- Spike in Rn^{222}
- Spike in flow
- Spike in DIN
- Spike in $D^{15}N$

- 2016 seepage run conducted as validation for 2014 run



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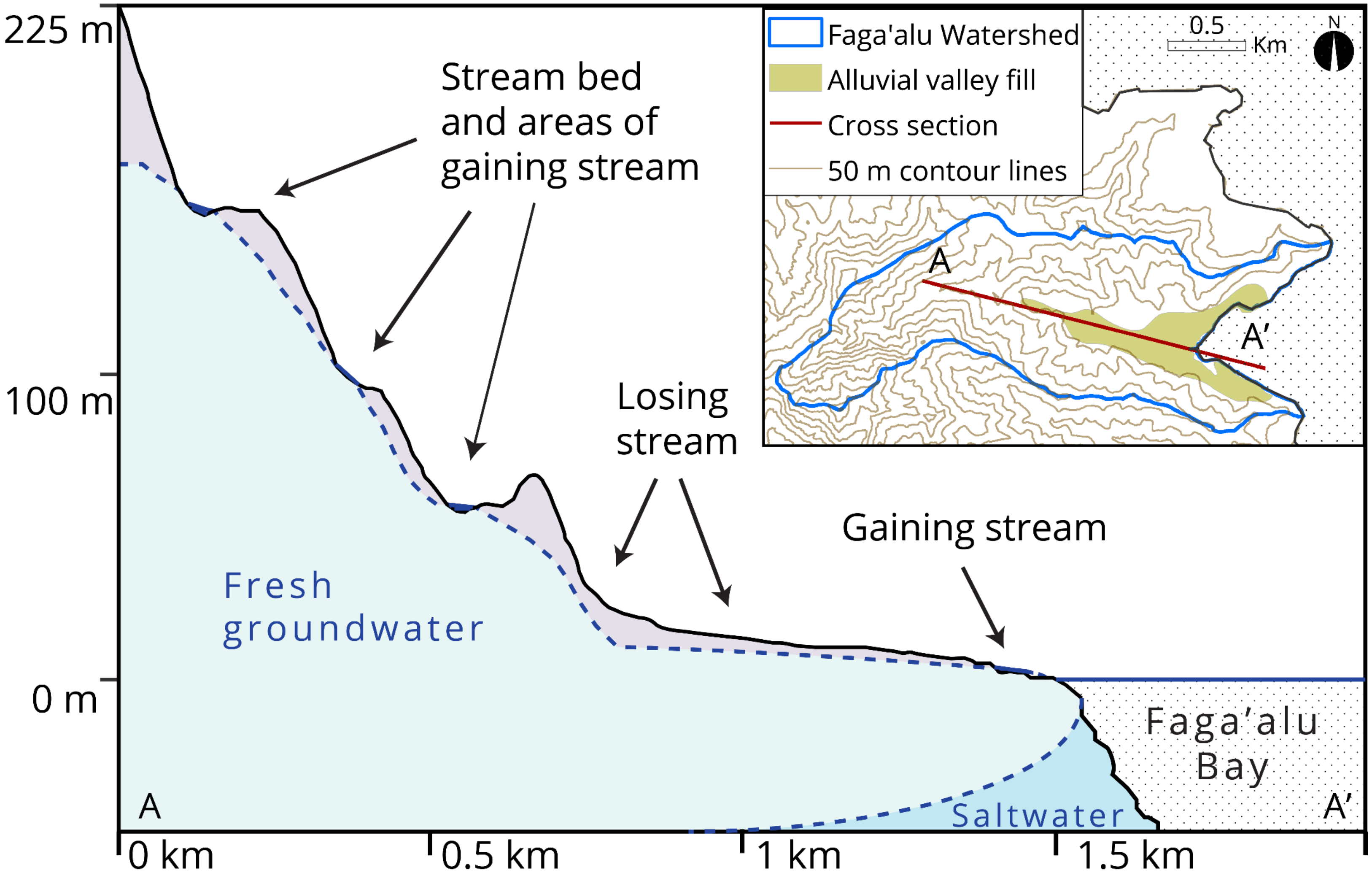
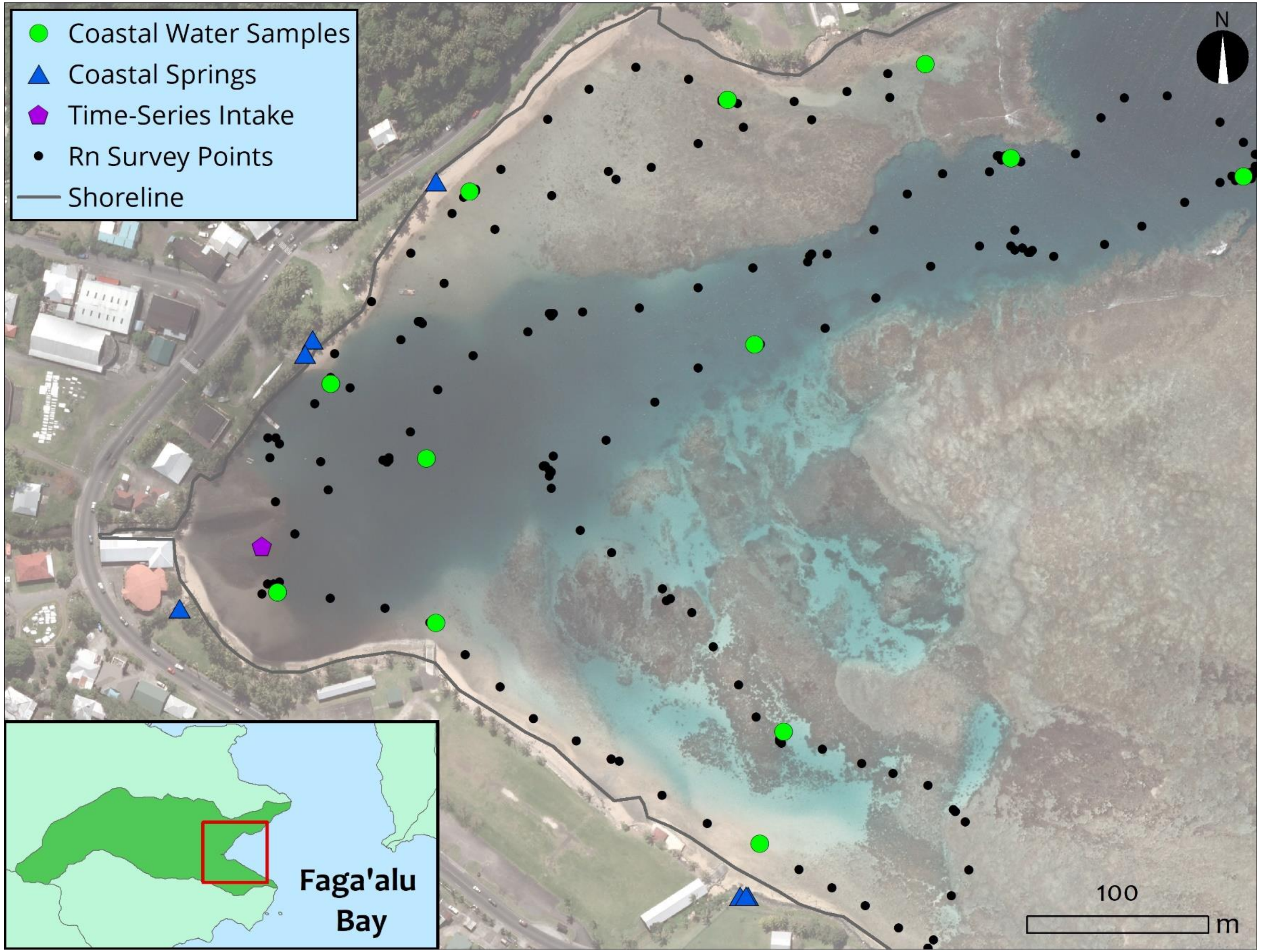


SGD Sampling Methods



Rn Time-Series

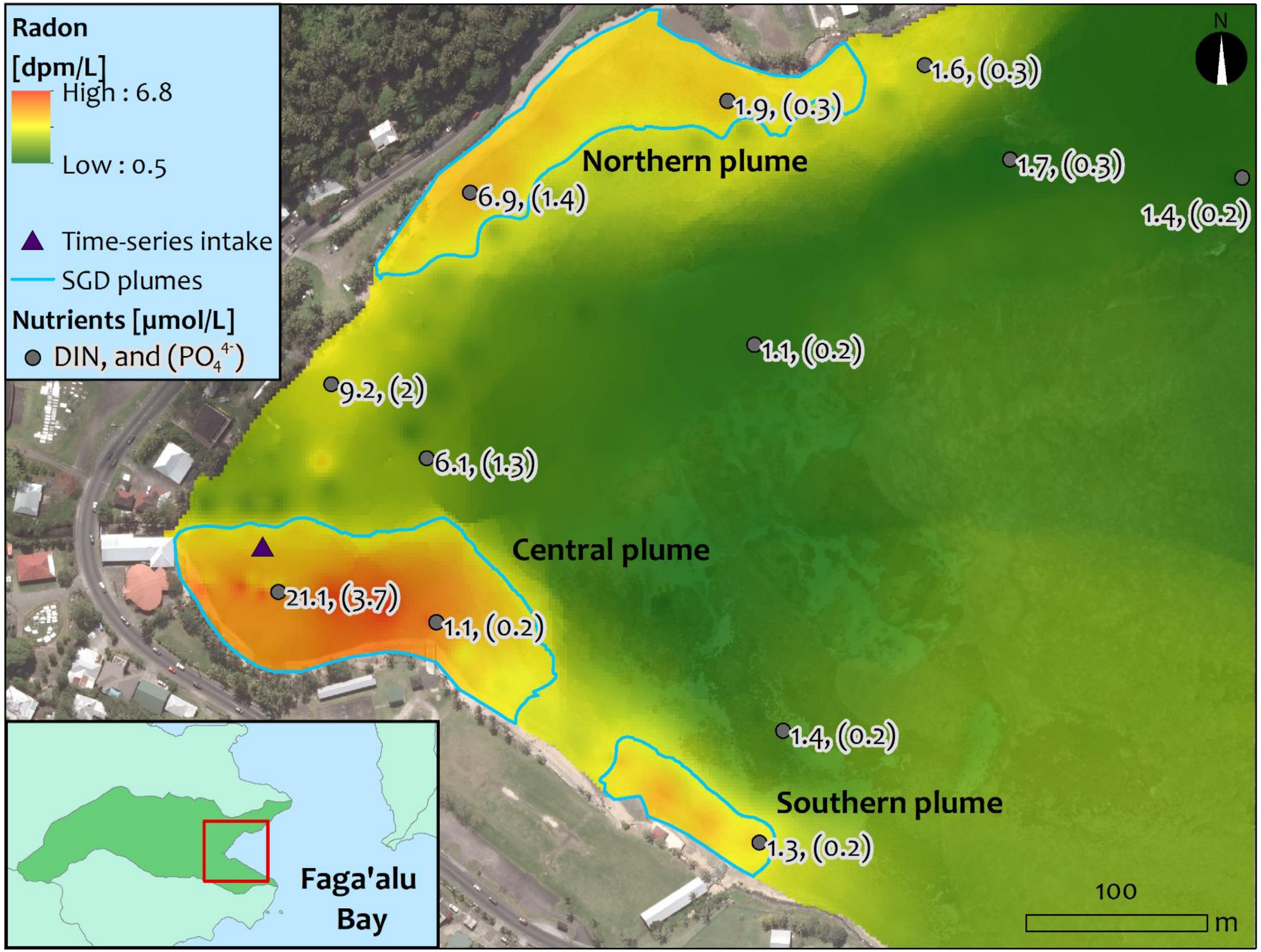
Rn Survey

Findings: SGD and Associated Nutrient Loading

Rn^{222} based SGD results:

- Survey: SGD in 3 plumes
- Time-Series: Higher SGD at low tide

	SGD	Baseflow
Water [m^3/d]	2,590 ± 900	3,530 ± 360
DIN load [kg-N/d]	2.2 ± 1.3	0.7 ± 0.5
DIP load [kg-P/d]	0.5 ± 0.3	0.4 ± 0.3

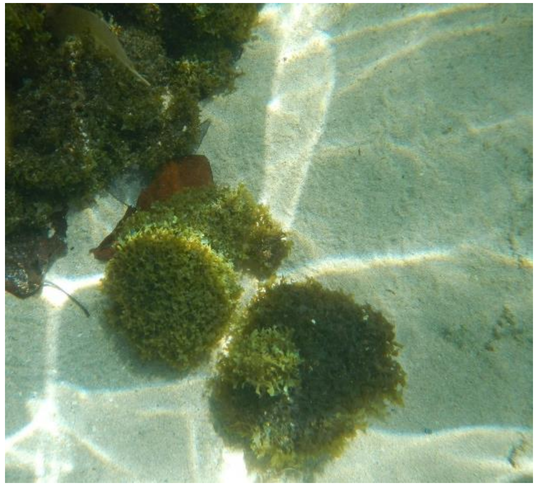


SGD Flux
Sampling Methods

Rn Survey x 4

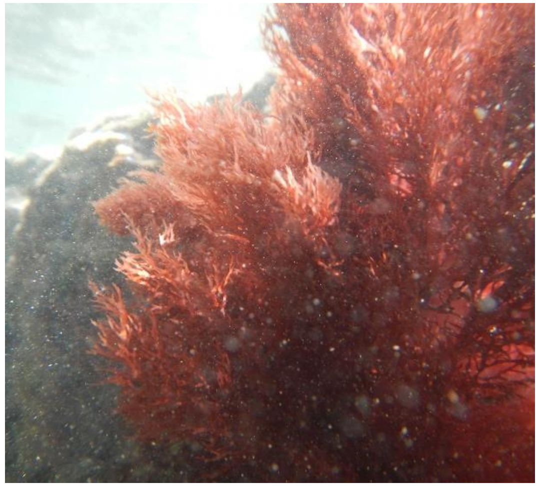
Rn Time-Series x 4

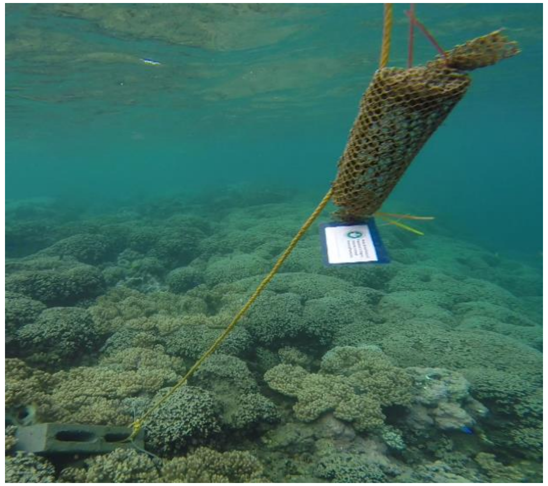
Macroalgae Sampling and Deployment Methods

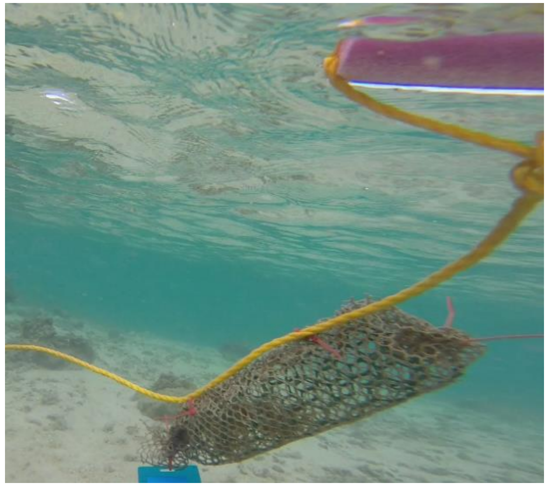


Collected 18 - 30 in-situ algal tissue samples at each location.
(112 total)

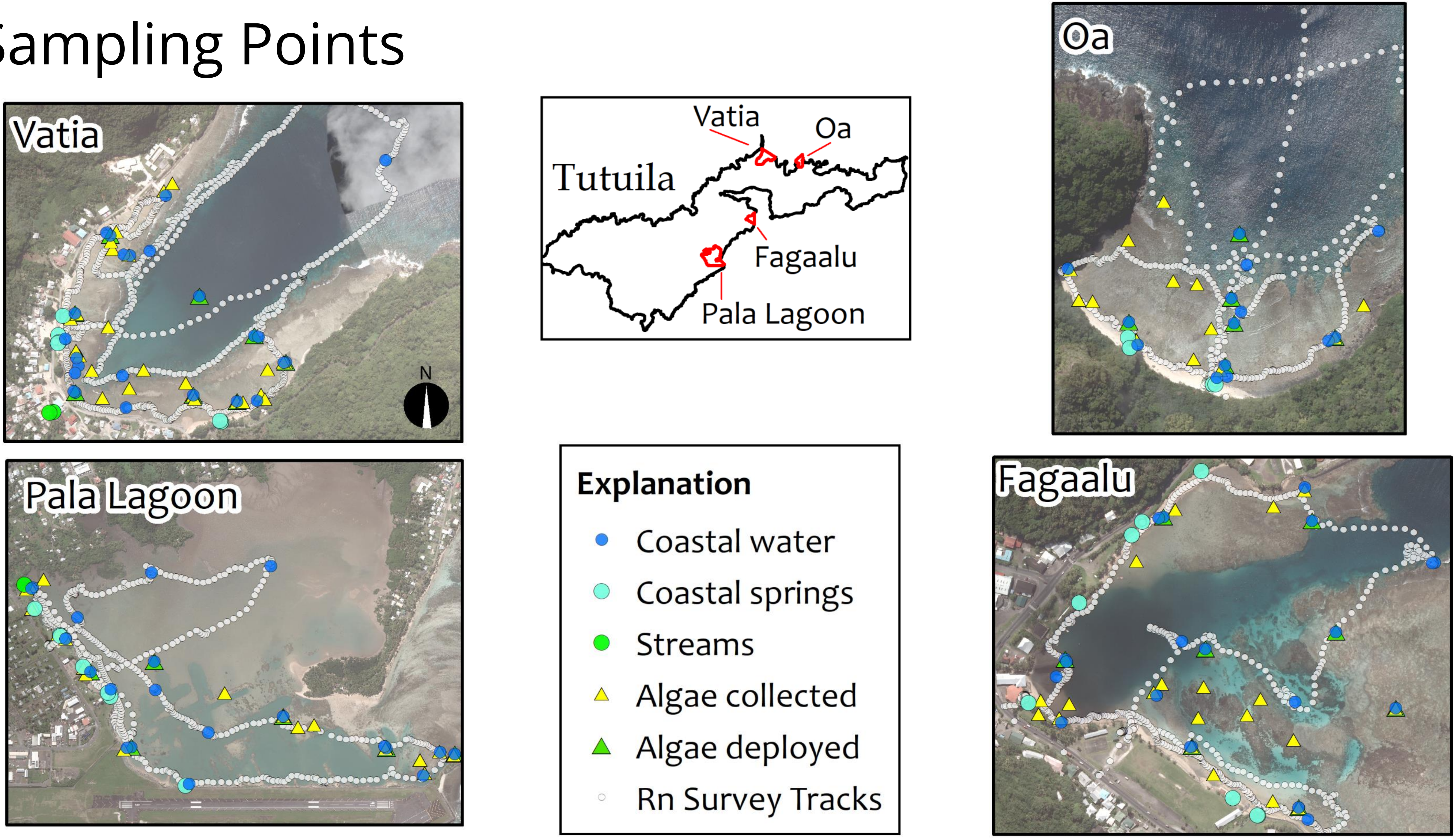
Deployed 6 – 10 *Hypnea pannosa* samples at each location.
(32 in total)



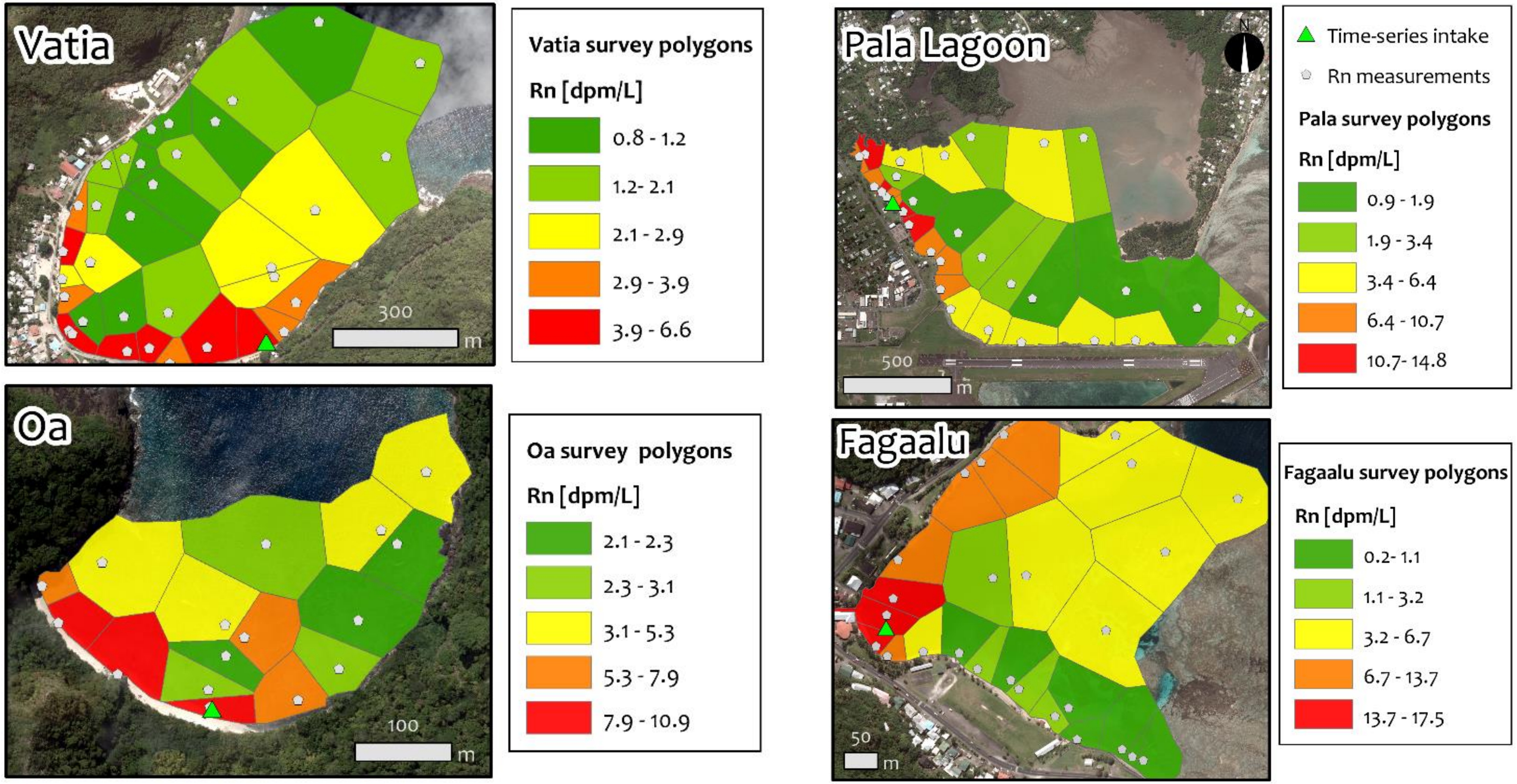


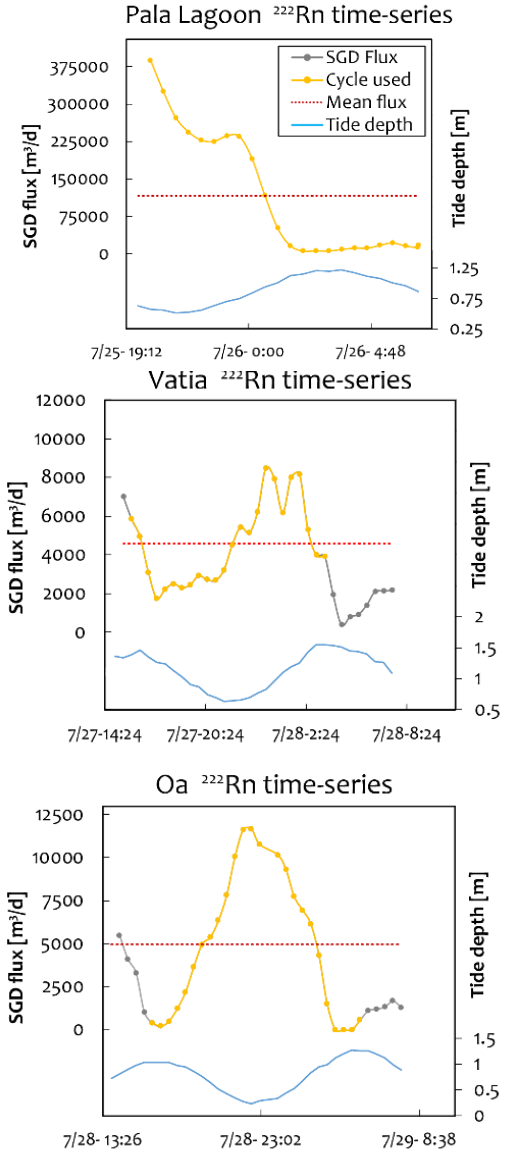


Sampling Points



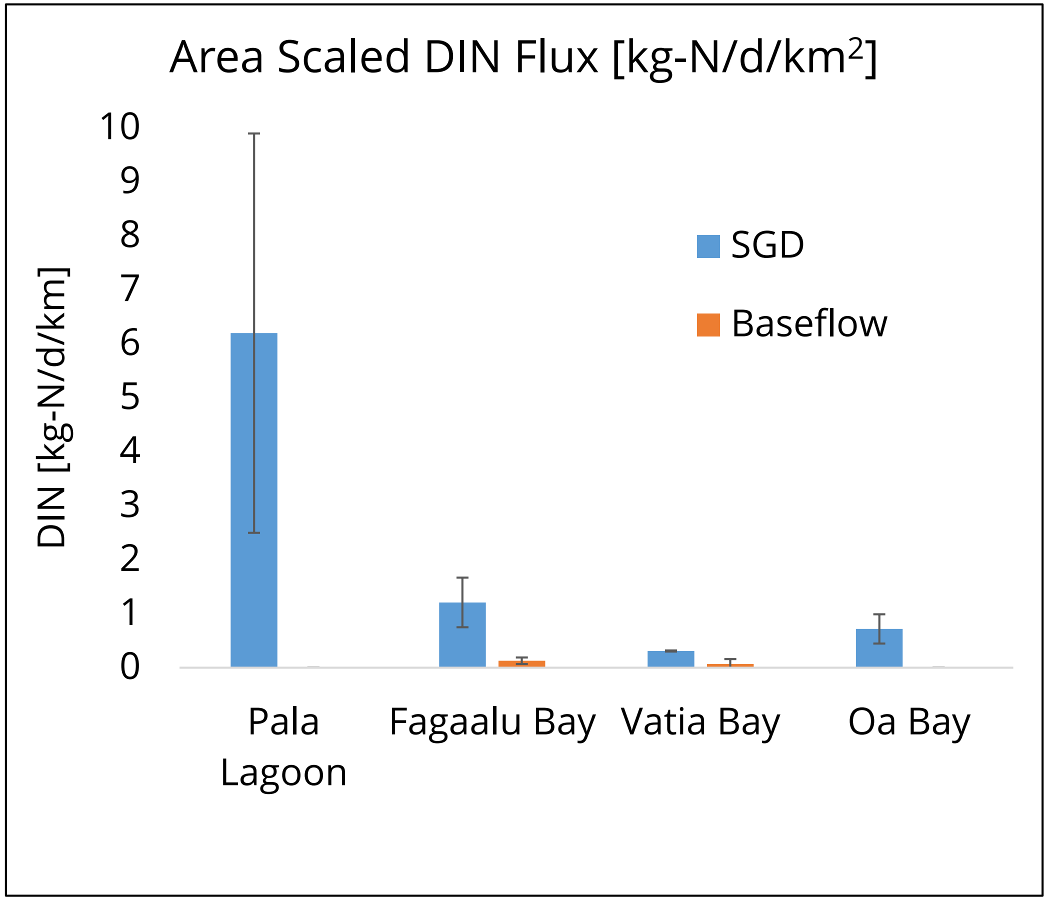
Findings: SGD Rates



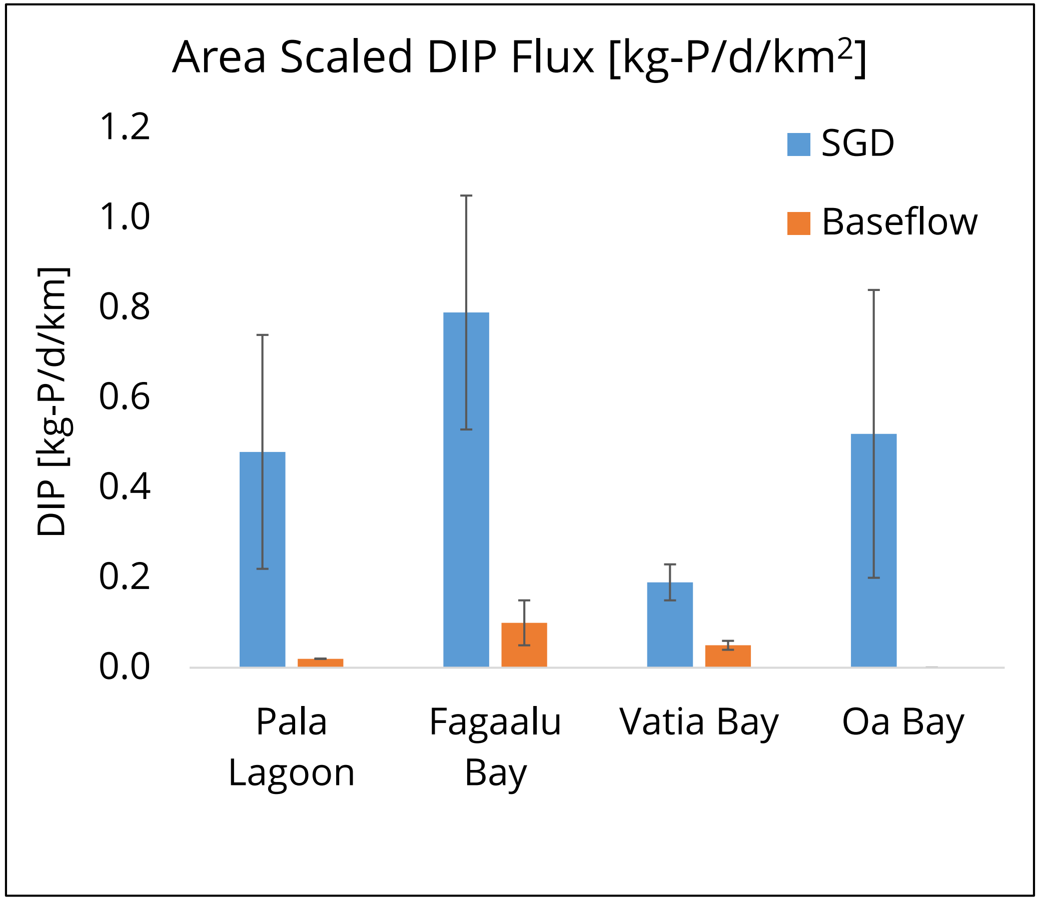


Findings: SGD and Associated Nutrient Loading

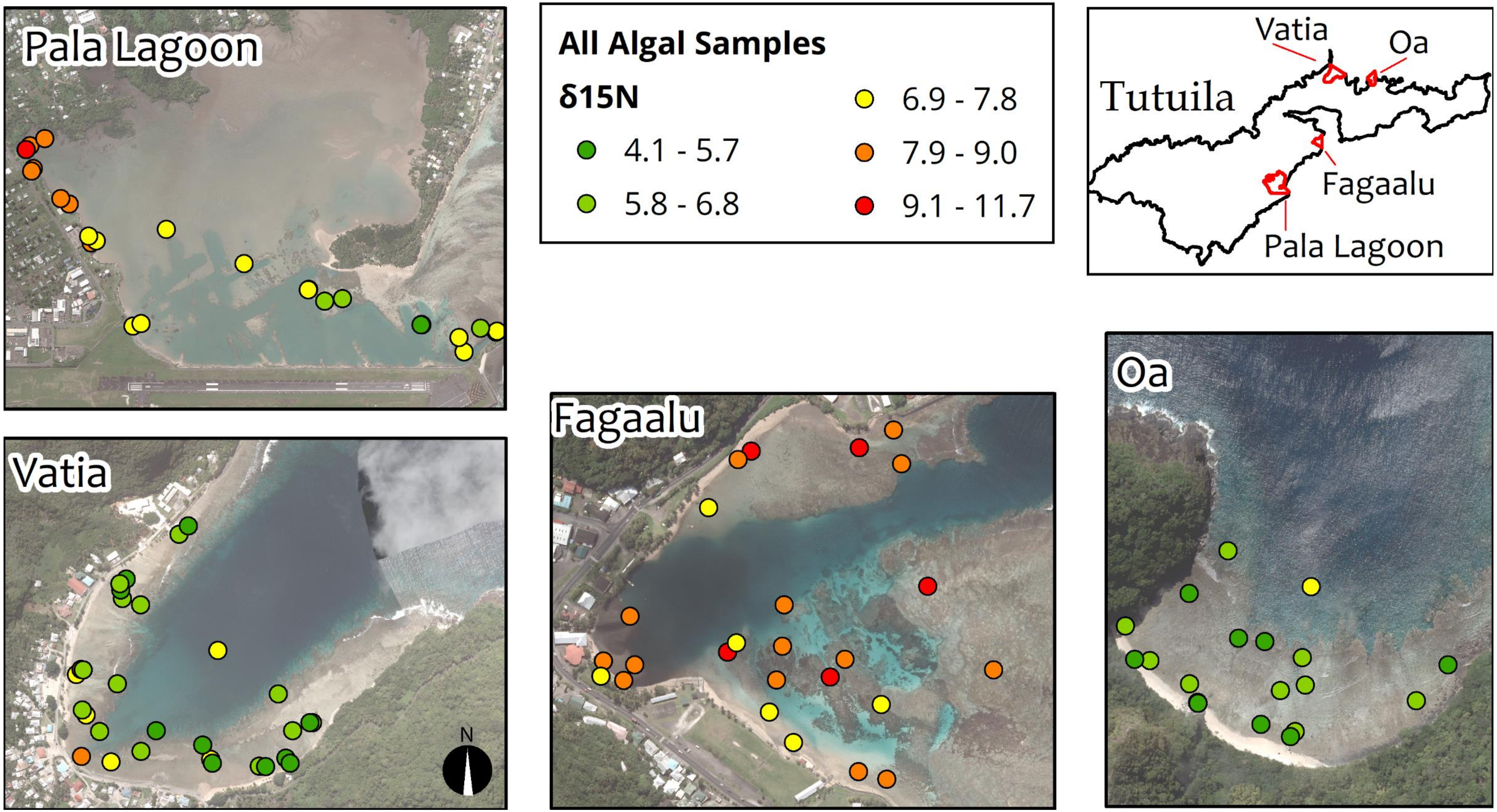
Dissolved Inorganic Nitrogen (DIN) levels correlate with human impact



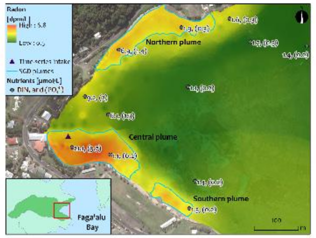
Phosphate levels are controlled by something else



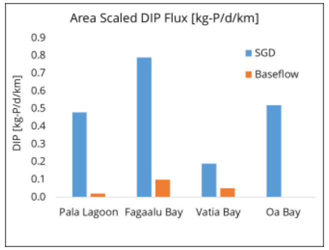
Findings: Macroalgae Parameters



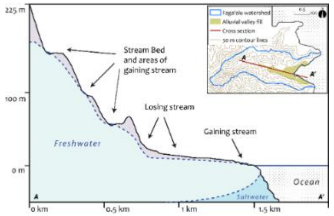
Conclusions



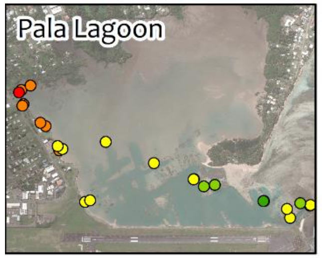
- Groundwater is important - contributes much of annual N to coast



- Groundwater has high natural phosphate levels, coastal waters are N limited



- Streams gain up high, lose in alluvium, gain again near coast



- DIN, $\delta^{15}N$, and algal tissue parameters, generally correlate with land-use impact

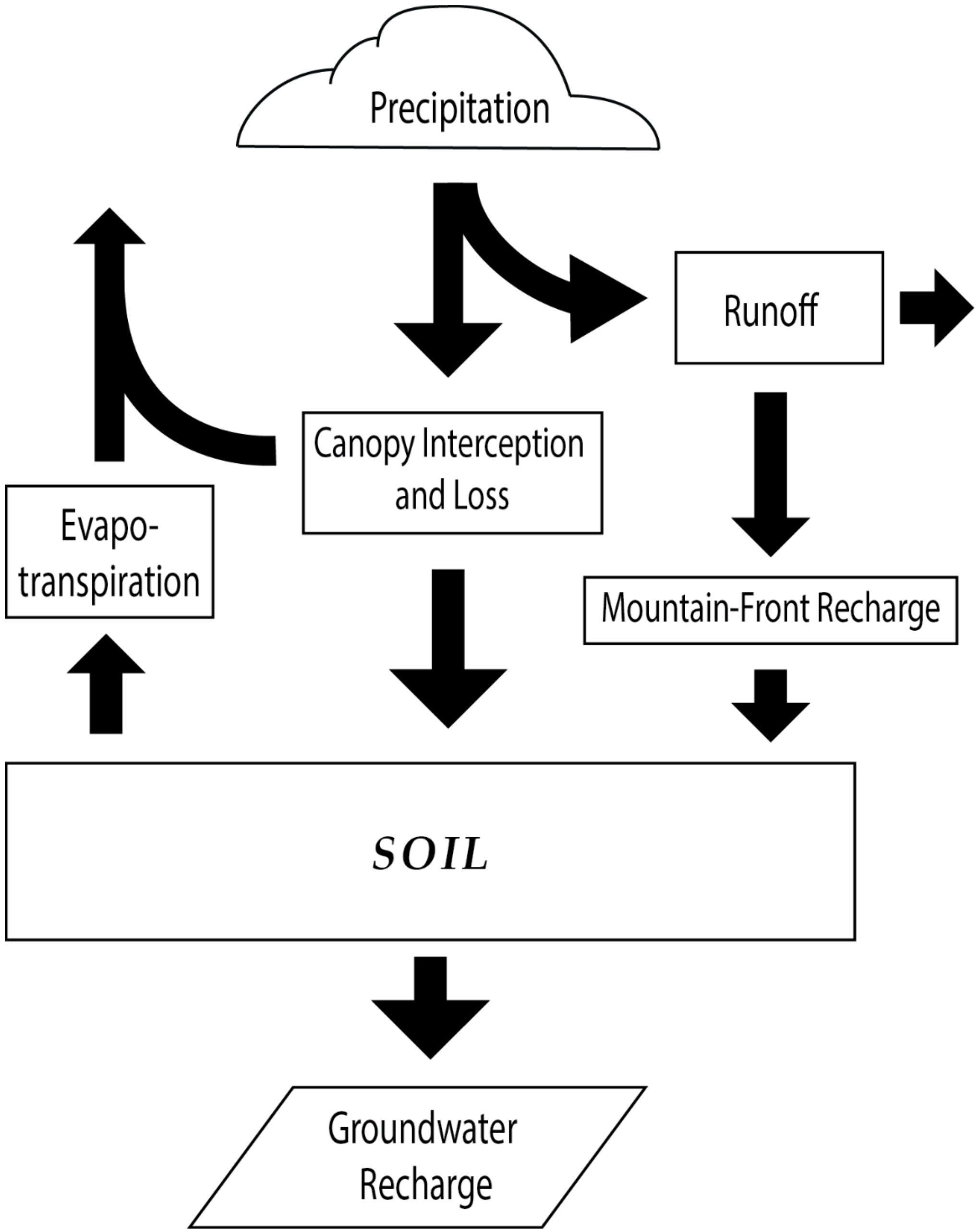
Water Quantification

part 1

Groundwater Recharge

Recharge = Rainfall – Evaporation - Runoff

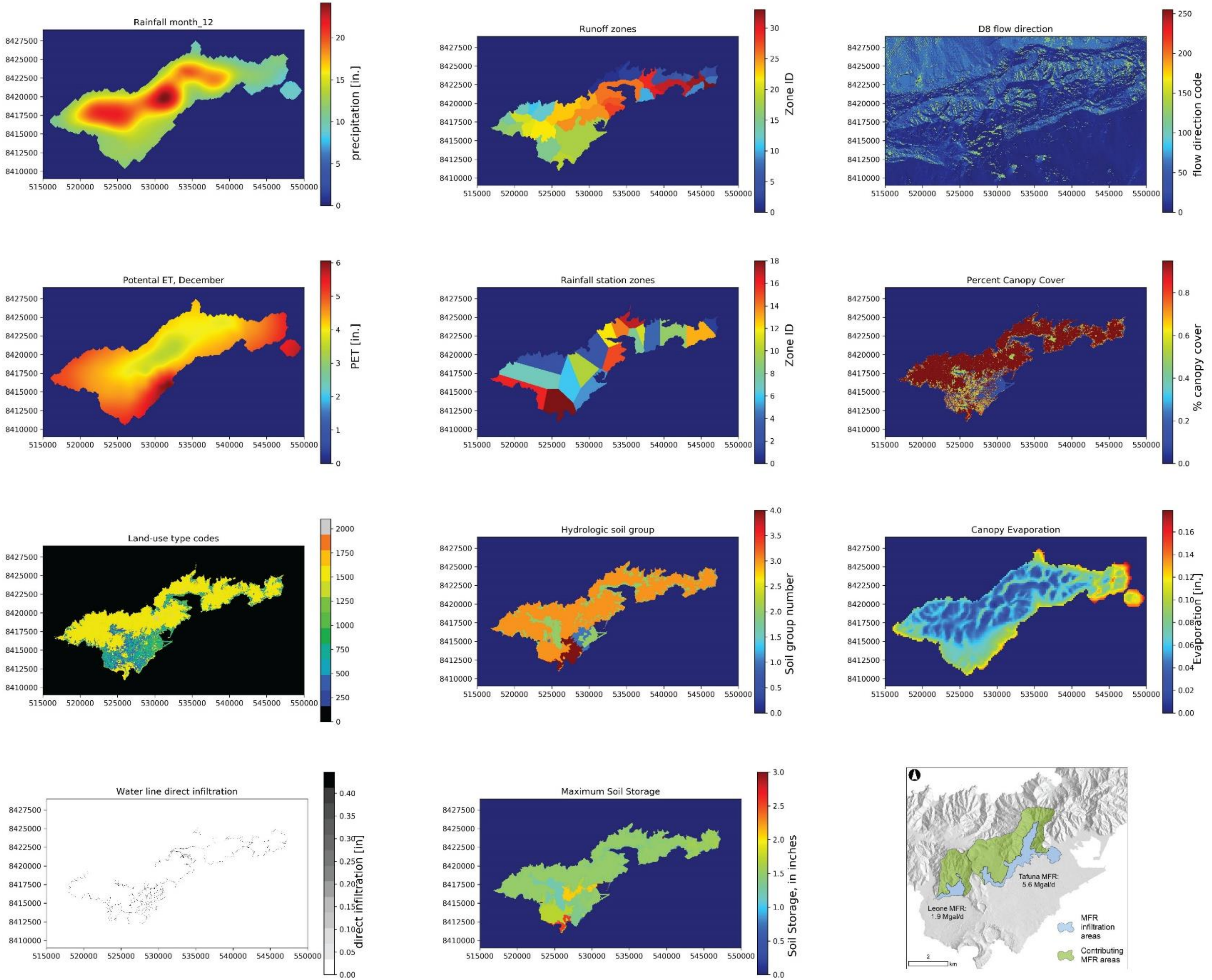
(Thornthwaite and Mather, 1955)



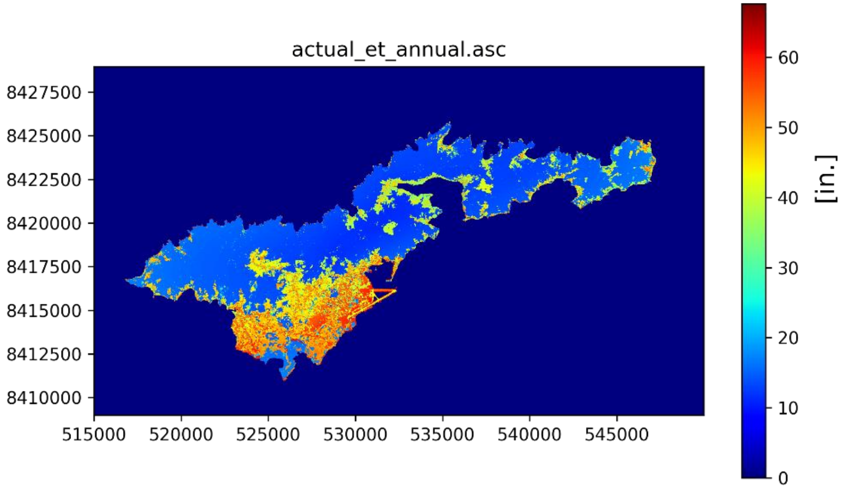
Using USGS Soil Water Balance 2 model

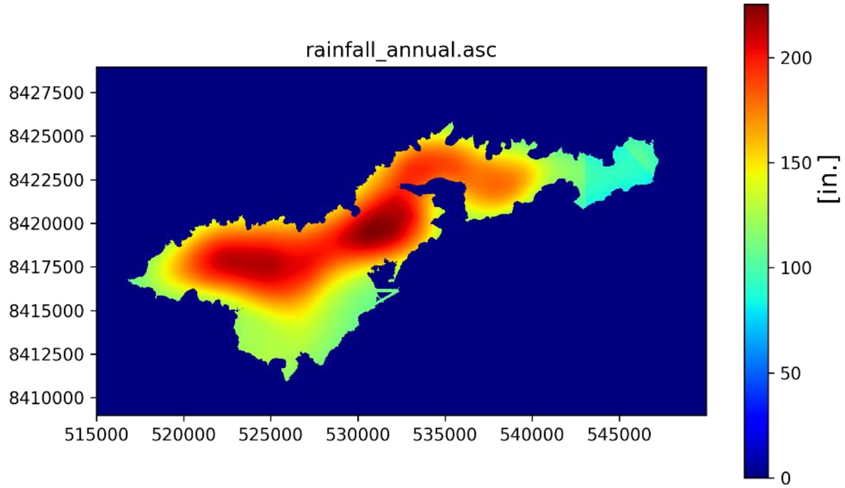
Model inputs

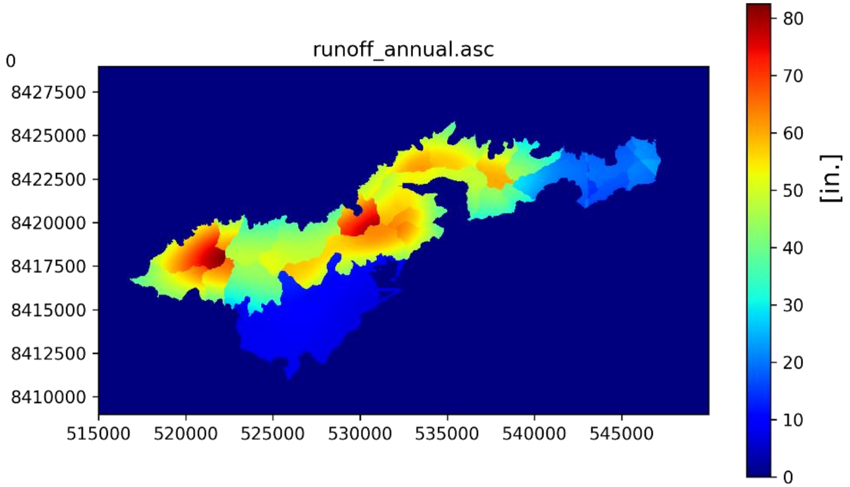
- Gridded monthly precipitation
- Temporal rainfall distributions
- Land use data
- Impervious surface ratios
- Canopy coverage ratios
- Soil type data
- Direct infiltration data
- Runoff-to-rainfall ratios
- Potential evapotranspiration
- Canopy evaporation data
- Gridded temperature data
- Mountain front recharge

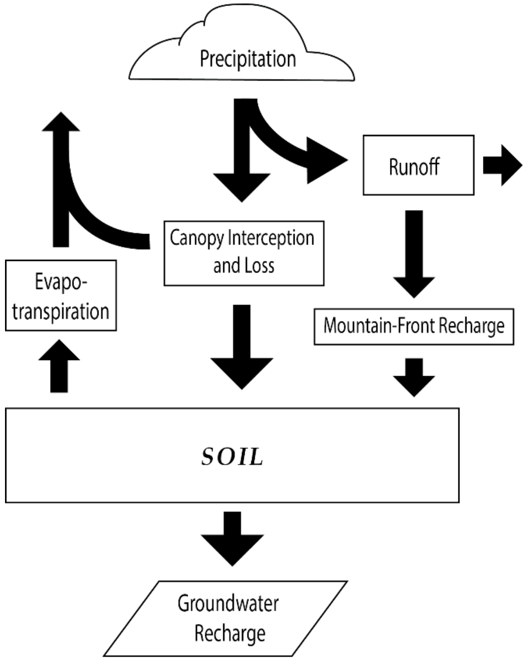


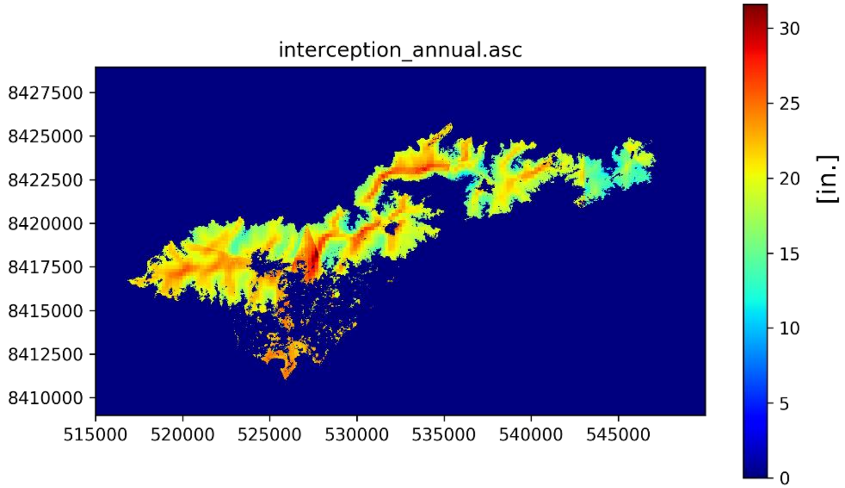
SWB2 Model Findings

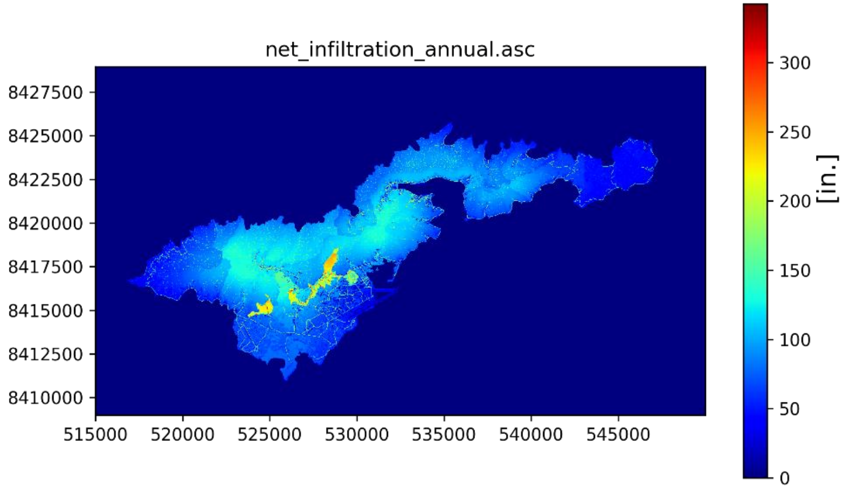




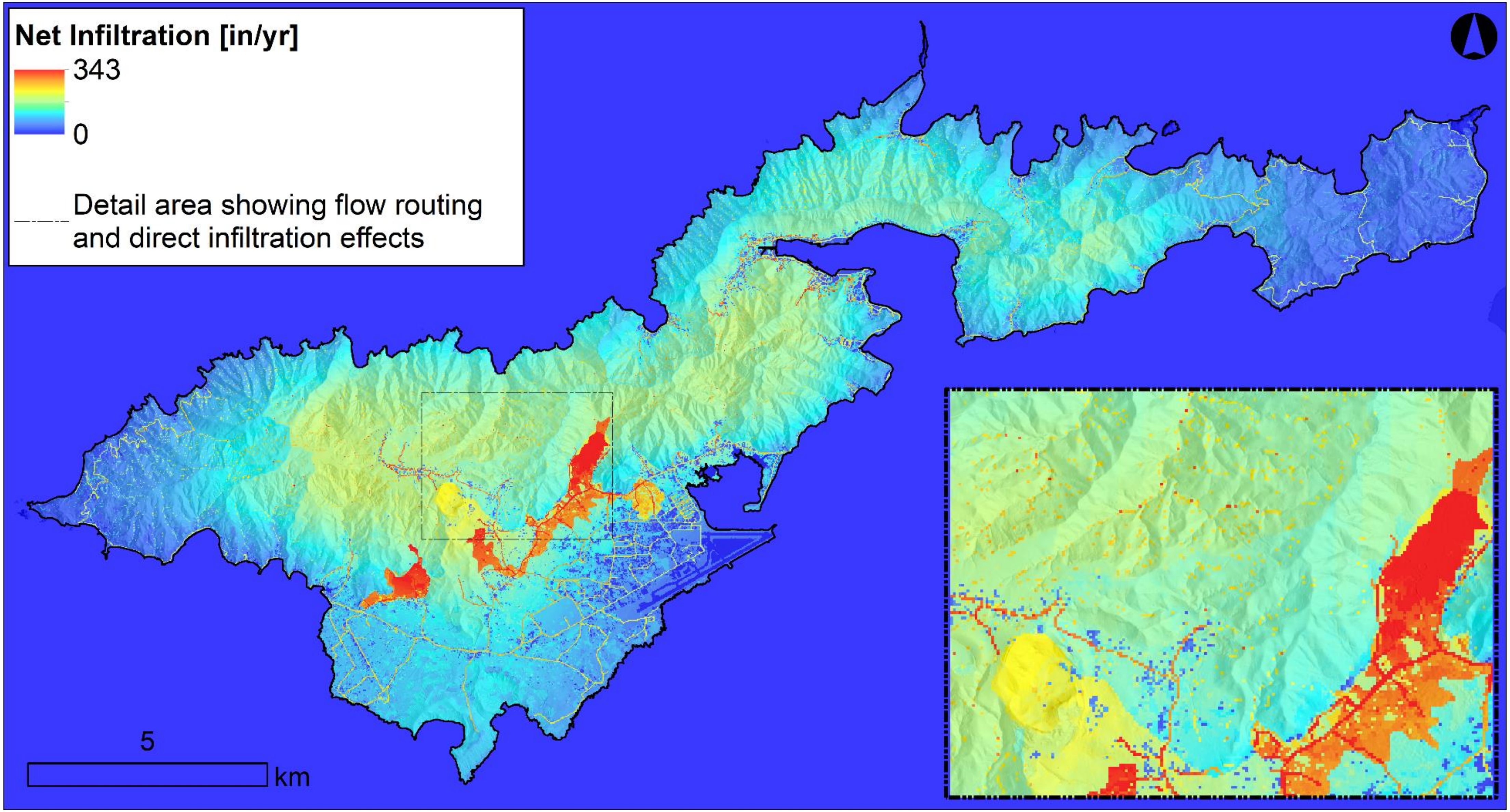




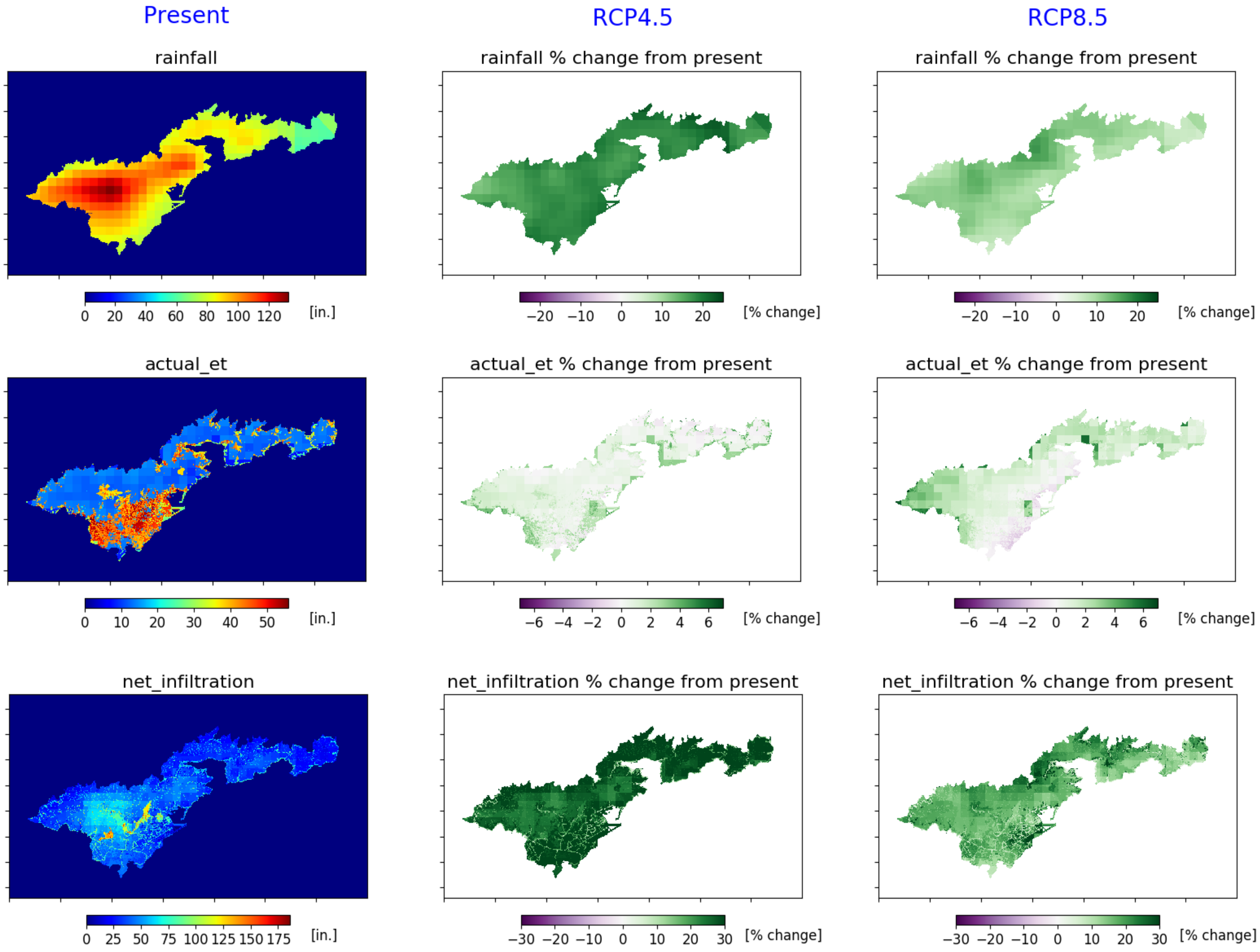




Recharge Map



Future Climate Scenarios
(Wang and Zhang, 2016)



Effect on
- ET

Effect on
- recharge

Water Quantification

part 2

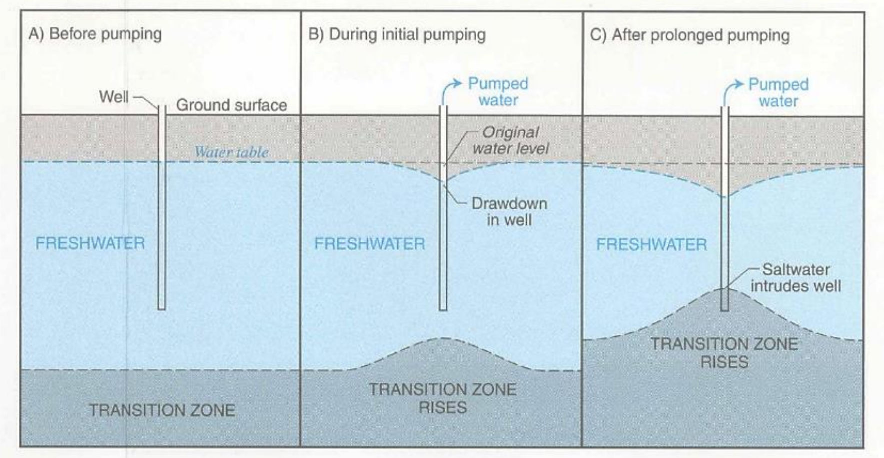


Figure 11. Diagram showing how chloride concentrations rise as a result of pumping from a well that penetrated close to the freshwater/saltwater transition zone.

Motivation for Collaborative Framework

Addressing modeling needs *with*, not *for* stakeholders

Traditional modeling framework

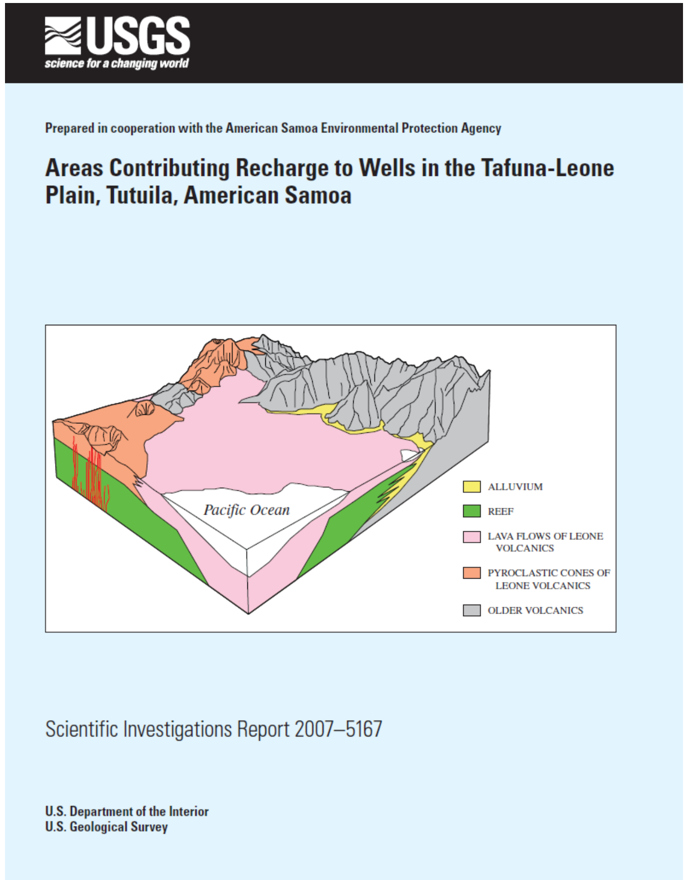
Static models (not interactive)

OR

In-house modelers (expensive)

Benefits of collaborative process

1) Increased Stakeholder buy-in / understanding
2) Dynamic, future applicability
3) Less expensive than dedicated modeling staff

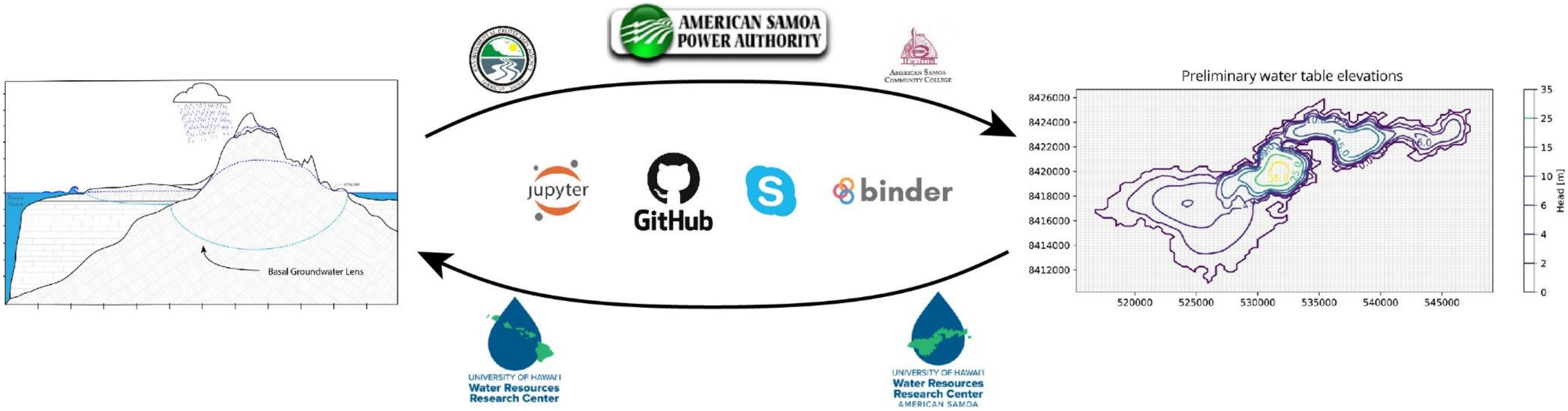


Collaborative Groundwater Modeling

“Collaborative modeling is where model developers, decision-makers, stakeholders, and others [researchers] *work together to develop a shared understanding of* [the region’s] *management objectives and the model’s role in supporting those objectives”*

(Moran, 2016)

Collaborative Groundwater Modeling



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(Moran, 2016)

Cloud-based Infrastructure

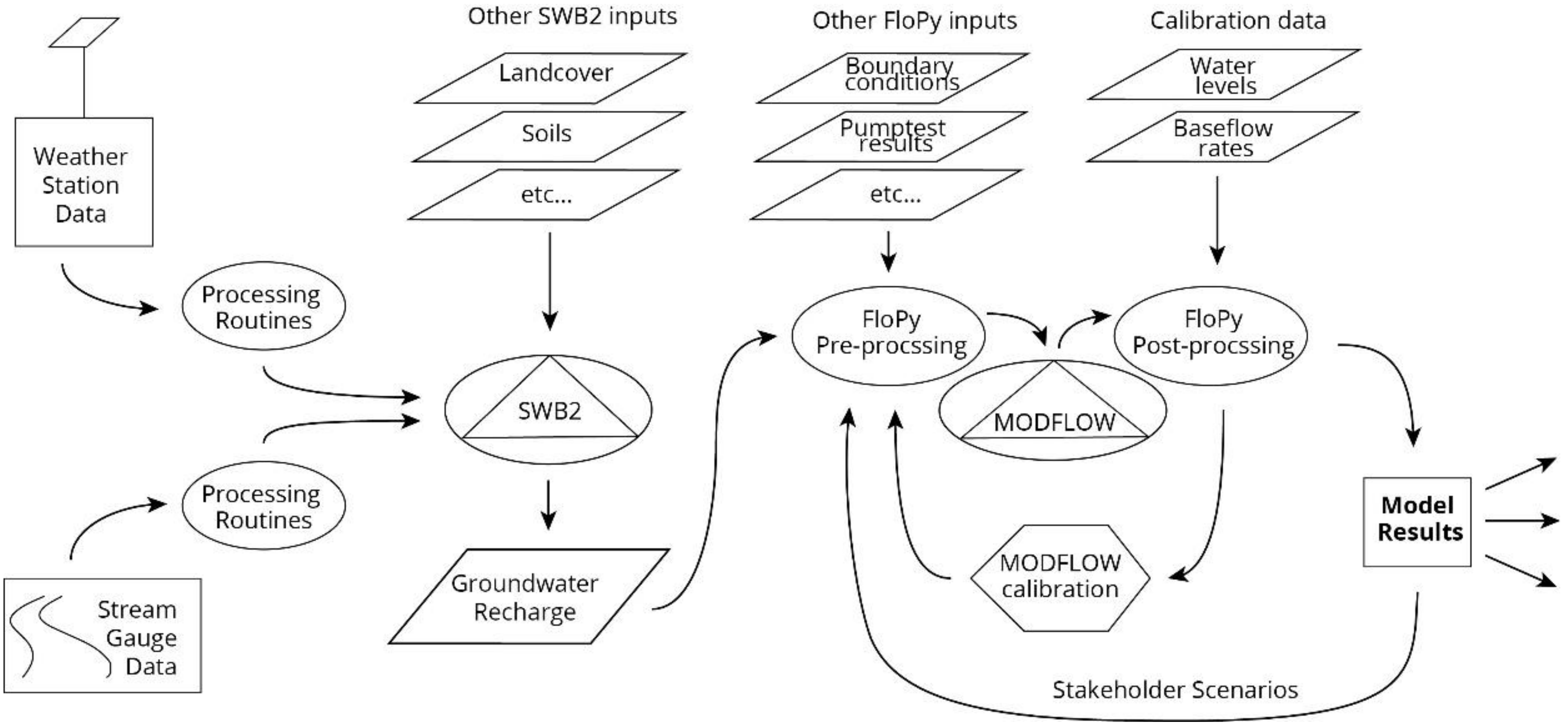
Jupyter Notebooks
Python-based coding and project development

Skype (or Hangouts)
International communication, screen sharing

Project storage and version control

Live cloud-based code execution

ASPA-UH-WRRC Cooperative Groundwater Modeling Framework



Cloud-based Infrastructure

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Workflow Demo

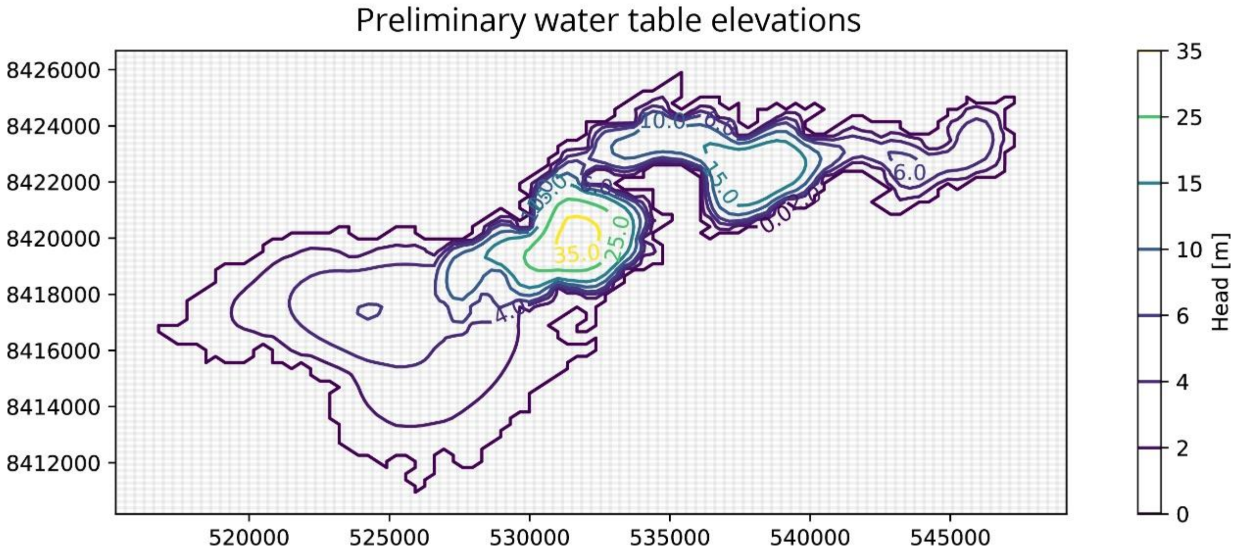
- Hydrologic data collection
- Instrument locations
- Markdown cells, annotations, inline figures
- Data processing
- Importing result to SWB2
- Results of SWB2
- Binder application (with FloPy)

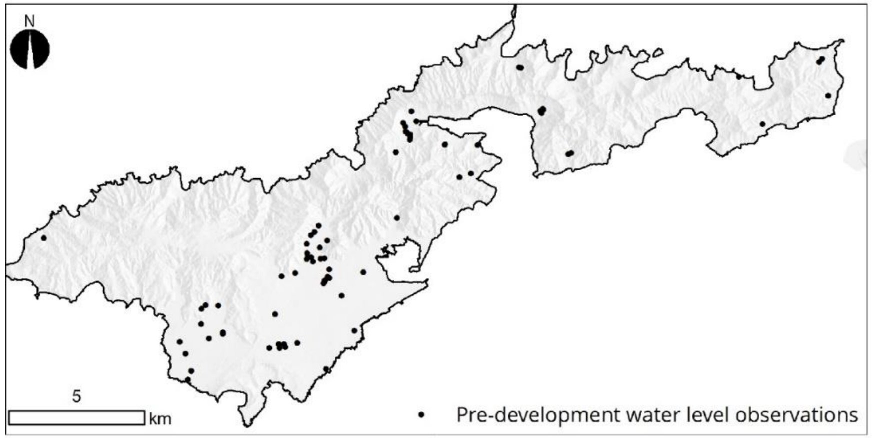
Key Benefits

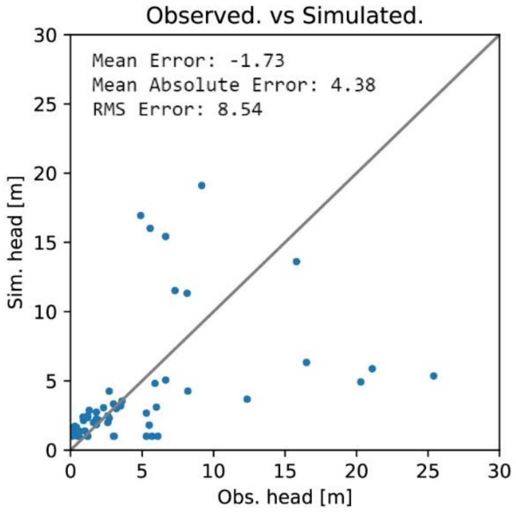
- Open-source, transparent reproducible, and dynamic
- Utilities avoid paying for dedicated modeling personnel
- Researchers can more effectively provide scientific expertise
- Allows for modification to address new research/management questions
- Managers better understand uncertainties implicit in approaches

Continuing Work

- Training trip to AS
- Continued identification of priorities with ASPA
- Exploration of hydraulic conductivity calibration methods
- Implementation of SWI for salinity predictions
- Expanding to other models (e.g. hydraulic system model)





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